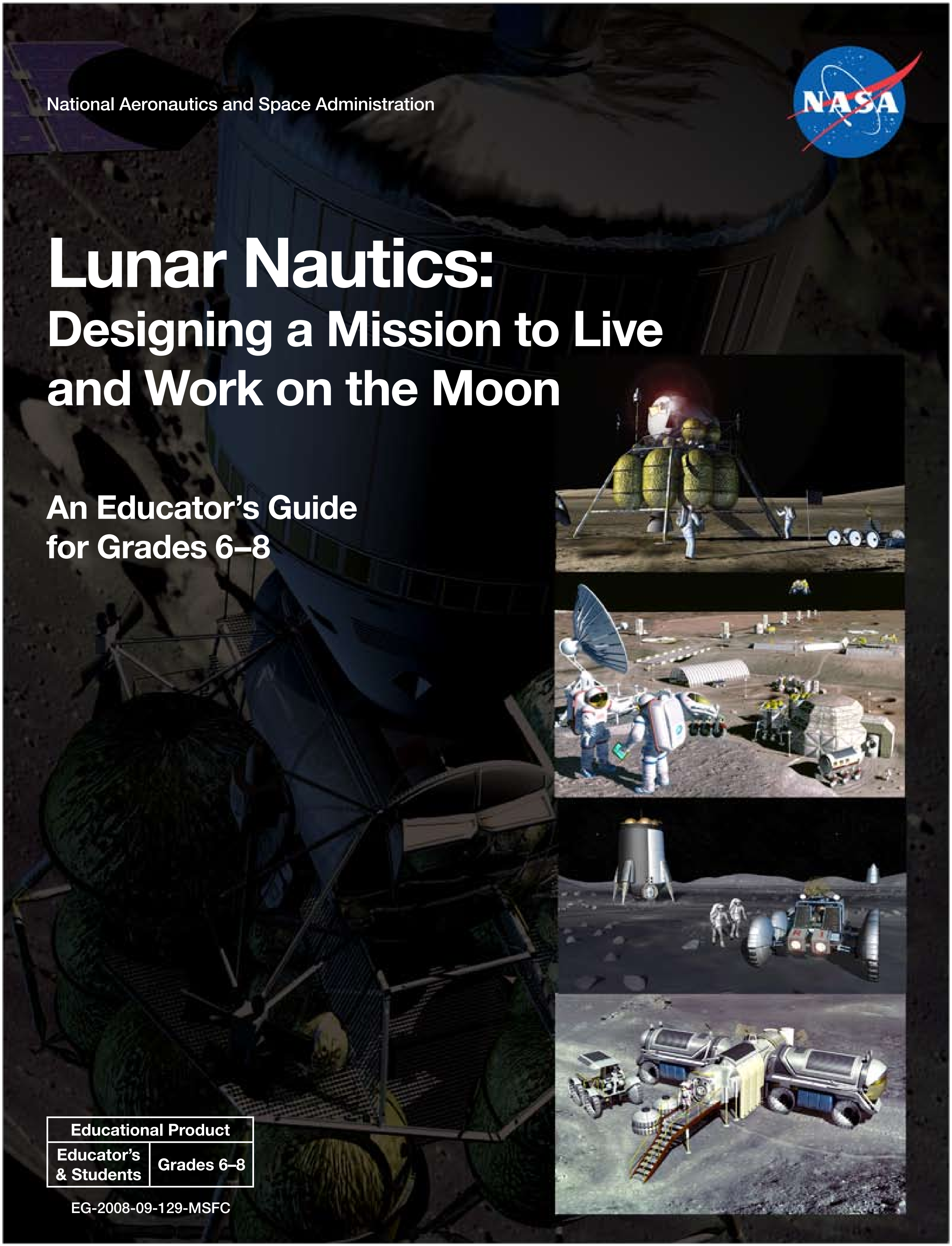
National Aeronautics and Space Administration



Lunar Nautics:
Designing a Mission to Live and Work on the Moon

An Educator's Guide for Grades 6–8

Educational Product	
Educator's & Students	Grades 6–8

EG-2008-09-129-MSFC

Lunar Nautics

Table of Contents

Acknowledgements

This publication was produced by:

Discovery Place, Inc.
301 N. Tryon Street
Charlotte, NC 28202
(704) 372-6261 (800) 935-0553
www.discoveryplace.org

Funded by a grant from NASA

NASA Liaisons: Lucia Cape
Paula M. Rodney

Produced by: Deborah J. Curry
Vice President Programs and Education
Discovery Place, Inc.

Michael Katz
Science Educator
Discovery Place, Inc.

Darlene Perry
Principal
Creative CYNERGY

Paula M. Rodney
Educational Curriculum Specialist
Marshall Space Flight Center
Academic Affairs Office

Design by: Shawn Pelham
Principal
W.S. Pelham Design

Graphics and Publications Office
NASA Marshall Space Flight Center

Interactives by: Shawn Pelham
James Twyford
Jason Appelbaum

About This Guide

Lunar Nautics is a hands-on curriculum targeted to youth in grades 6 to 8, that allows the students to design, test, analyze and manage a space mission from initial concept to project funding.

Lunar Nautics provides opportunities for development of problem solving skills and critical thinking skills that are needed to design, organize and manage a space mission through its life cycle. The curriculum is designed as a template curriculum that can be applied to any space mission: past, present or future. Each section of this guide contains background information, demonstrations and activities that support the section topic and the overall design and engineering goals of Lunar Nautics. This guide is divided into sections that touch upon space mission awareness, concept understanding, teamwork, design and proposal development. Educators can use this guide with great flexibility in a variety of formats such as week long day camps, after-school programs, a classroom unit or simply as supporting curriculum.

National Science Education Standard correlations include the following:
- Science as Inquiry.
- Physical Science.
- Earth and Space Science.
- Science and Technology.
- Science in Personal and Social Perspectives.
- History and Nature of Science.

Mission scenarios are linked to the three Lunar Exploration themes of the Exploration Systems Mission Directorate (ESMD) Research Office, which are as follows:
- Exploring the Moon.
- Human Presence on the Moon.
- Enabling Future Exploration.

Students assume positions at Lunar Nautics Space Systems, Inc., a fictional aerospace company specializing in mission management, lunar habitat and exploration design, and scientific research. A mission is selected and the youth work within guidelines set by NASA. Students work within a budget to design a lunar habitat, select scientific instruments, build a model of the habitat designed and prepare a presentation to obtain potential "NASA" funding for their project.

Goals and activities during the experience include the following:

- Concepts:
  - Goal: Develop understanding in concepts related to aerospace.
  - Activities: Include microgravity, Newton's Laws, rocket design and astronaut protection.
- Design Challenges:
  - Goal: Develop teamwork skills and abilities of technological design.
  - Activities: Include challenges for design, testing and analysis of a lunar lander, a robot for surface exploration, and a 2-liter soda bottle rocket designed for maximum height.
- Exploration of Past, Present and Future NASA Lunar Space Missions:
  - Goal: To make students aware of scientific instruments, habitat design, budget constraints and past successes and failures.
  - Activities: Gather materials from resource materials and computer activities that teach.
- Development of Lunar Nautics Mission:
  - Goal: Develop skills of budgeting, problem solving and critical thinking.
  - Activities:
    - Students prepare a multimedia presentation that is critiqued by other teams for potential project funding.
    - Students design on a computer and then build a model of their habitat.
    - Presentations include habitat objectives, science objectives, list of onboard systems and science instruments and why selected, mission timeline, mission budget, and expected mission results.

While educators are welcome to pick and choose among the demonstrations and activities in the Concepts, Design Challenge and Space Missions sections, the core remains the Lunar Nautics material. Logical sequences of events and corresponding activities can be found on the Sample Agenda pages.

Grade Level:
Grades 6 to 8 (middle school)

Project Length:
6 hours to 30 hours

Potential Formats:

- Weeklong day camp
- After-school programs
- Classroom unit

How to Use This Guide:

- Review agendas.
- Select activities according to your time frame.

Unless otherwise noted, all student data sheets are located in the Student Guide/Lunar Nautics Employee Handbook and informational handouts are located in the Educator's Guide.

Standards Correlations Matrix

	ADMINISTRATION	Survivor: Never ending quest	Survivor: Moon match	Survivor: Can we take it with us?	Lunar Nautics trivia challenge	**LUNAR NAUTICS SPACE SYSTEMS, INC.**	Lunar landing site selection	Lunar lander design and implement	Science instrument selection and budget	Lunar miner design, budget and implement	Lunar miner 3-Dimensional (3-D) model	Lunar base design, budget and implement	Lunar base 3-D model	Mission patch design	Lunar Nautics presentation	**LUNAR EXPLORATION**	Let's investigate the geology and geography of the moon	Lunar geology and geography exploration	Strange new moon	Lunar imagery	Impact craters	Lunar core sample	Edible rock abrasion tool (RAT)	Let's investigate lunar missions	Lunar mission exploration	Edible pioneer spacecraft	Edible Clementine spacecraft	Edible lunar rover	Edible lunar prospector spacecraft	Robots versus humans	Edible reconnaissance orbiter spacecraft	**DESIGN CHALLENGES AND CONCEPTS**	Concept: Balloon staging	Challenge: Pop bottle rocket	Concept: Swinging tray	Challenge: Lunar base supply egg drop	Concept: Rover relay	Challenge: Rover race	Concept: Potato astronaut	Concept: Bending under pressure	Challenge Space suit designer	Concept: Solar power	Challenge: Solar oven	Concept: Come-back bottle	Challenge: Microgravity sled
NATIONAL SCIENCE STANDARDS																																													
Unifying Concepts and Processes																																													
Systems, order and organization				■																																									
Evidence, models and explanation				■						■	■	■	■	■												■	■	■	■	■	■		■	■	■	■	■	■	■		■		■		■
Change, constancy and measurement				■				■																																					
Evolution and equilibrium																																													
Form and function																																													
Science as Inquiry																																													
Abilities necessary to do scientific inquiry																					■																								
Understanding about scientific inquiry																																													
Physical Science																																													
Properties and changes of properties in matter																																													
Motions and forces								■																									■	■	■	■			■	■				■	
Transfer of energy																																										■			
Earth and Space Science																																													
Structure of the Earth system																																													
Earth's history																																													
Earth in the solar system							■		■	■		■					■	■	■	■	■	■	■																						
Science and Technology																																													
Abilities of technological design								■		■		■																						■		■		■			■		■		■
Understanding about science and technology					■		■	■	■	■		■																						■		■	■	■			■		■		■
Science in Personal and Social Perspectives																																													
Science and technology in society									■	■		■		■	■			■	■	■		■	■		■	■	■	■	■	■	■											■			
History and Nature of Science																																													
Science as human endeavor		■	■		■							■		■	■				■				■		■												■		■	■					
Nature of science																																													
History of science					■				■	■				■					■					■	■	■	■	■	■	■										■					
NATIONAL MATHEMATICS STANDARDS																																													
Mathematics as problem solving				■																■																									
Mathematics as communication																				■																									
Mathematics as reasoning																																													
Mathematical connections																																													
Number and number relationships																																													
Computation and estimation				■				■	■	■		■			■				■		■					■	■	■	■												■				
Patterns and functions																																													
Algebra																																													
Geometry																				■																									
Measurement				■																																									
Notes					Computer		Computer	Computer	Computer	Computer	Computer	Computer	Computer	Computer	PPT			Computer							Computer																				

Sample Agendas

Full Day One-Week Camp
8 hours per day

Day One:

Lunar Nautics administration:
- Lunar Nautics Employee Handbook pages
  CD Location: Educator Resources/Guides (Student Guide with white Lunar Nautics logo cover only. Disregard the NASA cover for student distribution).
- Lunar Survivor

Lunar Nautics Space Systems, Inc.:
- Welcome to Lunar Nautics Space Systems, Inc. (computer)

Design challenge (rocket staging):
- Concept: Balloon staging
- Challenge: Pop Bottle Rocket

Lunar Missions:
- The Moon — Lunar History (computer)

Lunar explorations:
- Strange New Moon

Lunar missions:
- Edible Pioneer Spacecraft

Lunar Nautics Space Systems, Inc.:
- Journey to the Moon — Early Lander Concepts, Historic Mission, Future Lander Concepts

Day Two:

Design challenge (lunar landing):
- Concept: Swinging tray
- Challenge: Lunar base supply egg drop

Lunar exploration:
- The Moon — Lunar Geography, Lunar Resources, Select Landing Site (computer)
- Lunar Core Samples
- Impact Craters
- Edible RAT

Lunar Nautics Space Systems, Inc.:
- The Moon — Mission and Science Goals (computer)

Lunar missions
- Clementine

Lunar Nautics Space Systems, Inc.
- Journey to the Moon — Apollo Mission History, Patch History, Design a Mission Patch (computer)
- Initial PowerPoint presentation set up (i.e., lunar lander design, landing site selection and science objectives)

Begin mission patch design if time permits.

Day Three:

Design challenge (robots and rovers):
- Concept: Rover relay
- Challenge: Rover race

Lunar exploration:
- Imagery Activity

Lunar mission:
- Lunar Prospector

Lunar Nautics Space Systems, Inc.:
- On the Moon — Lunar Rover Concepts, Design a Lunar Miner 1, Design a Lunar Miner 2 (computer)
- Journey to the Moon — Design a Mission Patch (computer)
- Build 3-D model of lunar miner design
- PowerPoint development (e.g., complete mission patch design and add miner design)

Day Four:

Design challenge (microgravity):
- Concept: Microgravity Come-back Bottle
- Design challenge: Microgravity Sled

Lunar Missions:
- Selene

Lunar Nautics Space Systems, Inc.:
- On the Moon — Design a Base Part 1, Design a Base Part 2 (computer)
- Lunar Base 3-D model
- Continue PowerPoint development

Day Five:

Design challenge (spacesuits):
- Concept: Potato Astronaut
- Challenge: Design a Spacesuit

Lunar Nautics Space Systems, Inc.:
- Lunar Nautics Trivia Challenge (computer)
- Final PowerPoint presentation development
- Lunar Nautics presentation

Lunar missions:
- Lunar Reconnaissance Orbiter

Lunar Nautics administration:
- Educator Resources — Lunar Nautics Trivia Challenge (computer)
- Employee advancement checklist (CD location: Educator Resources/Printouts)
- Certificate of completion (CD location: Educator Resources/Printouts)
- Announcement of design challenge winning team

Half-Day One-Week Camp
4 hours per day

Day One:
Lunar Nautics administration:
- Lunar Nautics Employee Handbook pages (CD Location: Educator Resources/Guides)
- Lunar Survivor (two challenges only)

Lunar Nautics Space Systems, Inc.:
- Welcome to Lunar Nautics Space Systems, Inc. (computer)

Design challenge (rocket staging):
- Challenge: Pop Bottle Rocket

Lunar missions:
- The Moon — Lunar History (computer)

Lunar missions:
- Edible Pioneer Spacecraft
- Lunar Nautics Space Systems, Inc.
- Journey to the Moon — Early Lander Concepts, Historic Mission, Future Lander Concepts

Day Two:
Nova Lunar Nautics, space system design challenge (lunar landing):
- Challenge: Lunar Base Supply Egg Drop

Lunar Exploration Science:
- The Moon — Lunar Geography, Lunar Resources, Select Landing Site (computer)

Lunar Nautics Space Systems, Inc.:
- The Moon — Mission and Science Goals (computer)

Lunar missions:
- Clementine

Lunar Nautics Space Systems, Inc.:
- Initial PowerPoint presentation set up (i.e., lunar lander design, landing site selection and science objectives)

Day Three:
Design challenge (robots and rovers):
- Challenge: Rover Race

Lunar mission:
- Lunar Prospector

Lunar Nautics Space Systems, Inc.:
- On the Moon — Lunar Rover Concepts, Design a Lunar Miner 1, Design a Lunar Miner 2 (computer)
- Journey to the Moon — Apollo Mission History, Patch History, Design a Mission Patch (computer)
- Build 3-D model of lunar miner design
- PowerPoint development (e.g., complete mission patch design and add miner design)

Day Four:

Design Challenge (microgravity):

- Concept: Microgravity Come-back Bottle
- Design Challenge: Microgravity Sled

Lunar missions:

- Selene

Lunar Nautics Space Systems, Inc.:

- On the Moon — Design a Base Part 1, Design a Base Part 2 (computer)
- Lunar Base 3-D Model
- PowerPoint development

Day Five:

Lunar Nautics Space Systems, Inc.:

- Final PowerPoint presentation development
- Lunar Nautics presentation

Lunar missions:

- Lunar Reconnaissance Orbiter

Lunar Nautics administration:

- Educator Resources — Lunar Nautics Trivia Challenge (computer)
- Employee advancement checklist (CD location: Educator Resources/Printouts)
- Certificate of completion (CD location: Educator Resources/Printouts)
- Announcement of design challenge winning team

One Day Camp
6 hours

Lunar Nautics Administration:
- Lunar Nautics Employee Handbook pages (CD Location: Educator Resources/Guides)
- Lunar survivor

Lunar Nautics Space Systems, Inc.:
- Welcome to Lunar Nautics Space Systems, Inc. (computer)

Design Challenge (choose one)

Lunar missions:
- The Moon — Lunar History (computer)
- Edible Spacecraft (choose one)

Lunar Nautics Space Systems, Inc.:
- Journey to the Moon — Early Lander Concepts, Historic Mission, Future Lander Concepts

Lunar Exploration:
- The Moon — Lunar Geography, Lunar Resources, Select Landing Site (computer)

Lunar Nautics Space Systems, Inc.:
- The Moon — Mission and Science Goals (computer)
- Journey to the Moon — Apollo Mission History, Patch History, Design a Mission Patch (computer)
- On the Moon — Lunar Rover Concepts, Design a Lunar Miner 1, Design a Lunar Miner 2 (computer)
- On the Moon — Design a Base Part 1, Design a Base Part 2 (computer)
- Presentation (PowerPoint presentation and building of 3-D models not required)

Lunar Nautics administration:
- Educator Resources — Lunar Nautics Trivia Challenge (computer)
- Certificate of completion (CD Location: Educator Resources/Printouts)

After School Program
1.5 hours to 2 hours per day

Day One:

Lunar Nautics administration:
- Lunar Nautics Employee Handbook pages (CD Location: Educator Resources/Guides)
- Lunar Survivor

Lunar Nautics Space Systems, Inc.:
- Welcome to Lunar Nautics Space Systems, Inc. (computer)
- Journey to the Moon — Early Lander Concepts, Historic Mission, Future Lander Concepts

Day Two:

Design Challenge (choose one)

Lunar missions:
- The Moon — Lunar History (computer)
- Edible Spacecraft (choose one)

Day Three:

Design Challenge (choose one)

Lunar Nautics Space Systems, Inc:
- The Moon — Lunar Geography, Lunar Resources, Select Landing Site (computer)
- The Moon — Mission and Science Goals (computer)
- Journey to the Moon — Apollo Mission History, Patch History, Design a Mission Patch (computer)

Day Four:

Design Challenge (choose one)

Lunar Nautics Space Systems, Inc:
- On the Moon — Lunar Rover Concepts, Design a Lunar Miner 1, Design a Lunar Miner 2 (computer)

Day Five:

Lunar Nautics Space Systems, Inc.:
- On the Moon — Design a Base Part 1, Design a Base Part 2 (computer)
- Lunar Base 3-D model

Day Six:

Lunar Nautics administration:
- Educator Resources — Lunar Nautics Trivia Challenge (computer)

Lunar Nautics Space Systems, Inc.:
- Presentation of lunar base design

Lunar missions:
- Edible Spacecraft (choose one)

Lunar Nautics administration:
- Certificate of completion (CD Location: Educator Resources/Printouts)

Master Supply List

Full Day One-Week Camp:

Name Badges (CD Location: Educator Resources/Printouts)
Role Cards (CD Location: Educator Resources/Printouts)
Student sheets (CD Location: Noted in each material list)
Markers

Administration

The Never-Ending Quest

Per team:

- Never-Ending Quest Puzzle pieces (CD Location: Educator Resources/Printouts)
- Trivia questions on spacecraft
- Crypto-coded riddles
- Lunar reference book

Moon Match

Per team:

- Twenty Moon Match Cards (10 pairs of matching lunar-related images) (CD Location: Educator Resources/Printouts)

Can We Take it With Us?

Per team:

- 1 double balance scale
- 417 pennies
- 2 identical containers per group (one filled with weight that symbolizes mission weight (59 pennies) and one that will hold the chosen “payload components” weights)
- Inventory sheets (CD Location: Educator Resources/Guides/Student Guide)

Lunar Nautics Trivia Challenge

Per class:

- Computer
- Projector
- Educator Resources — Lunar Nautics Trivia Challenge (computer)
- Paper
- Pencil or pen

Per team:

- Bell or buzzer

Lunar Nautics Space Systems, Inc.

The Lunar Nautics Proposal Process

Per team:

- Lunar Nautics Budget Worksheets (CD Location: Lunar Nautics/Handbook and Budget)
- Lunar Nautics Proposal, Budget and Design Notes
- Lunar Nautics Proposal, Budget and Design Checklist
- Calculator

Destination Determination

Per team

- The Moon — Select Landing Site (computer)
- Computer

Design a Lunar Lander

Per team:

- Student data sheets (CD Location: Educator Resources/Guides/Student Guide)
- Role Cards
- Markers
- Paper or poster board
- Scissors
- Glue
- Computer
- Printer
- Drawings of other concepts (optional) (CD Location: Journey to the Moon/Future Lander Concepts)

Science Instruments

Per class:

- Student data sheets (CD Location: Educator Resources/Guides/Student Guide)
- Computer
- Projector
  - Overhead projector
  - Screen
- The Moon — Mission and Science Goals (computer)
- Supplies for the demonstrations include:
  - Digital camera
  - Mirror
  - Flashlight
  - Pebbles
  - BBs
  - Cup of Jello™
  - Portable table
  - Large book
  - Slinky™
  - Iron filings
  - Resealable bag
  - Magnet
  - Battery tester
  - Batteries (AAA, AA, C, D and 9 V)

Design a Lunar Miner/Rover

Per team:

- Student data sheets (CD Location: Educator Resources/Guides/Student Guide)
- Role cards
- Markers
- Paper or poster board
- Scissors
- Glue
- Computer
- Printer
- Drawings of other concepts (optional) (CD Location: On the Moon/Lunar Rover Concepts)

Luner Miner 3-Dimensional Model

Per team:

- Student data sheets (CD Location: Educator Resources/Guides/Student Guide)
- Role cards
- A variety of materials may be used for model construction. Suggested building materials include:
    - LEGO™
    - ROBOTIX™
    - K'NEX™
    - Recyclables (e.g., a variety of boxes, bottles, lids and containers in a variety of shapes and sizes)
- Other materials that have proven beneficial include:
    - Aluminum foil
    - Pipe cleaners
    - Clear plastic wrap
    - Glue gun and glue sticks
    - Exacto knives
    - Duct tape

Design a Lunar Base

Per team:

- Student data sheets (CD Location: Educator Resources/Guides/Student Guide)
- Role Cards
- Markers
- Paper or poster board
- Scissors
- Glue
- Computer
- Printer
- Drawings of other lunar base concepts (optional) (CD Location: On the Moon/Base Concepts)

Lunar Base 3-Dimensional Model

Per team:

- Student data sheets (CD Location: Educator Resources/Guides/Student Guide)
- Role Cards
- A variety of materials may be used for model construction. Suggested building materials include:
    - LEGO
    - ROBOTIX
    - K'NEX
    - Recyclables (e.g., a variety of boxes, bottles, lids, containers in a variety of shapes and sizes)
- Other materials that have proven beneficial include:

  - Aluminum foil
  - Pipe cleaners
  - Clear plastic wrap
  - Glue gun and glue sticks
  - Exacto knives
  - Duct tape

Mission Patch Design

Per team:

- Student data sheets (CD Location: Educator Resources/Guides/Student Guide)
- Logo examples gathered from magazines, products or newspapers
- Role Cards
- Computer
- Printer
- Markers
- Paper or poster board
- Scissors
- Glue
- Various art supplies such as construction paper, paint, aluminum foil, etc.

Lunar Nautics Presentation

Per class:

- Computer
- Projector
- Screen
- Lunar Nautics Presentation Funding worksheet (CD Location: Educator Resources/Guides/Student Guide)
- Calculators, and certificates/awards (optional)

Lunar Exploration

Investigate the Geography and Geology of the Moon

Per student:

- Student data sheets (CD Location: Educator Resources/Guides/Student Guide)
- Computer access or books/articles about Moon geography and geology information

Strange New Moon

Per team:

- Student data sheets (CD Location: Educator Resources/Guides/Student Guide)
- Plastic balls, Styrofoam™ balls, or rounded fruit (e.g., cantaloupe, pumpkin, oranges, etc.)
- Modeling clay or Play-Doh®
- Vinegar, perfume or other scents
- Small stickers, sequins, candy, marbles or anything small and interesting
- Toothpicks
- Glue (if needed)
- Towels (to drape over Moons)
- Pushpins
- Viewer material (e.g., sheet of paper, paper towel roll or toilet paper roll)
- 12.7 cm by 12.7 cm cellophane squares (one for each viewer) in blue plus other selected colors to provide other filters for additional information
- Rubber bands (one for each viewer)
- Masking tape to mark the observation distances

Digital Imagery

Per team:

- Student data sheets (CD Location: Educator Resources/Guides/Student Guide)
- Graph paper
- Colored markers or pencils

Impact Craters

Per team:

- Student data sheets (CD Location: Educator Resources/Guides/Student Guide)

Materials for Activity A:

- Plaster of paris
- 1 large, disposable pan or box (if used as a whole class demonstration) or three to four small, deep containers such as margarine tubs or loaf pans (for individuals or groups)
- Mixing container
- Stirring sticks
- Water (one part water to two parts plaster)
- Projectiles (e.g., marbles, pebbles, steel shot, lead fishing sinkers and ball bearings, etc.)
- Red or blue dry tempera paint (optional) (enough to sprinkle over the surface of the plaster) or substitute baby powder, flour, corn starch, fine-colored sand, powdered gelatin or cocoa.
- Strainer, shaker or sifter to distribute the fine layer material evenly
- Meter stick
- Dust mask
- Data charts (one per group)

Materials for Activity B:

- Large tray or sturdy box 8-cm to 10-cm deep and about 0.5 m on each side (a cat litter pan works nicely), two per class or one per group
- Fine sand (3 kg per tray)
- Baking soda (two to three 1.8-kg boxes) per tray, or flour (two 2.26-kg bags), or fine sand (sandbox sand, 3 kg per tray).
- Red or blue dry tempera paint (enough for a thin layer to cover the dry material surface). (Very fine craft glitter may be used as one color.) **A nose and mouth dust mask should be used when sprinkling paint.** Suggested substitutes for paint may be found in the materials list for Activity A.
- Projectiles (Provide one set of either type for each group of students.)
  - Set A: (Provide enough sets for all groups.) four marbles, ball bearings, or large sinkers of identical size and weight
  - Set B: (Provide one or two sets per class.) three spheres of equal size but different materials so that they will have different mass (e.g., glass, plastic, rubber, steel, wood, etc.)
- Strainer, shaker or sifter to distribute the paint
- Metric rulers and meter sticks
- Lab balance (one per class)
- Data charts (per group)

Lunar Core Sample

Per student:

- Student data sheets (CD Location: Educator Resources/Guides/Student Guide)
- Fun or bite size candy bar (e.g., Snickers®, Milky Way®, Mounds®, Reese's Peanut Butter Cup®, etc.)
- 2 7.62-cm long sections of clear plastic soda straw
- Paper plate
- Plastic knife
- Graph paper or small ruler
- Wet wipes (optional for hand clean-up prior to activity, since edible material is involved)

Edible Rock Abrasion Tool

Per student:

- Student data sheets (CD Location: Educator Resources/Guides/Student Guide)
- 1 fig bar-type cookie that you can get in a variety of flavors
- 1 cup cinnamon and sugar mixture (mixture to use for entire class: 1/3 cup cinnamon and 2/3 cup sugar)
- 1 jumbo pretzel stick (at least 0.635 cm in diameter)—RAT
- 1 paper baking cup (muffin tin liner)
- 1 Popsicle™ or craft stick
- 1 ruler (metric)
- 1 pencil

Lunar Missions

Edible Pioneer 3 Spacecraft

Per student:

- Student data sheets (CD Location: Educator Resources/Guides/Student Guide)
- 1 sugar cone
- 1 2-ounce package of Air Head Xtremes Sour Belts
- 2 HERSHEY'S KISSES®
- Marshmallow crème or cake icing (small containers or shared jar)
- 1 small plastic/paper plate
- 1 plastic knife
- Paper towels
- Wet wipes
- Toothpicks
- Scissors
- Plastic gloves (optional)

Edible Clementine Spacecraft

Per student:

- Student data sheets (CD Location: Educator Resources/Guides/Student Guide)
- 2 fig-bar type cookies
- 4 Crème wafers
- 3 jumbo marshmallows
- 10 toothpicks
- 5 gumdrops
- 1 Blow Pop
- 4 Crème Wafers
- 1 small plastic plate
- 1 plastic knife
- Paper towels
- Wet wipes

Edible Lunar Rover

Per student:

- Student data sheets (CD Location: Educator Resources/Guides/Student Guide)
- 2 sheets of graham crackers (four crackers total)
- 4 Oreos®
- 2 jumbo marshmallows
- 4 regular-size marshmallows
- 4 toothpicks
- 2 Starburst® fruit chews
- Marshmallow crème or cake icing (small containers or shared jar)
- 1 small plastic plate
- 1 plastic knife
- Paper towels
- Wet wipes
- 2 pretzel rods
- 4 miniature Tootsie Rolls
- 5 gumdrops
- 6 Crème Wafers

Edible Lunar Prospector

Per student:

- Student data sheets (CD Location: Educator Resources/Guides/Student Guide)
- 6 jumbo marshmallows
- 14 toothpicks
- 3 pretzel rods
- 3 gumdrops
- 1 Starburst fruit chew
- 2 JUJYFRUITs®
- 1 peppermint stick
- 1 small plastic/paper plate
- 1 plastic knife
- Paper towels
- Wet wipes
- Construction paper
- Plastic gloves (optional)

Robots Versus Humans

Per student:

- Student data sheets (CD Location: Educator Resources/Guides/Student Guide)
- LRO Fact Sheet and the Definition of a Robot (CD Location: Educator Resources/Guides/Educator Guide)
- Transparencies of LRO Fact Sheet and the Definition of a Robot (student and teacher versions) (CD Location: Educator Resources/Guides/Educator Guide)
- Overhead projector
- Erasable transparency markers
- Chart paper
- Magic markers
- Scissors

Edible Lunar Reconnaissance Orbiter Spacecraft

Per student:

- Student data sheets (CD Location: Educator Resources/Guides/Student Guide)
- 5 Crème Wafers
- 1 individual graham cracker (one-half of a sheet)
- 2 Starburst fruit chews
- 2 pieces of candy corn
- 2 individual Skittles® (a pack can be divided among students)
- 1 Tootsie Roll
- 1 jumbo marshmallow
- 3 pretzel sticks
- Marshmallow crème or icing (small containers or shared jar)
- 1 small paper/plastic plate
- 1 plastic knife
- Paper towels
- Wet wipes

Design Concepts and Challenges:

Rocket Staging: Balloon Staging

Per class:

- Student data sheets (CD Location: Educator Resources/Guides/Student Guide)
- 2 long, party balloons
- Nylon monofilament fishing line (any weight)
- 2 plastic straws (milkshake size)
- Styrofoam coffee cup
- Masking tape
- Scissors
- 2 spring clothespins

Soda Bottle Rocket

Per team:

- Student data sheets (CD Location: Educator Resources/Guides/Student Guide)
- Student sheets
- 2-liter plastic soft drink bottles
- Low-temperature glue guns
- Poster board
- Tape
- Modeling clay
- Scissors
- Safety Glasses
- Decals
- Stickers
- Marker pens
- Launch pad/bottle rocket launcher
- Bicycle pump with pressure gauge

Lunar Landing: Swinging Tray

Per class:

- Student data sheets (CD Location: Educator Resources/Guides/Student Guide)
- Metal pizza tray
- String
- Duct tape
- Plastic cup
- Water
- Food coloring
- Hard hat
- Safety glasses

Lunar Base Supply Egg Drop

Per team:

- Student data sheets (CD Location: Educator Resources/Guides/Student Guide)
- Eggs
- Scissors
- Cups
- Straws
- Paper towels
- Cotton balls
- Plastic bags
- Bubble wrap
- 17.78-cm round balloons (limit three per team)
- String
- Drop cloth
- Role Cards.
- Masking tape (about 60.96 cm per team)

Robots and Rovers: Rover Relay

Per team:

- Student data sheets (CD Location: Educator Resources/Guides/Student Guide)
- Objects to retrieve (e.g., cloth, jump rope, ball, traffic cones, yardstick, etc.)

Rover Race

Per team:

- Student data sheets (CD Location: Educator Resources/Guides/Student Guide)
- LEGO, ROBOTIX, K'NEX or other robotic systems to create a moving lunar rover/miner
- Materials for lunar terrain obstacle course (i.e., books, rocks, blocks, etc.)
- Masking tape to mark boundaries of obstacle course
- Two types of rocks that are visually distinct from each other

Spacesuits: Potato Astronaut

Per class:
- Chair
- PVC pipe (≈2.44 m in length, ≈1.27 cm in diameter)
- Large nail
- Latex glove
- 1 sheet of Mylar® (can usually be obtained at a camping store as an emergency blanket)
- 1 sheet of Kevlar® (can usually be obtained from a hunting store)
- 2 rubber bands
- Clip

Per team:
- Student data sheets (CD Location: Educator Resources/Guides/Student Guide)
- Plastic (milkshake-size) straw
- Potato
- Various materials to layer (e.g., tissue paper, notebook paper, handkerchiefs, rubber bands, napkins, aluminum foil, wax paper, plastic wrap, etc.)

Bending Under Pressure

Per team:
- Student data sheets (CD Location: Educator Resources/Guides/Student Guide)
- Two long balloons
- Three heavy-duty rubber bands
- Slinky®

Spacesuit Designer

Per team:
- Student data sheets (CD Location: Educator Resources/Guides/Student Guide)
- 10.16-cm diameter PVC cut into segments of the following lengths:
  - 4 25-mm lengths per team
  - 4 50-mm lengths per team
  - 4 75-mm lengths per team
  - 4 100-mm lengths per team
- Vinyl clothes-dryer hose (25 cm per team)
- Duct tape
- Measuring tape
- Scissors
- Thick rubber gloves
- Wire cutters
- Role cards

Solar Power: Solar Energy

Per team:

- Student data sheets (CD Location: Educator Resources/Guides/Student Guide)
- 4 0.55-V solar cells with leads
- Short lengths of 22-gauge wire
- 8 to 10 small alligator clips
- 1 red light emitting diode (LED)
- 1 multimeter capable of measuring voltages below 5 volts and current below 1 amp
- 1 reflector light socket (lamp)
- 5 light bulbs (i.e., 15 W, 40 W, 60 W, 75 W and 100 W)
- 1 20-ohm, 0.5-W resistor
- Several pieces of cellophane of various colors
- Screens of different mesh sizes and materials
- Translucent material such as wax paper
- Clear material such as a plate of glass or plastic

Solar Oven

Per team:

- Student data sheets (CD Location: Educator Resources/Guides/Student Guide)
- 1 3.79-liter plastic milk container
- Scissors and/or razor knives
- Aluminum foil
- Wire coat hanger (untwisted)
- Plastic wrap
- Hot dog
- Cotton balls
- Cotton batting
- Construction paper (assorted colors with plenty of black available)
- Cardboard
- Wire cutters
- Masking tape
- Books or other objects that can be used to prop up the oven at the proper angle
- Role cards
- Watch or clock with second hand

Microgravity: Come-Back Bottle

Per Class

- Student data sheets (CD Location: Educator Resources/Guides/Student Guide)
- Plastic soda pop bottle, any size
- 5 large washers
- 1 large paper clip
- 2 small paper clips
- Nail or drill
- Scissors or hobby knife
- Duct tape
- Assorted thick rubber bands
- Meter stick

Microgravity Sled

Per team:

- Student data sheets (CD Location: Educator Resources/Guides/Student Guide)
- PVC parts
  - 8 58.42-cm sections
  - 4 46.99-cm sections
  - 2 22.86-cm sections
  - 2 15.24-cm sections
  - 6 5.08-cm sections (spacers)
  - 1 60.96-cm section with all lengths marked off (used as a measuring stick)
  - 6 90-degree elbow couplings
  - 4 45-degree elbow couplings
  - 8 T-couplings
- 1 mesh dive bag per team to hold PVC and couplings
- Access to a swimming pool (approximately 1.22-m deep)
- Stopwatches
- Laminated copies of the structure diagram (two per team)
- Mask and snorkel or swim goggles, brought by students (one per student, optional)
- "Reaching for the Stars" Microgravity Training Video or Internet access to view astronauts training in pool
- Swimsuit (one per person)

Lunar Nautics Employee Handbook

- CD Location: Educator Resources/Guides (Student Guide or copy individual pages with white Lunar Nautics logo cover only. Disregard the NASA cover for student distribution)

Badge Master

- CD Location: Educator Resources/Printouts

Role Cards

- CD Location: Educator Resources/Printouts

Employee Advancement Checklist

- CD Location: Educator Resources/Printouts

Certificate of Completion

- CD Location: Educator Resources/Printouts

Survivor: SELENE "The Lunar Edition"

Purpose

The following exercises are to be used as icebreakers for Lunar Nautics. They are designed as team building activities. These activities can be completed independently or collectively, as time allows.

Introduction

You are stranded on the Lunar Island known as SELENE (our Moon). To increase your chances of surviving, you have been placed into three teams: The Lunas, The Artemis and The Celestials.

Much like in the television show Survivor®, you will be pushed beyond your limits.

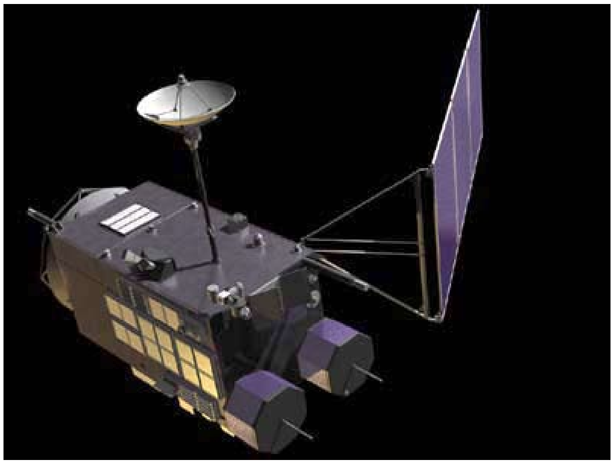
Your team will be put through demanding challenges. Winners will emerge.

Prepare yourself for Survivor: SELENE. You will be given three challenges.

Challenge number 1: The Never-Ending Quest (20 to 30 minutes)

Challenge number 2: Moon Match (15 to 25 minutes)

Challenge number 3: Can We Take It With Us? (25 to 40 minutes)



The Never Ending Quest

Overview

Students work in teams to complete four tasks. The tasks include assembling a puzzle, answering space mission trivia, decoding a message and solving a riddle. The first team to successfully complete all four tasks is declared the winner.

Purpose

By participating in this activity, students will:

- Assemble a puzzle of a lunar vehicle.
- Demonstrate knowledge of space missions.
- Apply critical thinking skills through decoding.
- Develop team cooperation skills.

Preparation

1. Copy and distribute a finalized picture of the spacecraft from the puzzle (available on the CD).
2. Set up an area for teams to put puzzles together.
3. Maintain a copy of answers to the following trivia questions:
   - Name two phases of the Moon (i.e., new Moon, full Moon, waxing crescent, first quarter, last quarter, waning crescent, waxing gibbous and waning gibbous).
   - Name two successful space missions (e.g., Mercury Freedom 7; Mercury Friendship 7; Mercury Aurora 7; Gemini 3, 4 and 6; Apollo 7, 8, 11, 14, 15 and 17).
4. The riddles are as follows (the answer key is on the back of each puzzle):
   - When is the Moon heaviest?
     Answer: When it is full.
   - This gum describes the Earth's movement around the Sun.
     Answer: Orbitz.
   - Expert surfers love the effects of the Moon on this daily Earth event.
     Answer: High tide.

Materials

Per team:

- Three Never-Ending Quest puzzles (CD Location: Educator Resources/Printouts)
- Pictures of each finalized puzzle

Teachers:

- One final puzzle piece (from each team)
- Three trivia questions and answer key
- Riddle answer key

Procedure

1. Students are divided into three teams.
2. Each team is given a puzzle and picture of the finalized puzzle. (Teachers: Keep one piece of each team's puzzle.)
3. Students work to complete puzzle. Puzzle should be complete up to their final piece before any team is given a trivia question.
4. Each team is given a space mission trivia question to earn their final puzzle piece.
5. Students flip puzzle over to view coded riddle on the back of the puzzle.
6. Students solve the riddle posed by coded message.
7. First team to complete all four tasks is the winner.
8. Direct students to clean up supplies.

Questions

1. Which spacecraft were created by the puzzles?
2. What did you know about the space mission and the Apollo Program? What did you learn?
3. How did you decipher the coded messages?
4. What was team discussion about the final riddle?

Answer Key/What is Happening?

N/A

The Never Ending Quest: Student Data Sheet

Team Name:

Team Members:

Follow these instructions:

- First task: Put puzzle of spacecraft together (puzzle is missing a key final piece).
- Second task: Earn puzzle piece by answering space related questions.
- Third task: With finished puzzle, flip puzzle over and decode riddle on the back of the puzzle.
- Fourth task: Solve the riddle posed by the decoded message.
- First team to complete all four tasks is the winner.

Student checklist;

☐ Puzzle is complete.
☐ Space mission trivia question correctly answered.
☐ Riddle on back of puzzle is decoded.
☐ Riddle is solved.

Moon Match

Overview
Students work in teams to match pairs of lunar spacecraft images.

Purpose
By participating in this activity, students will:
- Identify diverse lunar spacecraft.
- Exercise visual recall skills.
- Develop team cooperation skills.

Preparation
- Separate cards into decks of 20 (matching pair of 10 different images for each team's deck).

Materials
Per team:
- Three decks of Moon Match cards (CD Location: Educator Resources/Printouts)

Procedure
1. Students are divided into three teams.
2. Each team is given a deck of cards.
3. Students will work together as a team to compete against other teams.
4. Students take turns turning over two cards.
5. Students try to find matching cards.
6. First team to match all 10 pairs is the winner.
7. Direct students to clean up supplies.

Questions
1. Did recalling images appear easier/harder for some team members? Why?
2. Was team assistance helpful or hurtful? Explain.

Answer Key/What is Happening?
N/A

Moon Match: Student Data Sheet

Team Name:

Team Members:

Follow these Instructions:

- Shuffle the deck.
- Place cards face down in a grid (five across and two down) on the floor/table.
- Each person gets a chance to turn over two cards at a time — looking for a match.
- Each team continues taking turns until 10 matching pairs have been found.
- The team that finds all 10 matching pairs is the winner.

Student checklist

	First pair matched
	Second pair matched
	Third pair matched
	Fourth pair matched
	Fifth pair matched
	Sixth pair matched
	Seventh pair matched
	Eighth pair matched
	Ninth pair matched
	Tenth pair matched

Can We Take it With Us?

Overview

Students work in teams to determine the maximum amount of payload that they can take on a lunar mission. Students are given a container that represents the maximum weight allowed on a mission. They are also given a list of mandatory mission ratios, a double balance, 80 pennies, and an empty container to weigh their trial payloads. The team closest to the maximum payload weight without going over is declared the winner.

Purpose

By participating in this activity, students will:
- Calculate payload weights.
- Apply given ratios.
- Predict the consequences of weight adjustments.
- Develop team cooperation skills.

Preparation

- Prepare three containers with our maximum “mission weight” (59 pennies).
- Obtain three empty containers identical to the maximum “mission weight” containers.
- Copy our Shuttle inventory sheets for the mission.
- Review Shuttle inventory answer guide
- Obtain and calibrate balance equipment (three double balances).
- Gather 80 pennies for each team.

Materials

Per Team:
- Three double balances.
- Three empty containers (for trial weigh-ins).
- 417 Pennies (three rolls of 59 pennies + three groups of 80 pennies).
- Copies of the Shuttle payload inventory sheets.

Procedure

1. Students are divided into three teams.
2. Each team is given a balance and two identical containers (a max weight container and an empty container), 80 pennies, and a Shuttle payload inventory sheet.
3. Students are given the opportunity to review the payload sheets and ask questions.
4. Students work through three trial weigh-ins.
5. Students complete one final weigh-in.
6. Teacher collects the team answer sheets.
7. The team(s) closest to maximum weight without going over is/are declared the winner(s).
8. Direct students to clean up supplies.

Questions

N/A

Answer Key/What is Happening?

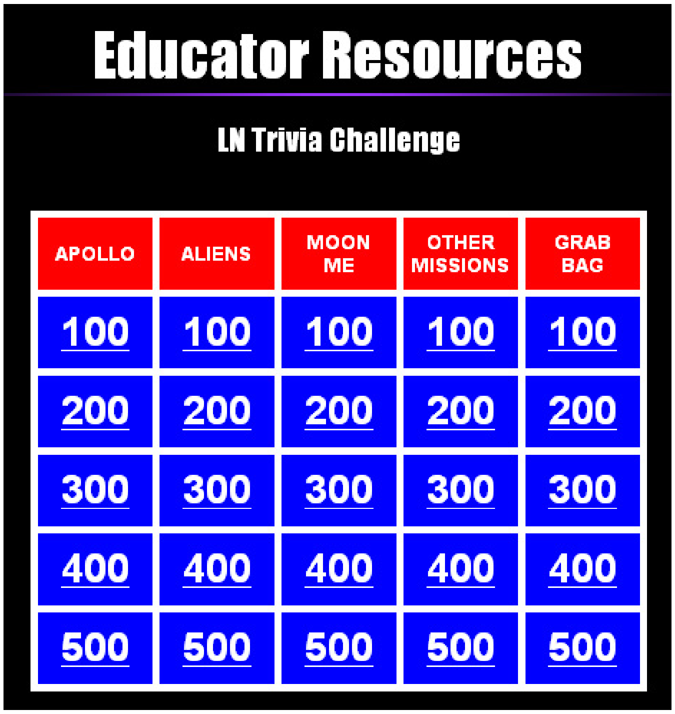
N/A

Payload Inventory Answer Guide for Educators

The following are examples of possible answers that students may come up with while completing the activity entitled, "Can We Take it With Us?." This list is not exhaustive.

Items to be included in payload	Example # 1	Example # 2	Example # 3	Example # 4	Example # 5
Length of mission	__3__Days	__4__Days	__4__Days	__3__Days	__5__Days
Humans in spacesuits	__6__pennies # of humans _2_	__6__pennies # of humans _2_	__9__pennies # of humans _3_	__12__pennies # of humans _4_	__6__pennies # of humans _2_
Food	__18__pennies (# humans × 3 meals × # days)	__24__pennies (# humans × 3 meals × # days)	__36__pennies (# humans × 3 meals × # days)	__36__pennies (# humans × 3 meals × # days)	__30__pennies (# humans × 3 meals × # days)
Tools	__8__pennies (# humans × 4)	__8__pennies (# humans × 4)	__12__pennies (# humans × 4)	__16__pennies (# humans × 4)	__8__pennies (# humans × 4)
Medical kits	__10__pennies (# humans × 5)	__10__pennies (# humans × 5)	__15__pennies (# humans × 5)	__20__pennies (# humans × 5)	__15__pennies (# humans × 5) 1 extra medical kit = 5 pennies.
Total number of pennies	**__42__pennies (17 pennies under max)**	**__48__pennies (11 pennies under max)**	**__72__pennies (13 pennies over max)**	**__84__pennies (4 pennies over max)**	**__59__pennies (exactly!)**

Lunar Nautics Trivia Challenge



Educator Resources

LN Trivia Challenge

APOLLO	ALIENS	MOON ME	OTHER MISSIONS	GRAB BAG
100	100	100	100	100
200	200	200	200	200
300	300	300	300	300
400	400	400	400	400
500	500	500	500	500

Overview

A culminating class computer activity overview of information learned in Lunar Nautics.

Purpose

Through the Lunar Nautics Trivia Challenge, team members will:

- Apply their knowledge of the Moon and lunar missions.

Preparation

1. Ensure that the "Lunar Nautics Trivia Challenge" program on the Lunar Nautics CD is accessible on a projector.

Materials

Per Class:

- Computer
- Projector
- Lunar Nautics Trivia Challenge program (CD Location: Educator Resources/LN Trivia Challenge)
- Paper
- Pencil or pen

Per Team:

- Bell or buzzer

Procedure

1. Open the "Lunar Nautics Trivia Challenge" program from the Lunar Nautics CD on each computer.
2. Conduct the Jeopardy-style trivia challenge by clearing each category's dollar amounts until the final trivia question is complete.
3. Keep a tally of each team's score until there is a team winner.

Questions
N/A

Answer Key/What is Happening?
N/A

Certificate of Completion
(CD Location: Educator Resources/Printouts)

Lunar Nautics Space Systems, Inc.

This section explores Lunar Nautics Space Systems, Inc.

Introduction to Lunar Nautics Space Systems, Inc.

Students learn the history of Lunar Nautics Space Systems, Inc., their roles and expectations as follows:

- About Lunar Nautics.
- Lunar Nautics Intern Employee Expectations.
- Mission Objectives:
  - Landing site.
  - Lunar lander.
  - Science.
  - Lunar miner.
  - Lunar base.
- Testing and evaluation.
- The job.

The Lunar Nautics Proposal Process

Students think creatively about mission objectives, mission needs and budgeting for their mission.

Lunar Base Proposal, Design and Budget Notes

Destination Determination

After exploring the Moon and some missions in other sections, students determine their lunar base site.

Design a Lunar Lander

Challenges students to develop a lunar lander with templates and creative thinking.

Science Instruments

Explores the concepts behind different science instruments that have been used on the Moon.

Lunar Exploration Science

Design a Lunar Miner

Challenges students to develop a lunar miner with templates and creative thinking.

Lunar Miner 3-Dimensional Model

Uses a variety of model kits or recyclables for students to build models of their lunar miner designs.

Design a Lunar Base

Challenges students to develop a lunar base with templates and creative thinking.

Lunar Base 3-Dimensional Model

Uses a variety of model kits or recyclables for students to build models of their lunar base designs.

Mission Patch Design

Students are creatively challenged to graphically represent their mission.

Lunar Nautics Presentation

Students showcase their creativity, organizational skills and teamwork.

Introduction to Lunar Nautics Space Systems, Inc.

- Welcome to Lunar Nautics Space Systems, Inc. (computer)
- LNSS PowerPoint/Educator Resources/PowerPoints

What is "Lunar Nautics"?

Lunar Nautics Space Systems, Inc. is a division of Nova Nautics Space Systems, Inc., an imaginary aerospace company created in 1955 as an aircraft manufacturer. Between 1960 and 1972, Nova Nautics developed key components for the United States (U.S.) Space Program. From 1969 to the present, Nova Nautics has become a world leader in spacecraft design, manufacturing and mission analysis planning. In 1990, the Lunar Nautics division was created to research, design and manufacture components for a return to the Moon.

Lunar Nautics Intern Employee Expectations

Student interns will work individually and as part of a team, as employees of Lunar Nautics, to develop a lunar base, with lunar miner, proposal and present it to Congress and NASA.

Mission Objectives

The following questions should be answered:

- What will we need to be successful?
- How much will this cost?
- What is needed to ensure the safety of astronauts?
- Is this several small outposts or one large base?

Landing Site

The following question should be answered:

- Where are we going?

Science

The following questions should be answered:

- What do we want to find out?
- What science instruments will astronauts need?

Miner Design

The following questions should be answered:

- What is needed to move astronauts, equipment or supplies on the terrain?
- Will sample collection be needed?
- Is this a manned or unmanned miner?
- What instruments will astronauts need?
- What attachments will astronauts need?
- Are backup systems needed?

Lunar Base Design

The following questions should be answered:

- How many astronauts will need a place for habitation?
- What science or experiments will astronauts conduct?
- What communications will astronauts need?
- Are airlocks needed?
- How will power be provided?
- Are vehicles needed for transportation?
- What will be mined or manufactured?
- How will the heat from systems be eliminated?
- Are backup systems needed?

Testing and Evaluation

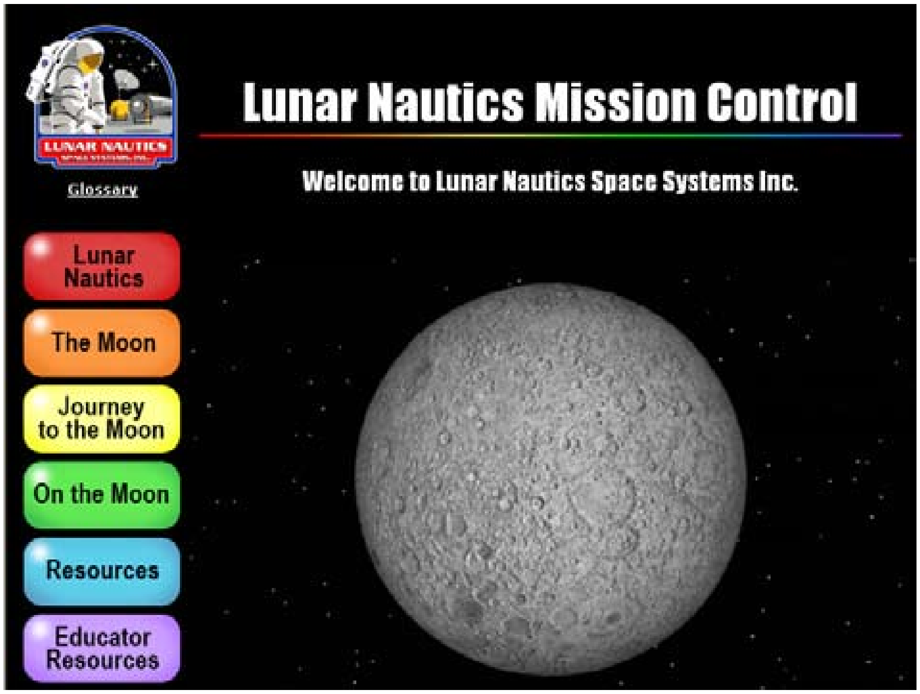
The following questions should be answered:

- What tests are needed to determine durability of designed elements and to complete mission objectives?
- Will the objectives be successful or will they endanger the astronauts?

The Job

Requirements are as follows:

- Employees will work as a team to develop a space mission proposal presentation to members of Congress or NASA using Microsoft PowerPoint or other presentation software.
- Employees are to use NASA development guidance as they create their proposals.
- Mission costs must be capped at $14 billion.



Lunar Nautics Mission Control

Welcome to Lunar Nautics Space Systems Inc.

The Lunar Nautics Proposal Process

Overview

Proposals come in all shapes and sizes depending on who will read them and what format the sponsors want you to follow. However, most are short, no nonsense descriptions of how you and your team can accomplish some goal or task. Proposals usually have an executive summary or brief overview of your intent to complete a task and a budget. A budget may also come in many forms, with the most common budget being an itemized list of expenses. In many careers, preparing proposals is one of the most common writing tasks workers perform.

Purpose

Through the development of a lunar base proposal, students will:

- Understand the importance of organizing information.
- Understand how a proposal is put together.
- Learn how a budget is prepared.
- Learn how to make decisions cooperatively.
- Develop teamwork and communication skills.

Preparation

1. Lunar Nautics Budget Worksheets from the Lunar Nautics CD
2. Lunar Nautics Base Proposal, Design and Budget Notes from this Lesson Plan
3. Lunar Nautics Base Proposal, Design and Budget Checklist

Materials

Per team:

- Lunar Nautics Budget Worksheets (CD Location: Lunar Nautics/Handbook and Budget)
- Lunar Nautics Lunar Base Proposal, Design and Budget Notes
- Lunar Nautics Lunar Base Proposal, Design and Budget Checklist
- Calculator

Procedure

1. Distribute proposal forms to each team.
2. Instruct each team to read and follow the instructions on the student forms.
3. As they build on their Lunar Nautics skills, they should refer to these worksheets and notes often.
4. Refer to the Glossary and Resources contained on the Lunar Nautics CD (or copied for the classroom) for further references.

Questions

1. What information is important to include in a proposal?
2. What steps will you use in developing your proposal?
3. How does developing a budget help you in making decisions about your project?
4. What seems to be the easiest part of developing your proposal?
5. What seems to be the hardest part of developing your proposal?

Answer Key/What is Happening?

There is no right or wrong answer. Each team has $14 billion dollars to develop a lunar base for Lunar Nautics Space Systems, Inc.

Lunar Nautics Proposal, Design and Budget Notes

Name of Team
List your team name.

Names of Team members
List names of teammates.

Mission Title
What is the overall name of the mission (Cassini, Voyager, Pathfinder, etc.)?

Mission Destination
Where on the Moon will your spacecraft land and why?

Mission Objectives
What is your mission supposed to accomplish and/or find out?

Science Experiments
List of chosen science experiments and why selected:

- Camera/telescopes
- Retroreflectors
- Collector detectors
- Seismology and ejecta detectors
- Magnetic detectors
- Electrical detectors

Questions to be Answered
1. What kinds of science are you going to do at your destination?
2. List the data you are collecting and why.
3. What kind of results are you expecting?
4. How can you build redundancy into your science instruments?

Miner Design
Design your miner with all the appropriate systems and science instruments. Find locations for each of your systems and state what you want to mine in those locations, using your miner.

Model of Miner
Build a model of your miner with all the appropriate systems and science instruments on board.

Lunar Base Design
Design your lunar base (or two lunar outposts) with all the appropriate systems and science instruments. Find a location for each of your systems and state why you want them in those locations. (e.g., if you choose a nuclear reactor too close to your communications antennas, what effect will this have?)

Model of Lunar Base
Build a lunar base model with all the appropriate systems and science instruments.

Types of Evaluation Tests and Anticipated Results

What kinds of tests are you going to conduct on your miner and lunar base to make sure it will do the job, last years in space and return science data when needed (hint: vibration tests, radiation tests, software and computer tests, etc.).

Mission Timeline

The following questions should be answered:

- How long do you need and what kind of staff do you need to watch over your miner and lunar base?
- How can you save money in staff costs and training?
- How long will it take to prepare your miner and lunar base?
- How long will it take to build and test your systems?
- Build a timeline from start of the mission to the end of the mission that will allow all the time needed to accomplish your objectives (hint: 1 year, 2 years, 3 years, 5 years, etc.).

List of Backup Systems

If one or more of your systems fail during your mission, what can you do?

Expected Mission Results

After gathering this information and making decisions, what do you expect to find and why?

Mission Costs (maximum $14 billion)

What are your mission costs? Add up the cost of all your systems and redundant systems.

Executive Summary

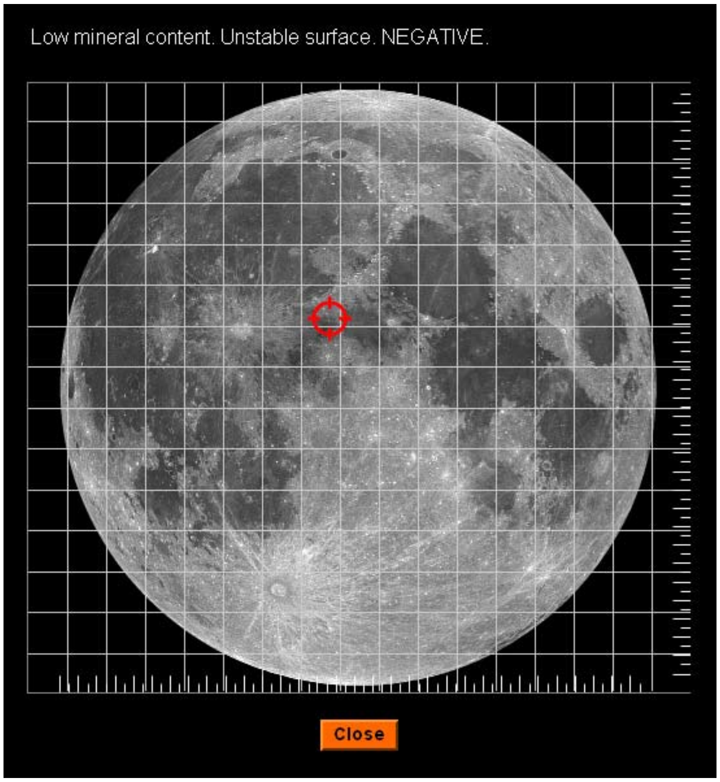
To summarize your results, you will need to know the following:

- Team name.
- Mission title.
- Destination.
- Science conducted.
- Miner functions.
- Lunar base layout.
- Length of mission.
- Anticipated mission results.
- Total mission costs.

Destination Determination

Overview

For each mission to the Moon, a destination is chosen and a detailed study made to determine exactly where the mission will visit and what will be studied. During this activity, team members will have the opportunity to choose and learn more about a lunar mission destination.



Low mineral content. Unstable surface. NEGATIVE.

Purpose

Through a study of the Moon, students will:

- Increase their knowledge of the Moon.
- Learn how to make decisions cooperatively.
- Develop teamwork and communication skills.

Preparation

1. Review The Moon section of the Lunar Nautics CD and related materials.
2. Ensure that the Select a Landing Site program in The Moon section on the Lunar Nautics CD is accessible on the computers.
3. Make copies of the Destination Determination Student Sheets.

Materials

Per Team:

- Student data sheets (CD Location: Educator Resources/Guides/Student Guide)
- Computer (CD Location: The Moon/Lunar Geography, Lunar Resources, Select Landing Site)

Procedure

1. Open the “Select a Landing Site” program from the Lunar Nautics CD on the computer.
2. Have students follow the Destination Determination Student Sheets.

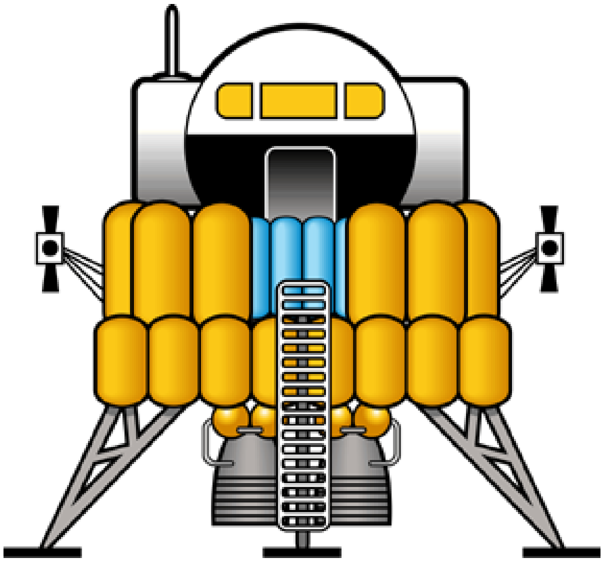
Questions

1. What are some of the features of the Moon?
2. What are some of the resources on the Moon?
3. What can some of the resources on the Moon be used for?
4. Where would be a good place to explore?
5. How did your group finally decide upon your chosen destination?
6. How effective were your team members in working together?
7. What could you do to improve your decision-making process? How could you work better as a team?

Answer Key/What is Happening?

N/A

Design a Lunar Lander



Overview

As an introduction to Lunar Nautics Space Systems, Inc. activity, team members will have the opportunity to prepare a paper and pencil version of their lunar lander for the Lunar Nautics mission.

Abilities of Technological Design

The design process can be broken down into the following five steps:
1. Identify appropriate problems for technological design.
2. Design a solution or product.
3. Implement the proposed design.
4. Evaluate completed technological designs or products.
5. Communicate the process of technological design.

Purpose

Through the creation of their lunar lander, team members will:
- Apply their knowledge of lunar lander systems and instruments.
- Apply their knowledge of the abilities of technological design.
- Learn how to make decisions cooperatively.
- Develop teamwork and communication skills.

Preparation

1. Ensure that the Lunar Lander template has been printed from the Lunar Nautics CD. (CD Location: Educator Resources/Extras/Lunar Lander Template)
2. Make copies of the Design a Lunar Lander sheets for each team.

Materials

Per team:
- Student data sheets (CD Location: Educator Resources/Guides/Student Guide)
- Role Cards
- Markers
- Paper or poster board
- Scissors
- Glue
- Computer (CD Location: Journey to the Moon/Early Lander Concepts, Historic Missions, Future Lander Concepts)
- Printer
- Drawings of other Lunar Lander concepts (optional)

Procedure

1. Distribute the Role Cards to each team member. Ensure that each person understands his/her role in the activity.
   a. Project Engineer: Provides leadership to discussions as the team moves through the steps of design.
   b. Facilities Engineer: Provides correct templates to meet spacecraft criteria.
   c. Developmental Engineer: Leads production of spacecraft design.
   d. Test Engineer: Makes records of team's decisions for each step of design.
2. Distribute the Lunar Lander Templates. Discuss.
3. Distribute the "Design a Lunar Lander" Student Sheets. Review the steps of design.
4. Challenge each team to use their worksheets, templates and samples of other space vehicle designs to create the most effective design for their miner.
5. Design should be saved as a picture for use in the students' presentations.

Questions

1. What process was used in determining your design?
2. How did your group make decisions about what should be included in your lander design?
3. How effective were your team members in working together?
4. What could you do to improve on your decision-making process? How could you work better as a team?

Answer Key/What is Happening?

N/A

Science Instruments

Overview

Lunar exploration will require a variety of science instruments that provide the means for studying the Moon. Many of those instruments are unfamiliar to students. This section of the curriculum provides a reference of major science instruments on the Lunar Nautics CD and a variety of hands-on activities and demonstrations meant to introduce students to the science behind these instruments.

Purpose

Through a study of science instruments, students will:

- Become aware of the variety of instruments that are available to do lunar science research.

Preparation

1. Review the Mission and Science Goals section of the Lunar Nautics CD or printed copies. (There is also a PowerPoint presentation in the Educator Resources.)
2. Review the science instrument activities that follow and select which activities you will use.

Materials

Per class:

- Student data sheets (CD Location: Educator Resources/Guides/Student Guide)
- Computer (CD Location: The Moon/Mission and Science Goals)
- Projector:
  - Overhead projector
  - Screen
- Lunar Science Instruments hard copy or Mission and Science Goals computer section
- Supplies for the demonstrations include:
  - Digital camera
  - Mirror
  - Flashlight
  - Pebbles
  - BBs
  - Cup of Jello
  - Portable table
  - Large book
  - Slinky
  - Iron filings
  - Resealable bag
  - Magnet
  - Battery tester
  - Batteries (AAA, AA, C, D and 9 V)

Procedure

1. Use the Lunar Science Instruments information to introduce systems and instruments.
2. Discuss the first instrument(s). Reinforce the concept by demonstrating core concepts. Move to the next instrument(s) and repeat.

Lunar Exploration Science

"They view the great vault above. They ponder shifting planets, eerie comets, the fixity of the stars—at first with wonder, then with speculation, and finally determination. They measure, weigh, calculate, analyze; and because of the inner nature of them...They finally go."
—Jeff Sutton, (Apollo at Go)

After the Apollo Program, NASA had other plans to explore the Moon. The Integrated Manned Space Flight Program, planned for 1970 to 1980, was presented in 1969. It considered some of the following options for the post-Apollo U.S. space program.

The proposal included six new Apollo-type lunar expeditions followed by a space workshop (later called Skylab), two additional lunar expeditions, and then a series of extended lunar missions (XLM) lasting several days. Shortly thereafter, a new Space Tug called the Lunar Module-B (LM-B) would launch. The LM-B could support a crew of three on the Moon for a month, while the Space Tug would house six men in space for a week. By 1975, a space station with a dozen astronauts would begin Mars flight simulations. The first reusable shuttle would begin flying soon after. The design for the shuttle included orbital flights of up to 30 days.

A Lunar Orbital Space Station (LOSS) Design Reference Mission, developed in 1970 by North American Rockwell, had Saturn V-B rockets launching crews of six to eight to a lunar orbiting space station in polar orbit. The 3-year mission plan included six month-long lunar surface expeditions each year. Scientific objectives for these missions included locating a site for a future lunar base and analysis of lunar resources.

However, Congress and the American public seemed to have lost interest in the Moon flights by the time of Apollo 16. The race had already been won. The last three scheduled Apollo missions (18, 19 and 20) were eventually cancelled (although their Saturn V rockets had already been built). However, lunar science was still in its infancy. Although we learned many things about the Moon, we had only landed in a small number of locations.

Experiments left on the Moon lasted for several years but were then powered down due to congressional funding cuts. Skylab and the (nonnuclear) Space Shuttle were the only two projects that escaped unscathed by congressional budget cuts in the 1970s. But many unanswered questions about the Moon still exist.

Since then, scientists have studied Moon rocks and the other results of experiments we left on the Moon, but are very adamant that we must return. It would be as if you landed in six places on the Earth, brought back some samples, and then decided you knew EVERYTHING there was to know about the Earth.

Recent missions to the Moon, Clementine and Lunar Prospector, have taught scientists more about the global surface composition of the Moon, its topography, its internal structure and about the poles. However, the findings leave more questions unanswered. For example, we now know that the Moon's crust is highly enriched in aluminum (supporting its origin by early global melting), but the mare basalts high in titanium returned in abundance by the astronauts on Apollo 11 and 17 are actually quite rare. We have found that zones rich in magnesium and iron, found in the lunar highlands, are usually associated with large impact basins, not highland terrain. While we know that the subsurface mass concentrations (mascons) inside the Moon cause a lumpy gravitational field (requiring constant adjustments for orbiting spacecraft), we can only speculate that the mascons found beneath the floors of large impact basins may represent dense uplifted rocks from the lunar mantle. The areas found near the lunar poles in permanent darkness may contain water ice (from impacting comets).

Dr. Paul Spudis, a lunar scientist and author of *The Once and Future Moon*, believes that NASA must return to the Moon for a variety of reasons. Not only would it be cheaper than going to Mars, he believes that it is a good place to begin to learn how to live and work in space. In addition, Spudis has written about the potential in terms of science to be learned on the Moon, in astronomy, physics, life sciences and geoscience. There is so much to be gained by expending no more fuel than it takes to launch a satellite to the higher geosynchronous orbit.

Various other plans to return to the Moon include the development of a lunar telescope, a permanent lunar base for testing long-duration space flight systems (e.g., life support, suits and tools, rovers, and laboratories), mining of lunar resources for use on Earth, and the development of manufacturing plants to produce hydrogen-oxygen chemical rocket propellants.

Many applications, both scientific and industrial, have been suggested for the Moon, including:
- A scientific laboratory complex.
- An astrophysical observatory.
- An industrial complex to support space-based manufacturing.
- A fueling station for spacecraft.
- A training site and assembly point for human expeditions to Mars.
- A nuclear waste repository.
- A response complex to protect the Earth from short-warning comets and asteroids.
- A studio for extraterrestrial entertainment using virtual reality and telepresence.

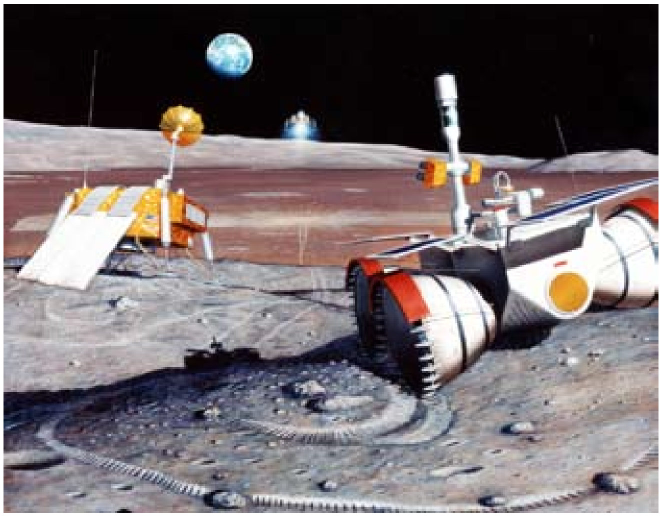
Science facilities on the Moon will take advantage of the Moon's unique environment to support astronomical, solar and space science observations. Special characteristics include the one-sixth gravity of the Moon, its high vacuum, seismic stability, low temperatures and a low radio-noise environment on the far side.

The far side of the Moon is permanently shielded from direct radio transmission from Earth. This uniquely quiet lunar environment may be the only location in space where radio telescopes can be used to their full advantage. The solid, seismically stable, low-gravity, high-vacuum platform will allow scientists to search for extrasolar planets using precise, interferometric techniques.

A fully equipped lunar science base also provides life scientists with the opportunity to extensively study biological processes in reduced gravity and in low-magnetic fields. Genetic engineers, for example, can conduct their experiments in facilities that are isolated from the Earth's biosphere.

Genetically engineered lunar plants could become a major food source and supplement the life support system of the base. Areas near the south pole that are permanently shadowed are near locations that are nearly always in Sunlight, providing unlimited solar energy resources for lunar facilities.

The first lunar researchers to live and work on the Moon will perform the scientific and engineering studies needed to confirm the specific role the Moon will play in our exploration of the solar system. The confirmation and harvesting of the Moon's ice reservoirs in the Polar Regions could significantly impact the development of future lunar bases.



Discoveries originating in lunar laboratories would be channeled directly into appropriate sectors on the Earth as new ideas and techniques. These ideas and techniques will be similar to the way the International Space Station laboratory discoveries will be made in the future.

The ability to provide useful products from native lunar materials will have an influence on the growth of lunar civilizations. These products could support overall space commercialization. They include:

- The production of oxygen for use as a propellant of orbital transfer vehicles.
- The use of raw lunar soil and rock (regolith) for radiation shielding on space stations, space settlements and transport vehicles.
- The production of ceramic and metal products to support the construction of structures and habitats in space.
- Harvesting hydrogen and water from lunar ice.

An initial lunar base will include the extraction of lunar resources and operation of factories to provide products for use on the Moon and in space. From the Apollo missions, we know that the Moon has large supplies of silicon, iron, aluminum, calcium, magnesium, titanium and oxygen. Lunar soil and rock can be melted to make glass fibers, slabs, tubes and rods. Sintering (heating materials so they coalesce) can produce lunar bricks and other ceramic products. Iron metal can be melted or cast into shapes using powder metallurgy. Lunar products could find a market as shielding materials, in habitat construction, in the construction of large space facilities and in electrical power generation and transmission systems.

Many space visionaries envision a day when the Moon will become the chief source of materials for space-based industry.

Telescopes

In 1972, the Apollo 16 crew deployed the first and, so far, only, lunar astronomical observatory. The Far Ultraviolet Camera/Spectrograph used a 7.62-cm diameter Schmidt telescope to photograph the Earth, nebulae, star clusters and the Large Magellanic Cloud. The tripod-mounted astronomical equipment was placed in the shadow of the Lunar Module so it would not overheat. The Far Ultraviolet Camera took pictures in ultraviolet (UV) light that would normally be blocked by the Earth's atmosphere. It had a field of view of 20 degrees, and could detect stars having visual magnitudes brighter than 11. One hundred seventy-eight images were recorded in a film cartridge returned to Earth. The observatory still stands on the Moon today.

The Apollo Lunar Telescope

Why is the Moon such a good place for astronomy? First of all, the Moon has no atmosphere. The sky is perfectly black and the stars do not twinkle. Stars and galaxies can be observed at all wavelengths, including X-ray, UV, visible, infrared (IR) and radio.

In contrast, the Earth's atmosphere absorbs light, causes distortion and totally blocks the X-ray, UV, and certain IR and low-frequency radio signals. These limitations prevent scientists from studying many important phenomena in stars, galaxies and black holes.

In addition, nighttime on the Moon lasts about 350 hours. This would permit scientists to watch deep space objects for very long periods, or to accumulate signals on very faint sources such as dim stars, galaxies or planets around other stars. In contrast, the Hubble Space Telescope, NASA's current premier telescope for space research, is in a low-Earth orbit some 575-km high (the Moon is 450,000 km away). Sunrise and Sunset are only 90 minutes apart on the HST, meaning that the dark time (the time HST is in Earth shadow) is only 45 minutes long, which is a major constraint for astronomers.

Unlike orbiting spacecraft, the Moon is a very large and ultra-stable platform for telescopes of any kind and has no seismic activity unless there is meteoric impact. Average ground motion on the surface is estimated to be less than 1 micron (one millionth of a meter or about the thickness of a hair).

This stability is crucial for optical interferometers — instruments needed to carry out a systematic search of planets around other stars within our own galaxy. An interferometer is an array of several telescopes that work together to increase magnification ability.

Round trip light-travel time between the Moon and the Earth is about 2.5 seconds. This means a telescope on the Moon can be controlled from a ground station with a nearly instantaneous response. (This goes for all kinds of remotely controlled operations, not just telescopes.) Except for rare meteoric hits, a lunar telescope could last almost indefinitely, since there is no weather on the Moon. For example, the retroreflectors left on the Moon by the Apollo astronauts are still in operation after more than 30 years. A telescope on the Moon will remain productive for many decades, at low cost. The purpose of the NASA Lunar Telescope Deployment task is to develop and demonstrate telerobotic technologies that enable an unmanned lunar observatory that is constructed and operated from Earth. Specifically, the task is to study an optical interferometric telescope for the Moon.

Types of Telescopes

Optical telescopes can be on either the nearside or the far side of the Moon. (The term dark side is not correct because it implies that the Sun does not shine there; in fact, the Sun shines on both sides equally.) There is very little atmosphere to scatter light from the Sun or Earth, so you could use an optical telescope even during the day.

Radio waves bend around small obstacles and it is harder to block them out. Being a half-mile from the point where you can no longer see any part of the Earth would not be enough to eliminate radio noise emanating from the Earth. Therefore, radio telescopes are best placed on the far side of the Moon to block out the radio noise from Earth and its increasingly noisy fleet of satellites.

A laser would transfer data communications from the lunar observatory to Earth through a lunar satellite to further avoid noise. Astronomers could control the telescopes through the international computer networks from their own offices on Earth.

A 1-meter transit telescope is mounted to a robotic lunar lander on the surface of the Moon. The Moon is a uniquely suitable platform for astronomy, which could include extreme UV images of Earth's magnetosphere (permitting study of solar wind interaction), the first far-UV sky survey, and could include first-generation optical interferometers and very long-wavelength radio telescopes.

The instrument illustrated above is a Lunar Ultraviolet Telescope Experiment (LUTE), which takes advantage of the stable and atmosphere-free lunar surface and uses the Moon's rotation to survey the UV sky. The lander is an Artemis class lander capable of delivering up to 200 kilograms to the lunar surface. The Artemis robotic lunar lander is designed for cost-effective delivery of payloads to the Moon to study lunar geology and astronomy. The effective operation of the Artemis lander is an important precursor to future human lunar expeditions.

Some scientists feel that the lunar far side — quiet, seismically stable and shielded from Earth's electronic noise — may be the solar system's best location for such an observatory. The facility would consist of optical telescope arrays, stellar monitoring telescopes and radio telescopes allowing nearly complete coverage of the radio and optical spectra.

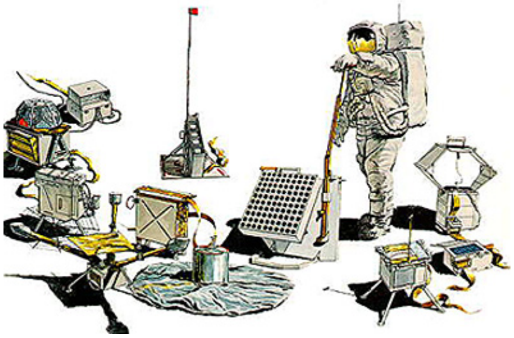
The observatory would also serve as a base for geologic exploration and for a modest life sciences laboratory. In the left foreground, a large fixed radio telescope is mounted on a crater. The telescope focuses signals into a centrally located collector, which is shown suspended above the crater. The lander in which the crew would live can be seen in the distance on the left. Two steerable radio telescopes are placed on the right. An astronaut is servicing the instrument in the foreground. The other astronaut is about to replace a small optical telescope that has been damaged by a micrometeorite. A very large baseline optical interferometer system can be seen in the right far background.

Questions to think about:

1. If you were an astronomer on the Moon, which type of telescope would you enjoy working on?
2. Which telescope should we consider putting on the Moon first? Why?
3. Imagine you discovered an Earth-like planet around another star using an interferometer array. What might the press release say?

Source; The aerospacescholars.JSC.NASA.GOV Web site.

Lunar Science Instruments



Camera/Telescopes

Take several pictures of the class with a digital camera. Eject the cartridge from the camera. Scientists can observe the universe from the perspective of the Moon with telescopes and cameras. Imagery can either be beamed back to Earth or cartridges removed and sent back to Earth for analysis.

Retroreflectors

Set a mirror up across the room. On the other side of the room, shine a flashlight beam at the mirror either directly back or angled. Scientists use mirrors on the Moon to reflect back laser beams to Earth to determine distance and motion of the Moon.

Collector Detectors

Drop pebbles or BB's into a cup of Jello. They will sink to various depths. For example, some instruments collect dust and other particles with aluminum or Aerogel™ for measurement or later study. The collectors can be taken back to a lab or returned to Earth. Alternatively, data can be beamed to a lab or Earth.

Seismology and Ejecta Detectors

Have the students place their hands around the edges of a large (portable) table. Take precautions that all materials are removed from the table. Take a large book, such as a dictionary, and drop it from a height of 0.61 m or 0.91 m in the center of the table, making sure that the book will not strike any students. The students should feel the vibration and a slight wind. There will probably be some unseen dust in that wind as well. Some instruments detect the vibrations and/or the wind or the particles ejecta as they fly away from the impact of a meteorite. Place a Slinky on the table. Press down on the top of one end of the Slinky and watch the rest of it react. This motion is called a shear wave. Now press the slinky inward from the end. This motion is called a compression wave. This also shows seismic vibrations and how there is action and reaction.

Magnetic Detectors

Place iron filings in a plastic zip lock bag. Place the bag on an overhead projector and evenly distribute the contents in the center of the bag. Place a magnet in the midst of the filings and observe the pattern. Much as the filings can be seen on the overhead projector, instruments can see (detect) and measure magnetic forces on the Moon.

Electrical Detectors

Take the battery tester (NOT to be confused with a current tester with leads) and individually test each battery: AAA, AA, C, D and 9 V. Show the students the meter reading for each different battery. Electrical detectors are used in surface and subsurface electrical experiments to help scientists discover how the Moon conducts or contains electricity.

Questions

1. Why are science instruments important for space science missions?
2. What systems/instruments do you think are the most important for a space science mission?
3. What systems/instruments do you think that your team should include on your spacecraft?

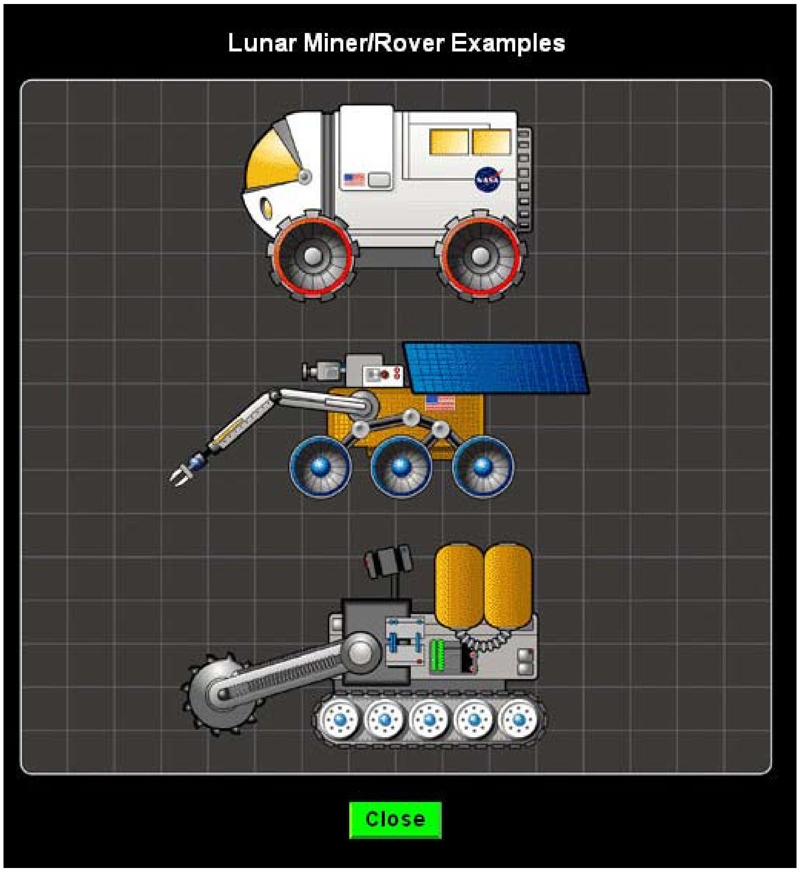
Answer Key/What is Happening?

N/A

Design a Lunar Miner/Rover

Overview

A major feature of designing a lunar mission is to develop the design for the miner. During this activity, team members will have the opportunity to prepare a computer or blueprint student sheet version of their miner for the Lunar Nautics mission.



Abilities of Technological Design

The design process can be broken down into the following five steps:

1. Identify appropriate problems for technological design.
2. Design a solution or product.
3. Implement the proposed design.
4. Evaluate completed technological designs or products.
5. Communicate the process of technological design.

Purpose

Through the creation of their miner, team members will:

- Apply their knowledge of miner systems and instruments.
- Apply their knowledge of the abilities of technological design.
- Learn how to make decisions cooperatively.
- Develop teamwork and communication skills.

Preparation

1. Ensure that the Design a Miner program on the Lunar Nautics CD is accessible on the computers. Make copies of the Miner Templates (print from Lunar Nautics CD) if no computer is available.
2. Make copies of the Design a Miner sheets for each team.

Materials

Per team:

- Student Data Sheets (CD Location: Educator Resources/Guides/Student Guide)
- Role cards
- Markers
- Paper or poster board
- Scissors
- Glue
- Computer (CD Location: On the Moon/Lunar Rover Concepts, Design a Lunar Miner Part 1, Design a Lunar Miner Part 2)
- Printer
- Drawings of other miner concepts (optional)

Procedure

1. Distribute the role cards to each team member. Ensure that each person understands his/her role in the activity.
   a. Project Engineer: Provides leadership to discussions as the team moves through the steps of design.
   b. Facilities Engineer: Provides correct templates to meet spacecraft criteria.
   c. Developmental Engineer: Leads production of spacecraft design.
   d. Test Engineer: Makes records of team's decisions for each step of design.
2. Open computers to Design a Lunar Miner 1 and 2 program from the Lunar Nautics CD or distribute the Design a Miner Templates. Discuss.
3. Distribute the Design a Miner Student Sheets. Review the steps of design.
4. Challenge each team to use their worksheets, templates and samples of other space vehicle designs to create the most effective design for their miner.
5. Print out miner for use in building a model.
6. Save design as a picture for use in presentation.

Questions

1. What process was used in determining your design?
2. How did your group make decisions about what should be included in your miner design?
3. How effective were your team members in working together?
4. What could you do to improve on your decision making process? How could you work better as a team?

Answer Key/What is Happening?

N/A

Lunar Miner 3-Dimensional Model

Overview
This activity will provide the participants the opportunity to produce a 3-D model of their designed miner.

Purpose
Through the creation of their miner model, students will:
- Apply their knowledge of miner systems and instruments.
- Develop skills in model construction.
- Learn how to make decisions cooperatively.
- Develop teamwork and communication skills.

Preparation
Collect or prepare materials.

Materials
Per team:
- Student Data Sheets (CD Location: Educator Resources/Guides/Student Guide)
- Role cards
- Suggested building materials include:
  - Building materials such as LEGO, ROBOTIX, K'NEX.
  - Recyclables (a variety of boxes, bottles, lids, containers in a variety of shapes and sizes).
- Other materials that have proven beneficial include:
  - Aluminum foil
  - Pipe cleaners
  - Clear plastic wrap
  - Glue gun and glue sticks
  - Razor knives
  - Duct tape

Procedure
1. Distribute the role cards to each team member. Ensure that each person understands his/her role.
   a. Project Engineer: Provides leadership to discussions as the team moves through the building process.
   b. Facilities Engineer: Provides correct materials to meet miner criteria.
   c. Developmental Engineer: Leads production of miner model.
   d. Test Engineer: Makes records of team's decisions for each step of building.
2. Discuss safety rules for use of materials.
3. Discuss scale modeling and determine the scale to be used for the models (optional).
4. Encourage each team to implement the design that they prepared using the design templates. Ensure that team members understand that it is acceptable to make improvements to their design as they construct.
5. Under the Test Engineer's leadership, each team should develop a summary of the construction process and a list of information to be presented in the final presentation.

Questions
1. What changes, if any, did you make to your design during the construction process? Why were these changes necessary?
2. What characteristics of your spacecraft have the potential to make it an award-winning project?
3. How effective were your team members in working together? How could you work better as a team?

Answer Key/What is Happening?
N/A

Design a Lunar Base

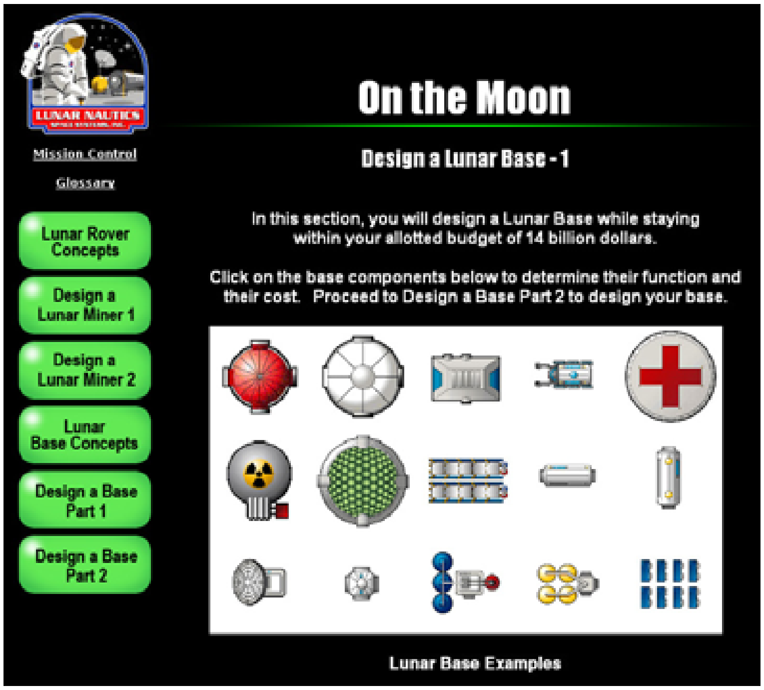
Overview

During this activity, team members will have the opportunity to prepare a computer or a blueprint student sheet version of their lunar base for the Lunar Nautics mission.

Abilities of Technological Design

The design process can be broken down into the following five steps:

1. Identify appropriate problems for technological design.
2. Design a solution or product.
3. Implement the proposed design.
4. Evaluate completed technological designs or products.
5. Communicate the process of technological design.



On the Moon

Design a Lunar Base - 1

In this section, you will design a Lunar Base while staying within your allotted budget of 14 billion dollars.

Click on the base components below to determine their function and their cost. Proceed to Design a Base Part 2 to design your base.

Lunar Base Examples

Overview

Through the creation of their lunar base, team members will:

- Apply their knowledge of lunar base systems and instruments.
- Apply their knowledge of the abilities of technological design.
- Learn how to make decisions cooperatively.
- Develop teamwork and communication skills.

Preparation

1. Ensure that the Design a Lunar Base program on the Lunar Nautics CD is accessible on the computers. Make copies of the Lunar Base Templates (print from Lunar Nautics CD) if no computer is available. (There is also a PowerPoint presentation in the Educator Resources.)
2. Make copies of the Design a Lunar Base sheets for each team.

Materials

Per Team:

- Student Data Sheets (CD Location: Educator Resources/Guides/Student Guide)
- Role cards
- Markers
- Paper or poster board
- Scissors
- Glue
- Computer (CD Location: On the Moon/Design a Base Part 1, Design a Base Part 2)
- Printer
- Drawings of other lunar base concepts (optional)

Procedure

1. Distribute the role cards to each team member. Ensure that each person understands his/her role in the activity.
    a. Project Engineer: Provides leadership to discussions as the team moves through the steps of design.
    b. Facilities Engineer: Provides correct templates to meet lunar base criteria.
    c. Developmental Engineer: Leads production of lunar base design.
    d. Test Engineer: Makes records of team's decisions for each step of design.
2. Open computers to the Design a Lunar Base program from the Lunar Nautics CD or distribute the Design a Lunar Base Templates. Discuss.
3. Distribute the Design a Lunar Base Student Sheets. Review the steps of design.
4. Challenge each team to use their worksheets, templates and samples of other lunar base designs to create the most effective design for their lunar base.
5. Print out lunar base for use in building a model.
6. Save design as a picture for use in presentation.

Questions

1. What process was used in determining your design?
2. How did your group make decisions about what should be included in your lunar base design?
3. How effective were your team members in working together?
4. What could you do to improve on your decision making process? How could you work better as a team?

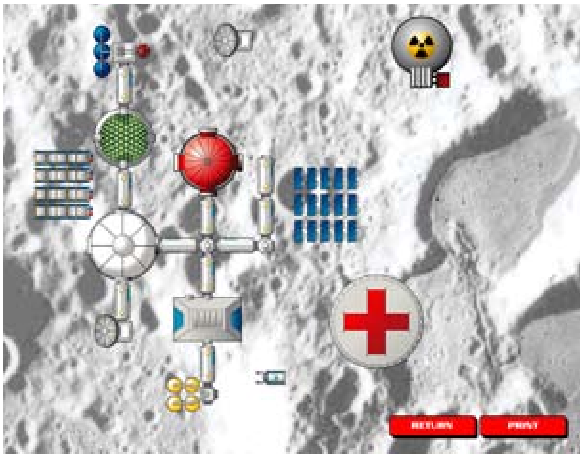
Answer Key/What is Happening?

N/A

Lunar Base 3-Dimensional Model

Overview

This activity will provide the participants with the opportunity to produce a 3-D model of their lunar base.



Purpose

Through the creation of their model, students will:

- Apply their knowledge of lunar base systems and instruments.
- Develop skills in model construction.
- Learn how to make decisions cooperatively.
- Develop teamwork and communication skills.

Preparation

Collect or prepare materials.

Materials

Per Team:

- Student Data Sheets (CD Location: Educator Resources/Guides/Student Guide)
- Role cards
- Suggested building materials include:
  - Building materials such as LEGO, ROBOTIX, K'NEX
  - Recyclables (a variety of boxes, bottles, lids, containers in a variety of shapes and sizes)
- Other materials that have proven beneficial include:
  - Aluminum foil
  - Pipe cleaners
  - Clear plastic wrap
  - Glue gun and glue sticks
  - Razor knives
  - Duct tape

Procedure

1. Distribute the role cards to each team member. Ensure that each one understands his/her role.
   a. Project Engineer: Provides leadership to discussions as the team moves through the building process.
   b. Facilities Engineer: Provides correct materials to meet lunar base criteria.
   c. Developmental Engineer: Leads production of lunar base model.
   d. Test Engineer: Makes records of team's decisions for each step of building.
2. Discuss safety rules for use of materials.
3. Discuss scale modeling and determine the scale to be used for the models (optional).
4. Encourage each team to implement the design that they prepared using the design templates. Ensure that team members understand that it is acceptable to make improvements to their design as they construct.
5. Under the Test Engineer's leadership, each team should develop a summary of the construction process and a list of information to be presented in the final presentation.

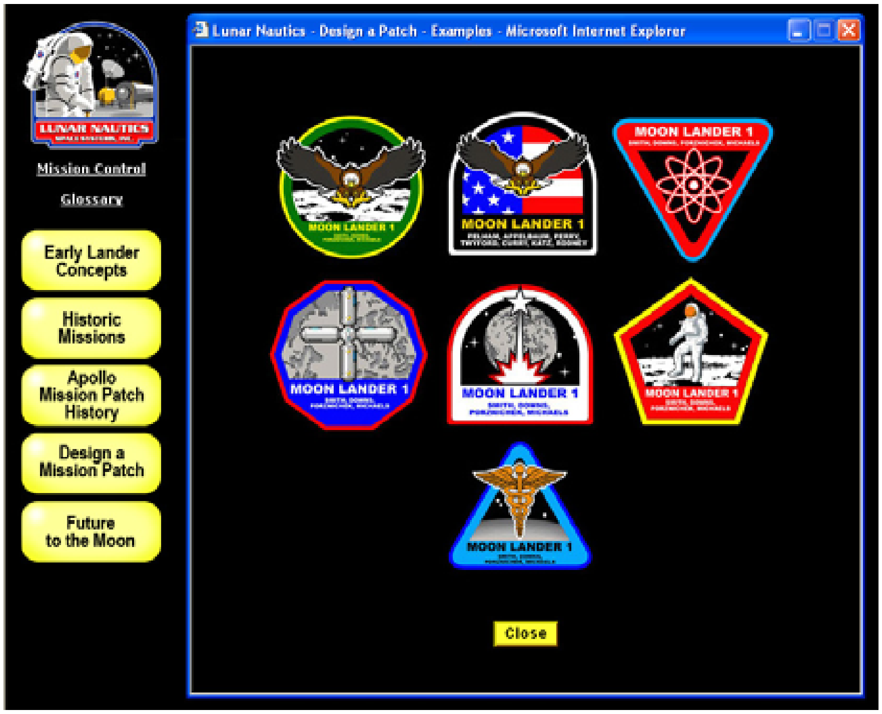
Questions

1. What changes, if any, did you make to your design during construction, and why were they necessary?
2. What characteristics of your lunar base have the potential to make it an award-winning project?
3. How effective were your team members in working together? How could you work better as a team?

Answer Key/What is Happening?

N/A

Mission Patch Design



Overview

During planning for each space mission, a logo is developed for that mission. Incorporated into the logo design are various elements depicting the different mission phases or goals. The crew usually designs this logo or patch. During this activity, team members will have the opportunity to design a logo/patch to represent their Lunar Nautics mission.

Purpose

Through the creation of their mission patch, members will:

- Increase their knowledge of current and future space missions.
- Learn how to make decisions cooperatively.
- Develop teamwork and communication skills.

Preparation

1. Collect some examples of logos. A logo is a symbol or trademark, usually representing a particular company or product. Examples in popular advertising include: Nike's swoosh, McDonald's golden arches and Wendy's young girl.
2. Make copies of the student Mission Patch Design sheet for each team.
3. Make a copy of role cards for each team.
4. Ensure the Mission Patch Design section on the Lunar Nautics CD is accessible.

Materials

Per team:

- Student Data Sheets (CD Location: Educator Resources/Guides/Student Guide)
- Logo examples gathered from magazines, products or newspapers
- Role cards
- Computer (CD Location: Journey to the Moon/Apollo Mission History, Patch History, Design a Mission Patch)
- Printer
- Markers
- Paper or poster board
- Scissors
- Glue
- Various art supplies such as construction paper, paint, aluminum foil, etc.

Procedure

1. Distribute the role cards to each team member. Ensure that each person understands his/her role in the activity.
   a. Project Engineer: Provides leadership to discussions as the team moves through the steps of design.
   b. Facilities Engineer: Provides correct templates to meet mision patch design criteria.
   c. Developmental Engineer: Leads production of the mission patch design.
   d. Test Engineer: Makes records of team's decisions for each step of design.
2. Ask the group what a logo is. Discuss logos and show some examples of logos used in popular advertising.
3. Ask the group if they have ever seen a NASA mission patch. Can they describe the patch?
4. Distribute the student Mission Patch Design sheet to each group.
5. Have the students pull up the Apollo Mission Patch history on the Lunar Nautics CD or print a copy of the history from the CD.
6. Discuss the Apollo patches. What do the patches illustrate? How are the patches alike? How are they different? Tell the group that, in human space flight missions, the names of the team members are worked into the patch design.
7. Team members should act in their roles as they work together to design a patch to represent their Lunar Nautics mission. Note: Students can first design their own patch and then design a group patch if time allows.
8. Patches should be presented during the final Lunar Nautics presentation, with the significance of the patch explained.

Questions

1. Explain the symbols on your patch.
2. How did your group make decisions about what should be included in your patch?
3. How effective were your team members in working together?
4. What could you do to improve on your decision making process? How could you work better as a team?

Answer Key/What is Happening?

N/A

Lunar Nautics Presentation

Overview

The culmination of the Lunar Nautics project is a presentation by each engineering design team. The audience for the presentation includes peer teams and instructors. Instructors act in the role of Congress and NASA. Together they determine if the proposal merits funding.

Purpose

Through presentation of their Lunar Nautics proposal, students will:

- Reinforce their skills of technological design.
- Develop communication skills.
- Reinforce teamwork skills.

Preparation

1. Provide materials to enable student presentations.
2. Make copies of the Lunar Nautics Presentation Funding Worksheet. Sheets should be provided for each team to critique their peer teams as well as one sheet per team for each instructor.
3. Review Lunar Base Proposal and Budget activity.
4. Prepare certificates/awards for teams whose projects are funded and for the design challenge team winner.

Materials

Per team:

- Student Data Sheets (CD Location: Educator Resources/Guides/Student Guide)
- Computer
- Projector
- Screen
- Copies of Lunar Nautics Presentation Funding Worksheet
- Calculators, certificates/awards (optional)

Procedure

1. Allow time for each team to do final preparations for their presentations.
2. Each team should present their PowerPoint presentation. All team members should participate. See Lunar Base Proposal and Budget activity for correlating activity.
3. If you have multiple teams, a break after three team presentations is recommended.
4. At the conclusion of each presentation, each team and instructor should complete a scoring worksheet on that presentation. Total the score at the bottom of the page.
5. At the conclusion of all presentations, scoring sheets are returned to the instructor.
6. The instructor should average scores for each team.
7. At the instructor's discretion, awards can be announced and presented to highest-scoring teams as space science projects that will be funded.
8. Instructors may also choose to present awards to the team(s) that scored the highest number of points during the design challenges.

Questions

1. What qualities make for an award-winning presentation?
2. Which of the proposed projects accomplished the most space science research?
3. How do you think NASA determines which lunar base to fund?

Answer Key/What is Happening?

N/A

Lunar Exploration

In this section, students discover the Moon's geography and geology. Research topics are as follows:

The Moon
A lithograph and a set of photographs.

Lunar Geology
Takes a look at geological features and makeup of the Moon.

Mining and Manufacturing on the Moon
Explores the Moon's resources and how they might be mined and produced to build and provide supplies for future lunar bases.

Investigate the Geography and Geology of the Moon
Investigate the geography and geology of the Moon and the science used to obtain information.

Strange New Moon
Challenges students to create a Moon and then discover the processes of observation and exploration.

Digital Imagery
Students gain an understanding of sending and receiving imagery between a spacecraft and Earth.

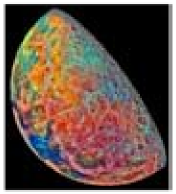
Impact Craters
Challenges students to create their own impact craters in different media, create different scenarios, and examine the results.

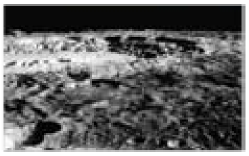
Lunar Core Sample
Challenges students to think of robot systems and instruments and their human counterparts.

Edible Rock Abrasion Tool
Uses a variety of candies and cookies to design a model of the RAT.

Edible Lunar Rover
Uses a variety of candies and cookies to design a model of the Lunar Rover.

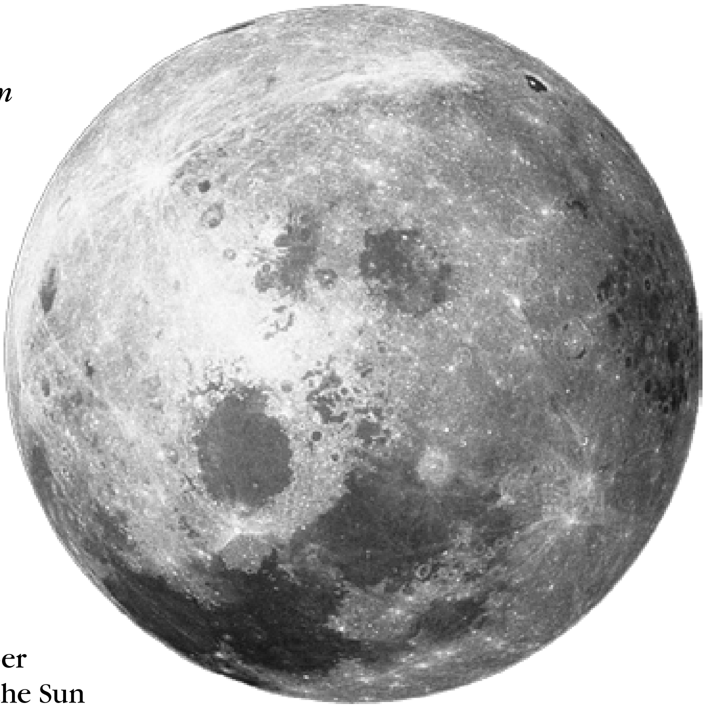
The Moon






0
300,000,000
900,000,000
1,500,000,000
2,100,000,000
2,700,000,000
3,300,000,000
3,900,000,000
4,500,000,000
5,100,000,000
5,700,000,000
kilometers

Lunar Geology



"The expedition round the Moon had enabled them to correct the many theories regarding the terrestrial satellite. They knew which systems should be rejected, what retained with regard to the formation of that orb, its origin, and its habitability. Its past, present and future had even given up its last secrets."
—Jules Verne, (Round the Moon, 1865)

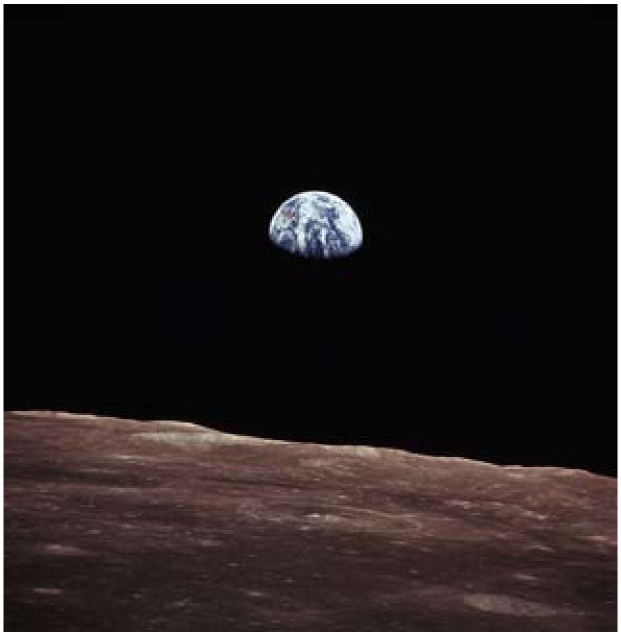
Moon Facts

The Moon is the only natural satellite of the Earth. It is 384,400 km from Earth and has a diameter of 3,476 km. The Moon was called Luna by the Romans, Selene and Artemis by the Greeks, and many other names in other mythologies. The Moon is the second brightest object in the sky after the Sun. As the Moon orbits around the Earth once per month, the angle between the Earth, the Moon and the Sun changes; and we see this as the cycle of the Moon's phases. The time between successive new Moons is 29.5 days (709 hours), slightly different from the Moon's orbital period (as measured against the stars), because the Earth moves a significant distance in its orbit around the Sun in that time.

The gravitational forces between the Earth and the Moon cause some interesting effects. The most obvious is the tides. The Moon's gravitational attraction is stronger on the side of the Earth nearest to the Moon and weaker on the Earth's opposite side.

The Earth is not perfectly rigid, particularly the oceans. For this reason, the Earth is stretched out along its side that faces the Moon and stretched inward along the side opposite the Moon. From our perspective on the Earth's surface, we see two small bulges, one in the direction of the Moon and one directly opposite. The effect is much stronger in the ocean water than in the solid crust so the water bulges are higher. Because the Earth rotates much faster than the Moon moves in its orbit, the bulges move around the Earth about once a day, giving two high tides per day.

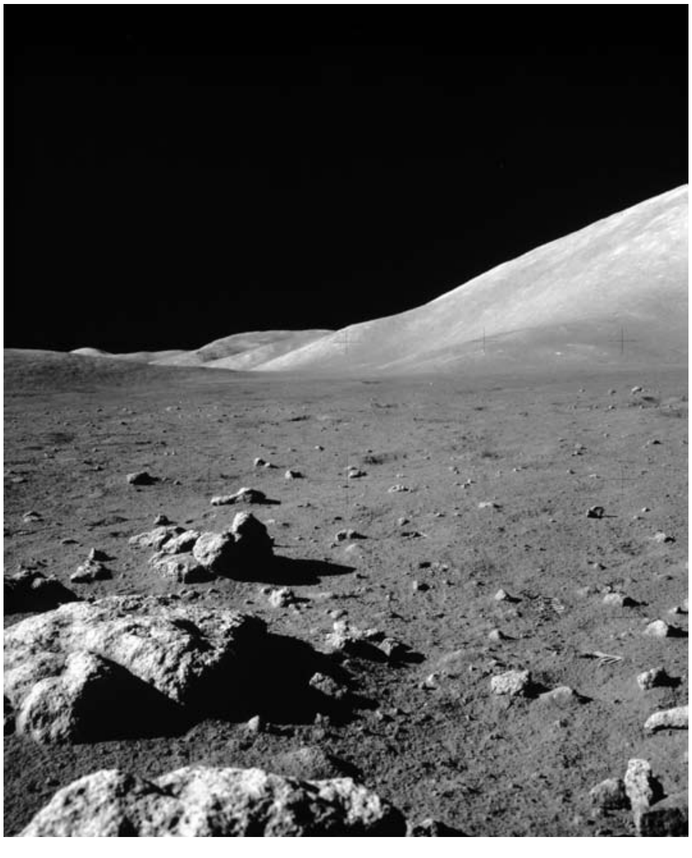
But, the Earth is not completely fluid either. The Earth's rotation carries the Earth's bulges slightly ahead of the point directly beneath the Moon. This means that the force between the Earth and the Moon is not exactly along the line between their centers, producing a torque on the Earth and an accelerating force on the Moon. This causes a net transfer of rotational energy from the Earth to the Moon, slowing down the Earth's rotation by about 1.5 ms per century and raising the Moon into a higher orbit by about 3.8 cm per year.



The asymmetric nature of this gravitational interaction is also responsible for the fact that the Moon is locked in phase with its orbit so that the same side is always facing toward the Earth. Just as the Earth's rotation is now being slowed by the Moon's influence, in the distant past, the Moon's rotation was slowed by the action of the Earth; but in that case, the effect was much stronger. When the Moon's rotation rate was slowed to match its orbital period (such that the bulge always faced the Earth), there was no longer an off-center torque on the Moon and a stable situation was achieved. The same thing has happened to most of the other satellites in the solar system. Eventually, the Earth's rotation will be slowed to match the Moon's period, as is the case with Pluto and its Moon Charon.

Actually, the Moon appears to wobble a bit (due to its slightly noncircular orbit) so that a few degrees of the far side can be seen from time to time, but the majority of the far side (left) was completely unknown until the Soviet spacecraft Luna 3 photographed it in 1959. There is no literal "dark side" of the Moon; all parts of the Moon get Sunlight half the time, except for a few deep craters near the poles.

The Moon has no atmosphere. However, evidence from the Clementine spacecraft suggested that there might be water ice in some deep craters that are permanently shaded near the Moon's south pole. The Lunar Prospector spacecraft has also confirmed this. There is apparently ice at the north pole as well.



The Moon's crust averages 68 km thick and varies from essentially 0 km under Mare Crisium to 107 km north of the crater Korolev on the lunar far side. A mantle and probably a small core (roughly 340 km radius and 2 percent of the Moon's mass) are below the crust. However, unlike the Earth's mantle, the Moon's mantle is only partially molten. Curiously, the Moon's center of mass is offset from its geometric center by about 2 km in the direction toward the Earth. Also, the crust is thinner on the lunar near side.

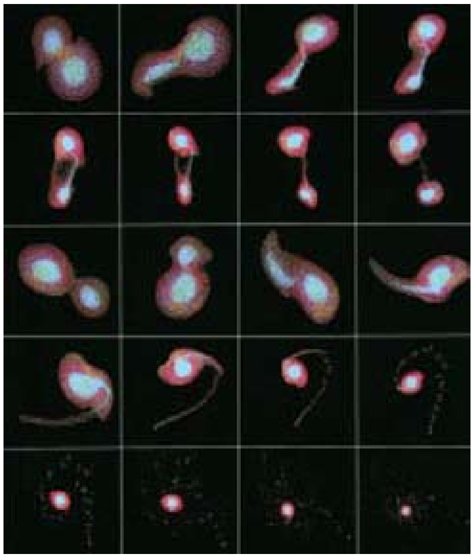
There are two primary types of terrain on the Moon: the heavily cratered and very old highlands and the relatively smooth and younger maria. The maria (which comprise about 16 percent of the Moon's surface) are huge impact craters that were later flooded by molten lava. Most of the surface is covered with regolith, a mixture of fine dust and rocky debris produced by meteor impacts.

For some unknown reason, the maria are concentrated on the near side. Most of the craters on the near side are named for famous figures in the history of science such as Tycho, Copernicus and Ptolemaeus. Features on the far side of the Moon have more modern references such as Apollo, Gagarin and Korolev (with a distinctly Russian bias since the first images were obtained by Luna 3).

In addition to the familiar features on the near side, the Moon also has huge craters like the South Pole-Aitken basin on the far side, which is 2,250 km in diameter and 12-km deep (making it the largest impact basin in the solar system) and Orientale on the western limb (as seen from Earth—in the center of the image at right), which is a splendid example of a multi-ring crater.

A total of 382 kg of rock samples were returned to the Earth by the Apollo and Luna programs. These provide most of our detailed knowledge of the Moon. They are particularly valuable in that they can be dated. Even today, decades after the last Moon landing, scientists still study these precious samples. Most rocks on the surface of the Moon seem to be between 3 billion and 4.6 billion years old. This is a fortuitous match with the oldest terrestrial rocks that are rarely more than 3 billion years old. Thus, the Moon provides evidence about the early history of the solar system not available on the Earth. Explore the Moon's terrain at the interactive Lunar Atlas site.

Origin of the Moon



Prior to the study of the Apollo samples, there was no consensus about the origin of the Moon. There were three principal theories: coaccretion, which asserted that the Moon and the Earth formed at the same time from the Solar Nebula; fission, which asserted that the Moon split off of the Earth; and capture, which held that the Moon formed elsewhere and was subsequently captured by the Earth. None of these theories worked very well. But the new and detailed information from the Moon rocks led to the impact theory, that the Earth collided with a very large object (as big as Mars or more) and the Moon formed from the ejected material.

At the time Earth formed 4.5 billion years ago, other smaller planetary bodies were also growing. One of these hit Earth late in Earth's growth process, blowing out rocky debris. A fraction of that debris went into orbit around the Earth and aggregated into the Moon.

Two scientists, Dr. William K. Hartmann and Dr. Donald R. Davis, were the first to suggest the leading modern hypothesis of the Moon's origin (impact theory) in a paper published in 1975 in the journal *Icarus*.

Computer Simulation of the Formation of the Moon

The Moon has no global magnetic field; however, some of its surface rocks exhibit remnant magnetism indicating that there may have been a global magnetic field early in the Moon's history. With no atmosphere and no magnetic field, the Moon's surface is exposed directly to the solar wind. Over its 4-billion-year lifetime, many hydrogen ions from the solar wind have become embedded in the Moon's regolith. Thus samples of regolith returned by the Apollo missions proved valuable in studies of the solar wind. This lunar hydrogen may also be of use someday as rocket fuel.

Here are the traditional names given to each month's full Moon from the "Old Farmer's Almanac":

- January: Wolf Moon
- February: Snow Moon
- March: Worm Moon
- April: Pink Moon
- May: Flower Moon
- June: Strawberry Moon
- July: Buck Moon
- August: Sturgeon Moon
- September: Harvest Moon
- October: Hunter's Moon
- November: Beaver Moon
- December: Cold Moon

Exploring the Moon From the University of North Dakota

Interested in why the Moon looks huge sometimes? Find out about the lunar size illusion, or why the Moon looks bigger near the horizon. This information can be found at <http://www.space.edu/Moon/>, <http://www.space.edu/Moon/intro/ExplMoon-Intro.html> or <http://apollo-society.org/luna.html>.

Source: <http://www.nineplanets.org/luna.html>.

Mining and Manufacturing on the Moon

Lunar Mining Facility

"Engineering is the professional art of applying science to the optimum conversion of natural resources to the benefit of man."

—Ralph J. Smith (1962)

Resource utilization will play an important role in the establishment and support of a permanently manned lunar base. The identification of new and innovative technologies will ensure the success, sustainability and growth of a future lunar base. These new technologies will certainly utilize lunar resources. Lunar resources can be used to supply replenishables such as oxygen, fuel, water and construction materials. These materials would otherwise have to be brought from Earth at considerable expense.

Lunar resources include oxygen from the lunar soil, water from the poles and a supply of volatile gases. One of the most significant steps towards self-sufficiency and independence from the Earth will be the use of lunar materials for construction.

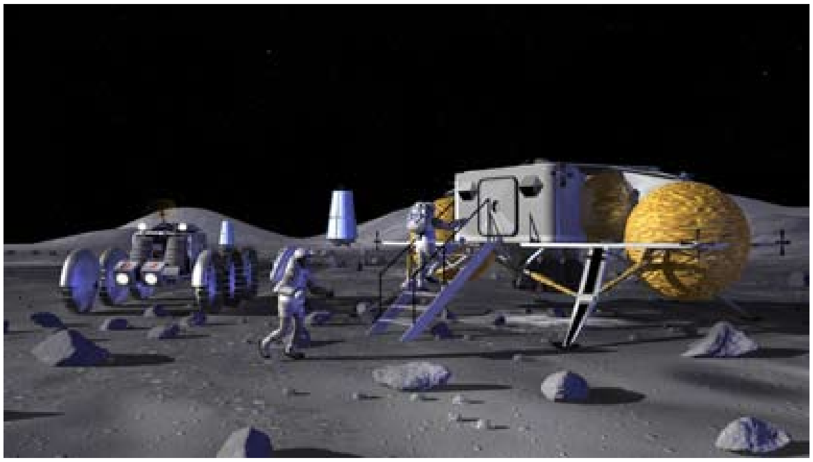
At least seven major potential lunar construction materials have been identified. These include the following:

- Concrete.
- Sulfur concrete.
- Cast basalt.
- Sintered basalt.
- Fiberglass.
- Cast glass.
- Metals.

All of these materials may be used to construct a future lunar base. The basalt materials can be formed out of lunar regolith by a simple process of heating and cooling, and they are the most likely to be used to build the first bases.

Lunar Structures

With the gravity level of the Moon being one-sixth that of Earth, lunar structures can carry a load that is six times that of similar structures on Earth. This allows for structures that are thicker and can provide better micrometeorite, radiation and thermal shielding for the crew. Lunar basalt can handle the extreme thermal ranges of 100 C above zero to over 150 C below zero. The lack of weather on the Moon will give lunar structures a very long life span. However, lunar dust is extremely abrasive. Basalt is highly resistant to abrasion and thus is an ideal structural material for the Moon.



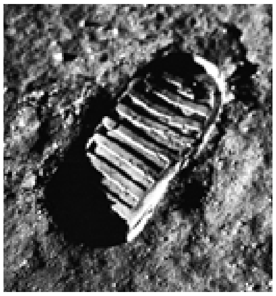
Designs for a subsurface lunar base are very appealing to engineers because the surrounding regolith helps to relieve loads on the structure by equalizing the internal forces of a pressurized structure. A subsurface base has a reduced amount of area that needs to be protected from solar and cosmic radiation and offers protection from drastic thermal changes.

Factories and habitats consist of walls, beams, radiation shielding and internal components. These can all be made from lunar fiberglass, lunar glass ceramics, lunar iron or other metals. Beams, walls and shielding can be made using solar ovens and casting techniques. Windows can be made from lunar glass and mirrors can be made from lunar aluminum.

Resources

It is estimated that transporting material from the Earth to the Moon would cost $25,000 per pound. Therefore, it is imperative that we use resources already on the Moon to offset the cost. Of all the resources available, the lunar regolith is the most accessible and most easily converted into construction materials. Lunar regolith contains oxygen, silicon, magnesium, iron, calcium, aluminum and titanium.

About 40 percent of the lunar soil is oxygen, bound up in molecular silicates and metal oxides. The reason that oxygen is so abundant on the Moon is that it bonds easily to so many things. Oxygen-bonded materials are lightweight and thus float up to the surface to form the crust of a planetary body as it evolves. (Metals do not like to bond with oxygen and usually sink to the core of a planet. They are rare in the crust and precious to those living on the surface.) Oxygen can literally be cooked out of the regolith and can be used for breathable air. Another use is for making oxygen-hydrogen rocket fuel, which is about 86 percent oxygen. Even without hydrogen from supplies of lunar ice, a majority of the material needed for rocket fuel can be manufactured on the Moon.



The Moon's surface is very powdery due to millions of years of micrometeorite impacts and no active geology. In fact, Apollo designers worried that the lander and astronauts might sink into the surface. You can see in the boot print how every contour was finely imprinted in the dust. Mining of the powder would not require heavy Earth-moving machinery because of the very powdery surface of the Moon and the one-sixth gravity. It is ideal for cheap mining and mineral processing.

On Earth, aluminum and iron mines do not dig out pure metals from the ground. They dig out silicates that have metallic elements bonded to silicon and oxygen. Heat, chemicals or electricity are used to process the material to separate the metal out. These facilities are called smelters. The lunar highland mineral anorthite is similar to the mineral bauxite that is used on Earth to smelt out aluminum. Anorthite consists of aluminum, calcium, silicon and oxygen. Smelters can produce pure aluminum, calcium metal, oxygen and silica glass from anorthite. The average anorthite concentration in the lunar highlands where the Apollo astronauts landed was between 75 percent and 98 percent. Raw anorthite is also good for making fiberglass and other glass and ceramic products.

Aluminum can be used as an electrical conductor. It is lightweight and makes good structural elements and mirrors, Atomized aluminum powder makes a good fuel when burned with oxygen. In fact, it is the fuel source of the Space Shuttle solid rocket boosters.

Calcium metal, a by-product of aluminum production, is also a good electrical conductor. It will conduct more electricity than aluminum or copper at higher temperatures and is easy to work with. It is easily shaped, molded, machined and made into wire, pressed and hammered.

Ilmenite, a mineral found in abundance by the Apollo astronauts, is high in titanium and can be used to trap solar hydrogen. Processing of ilmenite could produce hydrogen (an otherwise rare element on the Moon, unless lunar water ice is located). Iron can also be extracted from ilmenite. A very small amount (one-half of one percent) of free iron is found in the lunar regolith and could be extracted by magnets after grinding. Iron powder can be used to make parts using a standard Earth process called powder metallurgy.

Oxygen Production

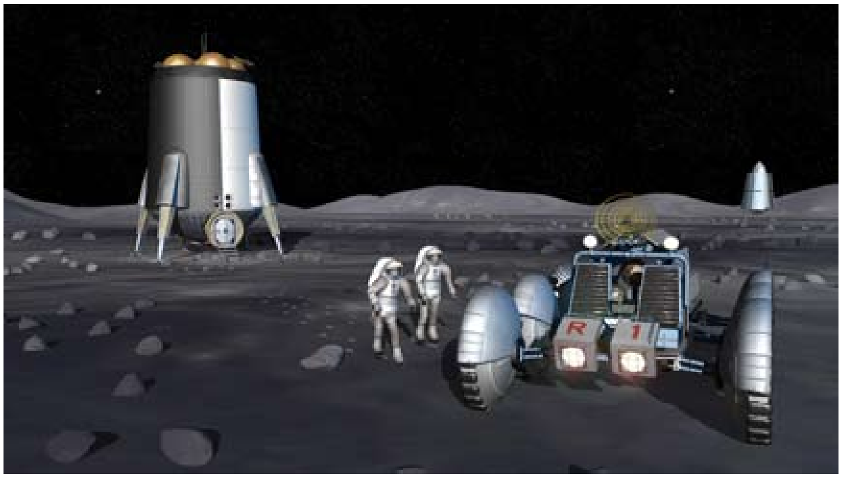
NASA scientist Carlton Allen writes in his paper *Oxygen Extraction from Lunar Soils and Pyroclastic Glass*: "All lunar rock and soil do, however, contain approximately 45 wt% oxygen, combined with metals or nonmetals to form oxides. This oxygen can be extracted if thermal, electrical or chemical energy is invested to break the chemical bonds. Over 20 different methods have been proposed for oxygen extraction on the Moon. Oxygen that is chemically bound to iron in lunar minerals and glasses can be extracted by heating the material to temperatures above 900 C and exposing it to hydrogen gas. The basic equation is: $FeO + H_2 \rightarrow Fe + H_2O$. This process results in release of the oxygen as water vapor. The vapor must be separated from the excess hydrogen and other gases and electrolyzed. The resulting oxygen is then condensed to liquid and stored. Experiments using samples of lunar ilmenite, basalt, soil and volcanic glass have demonstrated the required conditions and efficiency of this process."

Most early work on lunar resources has focused on the mineral ilmenite ($FeTiO_3$) as the feedstock for oxygen production. This mineral is easily reduced, and oxygen yields of 8 to 10 wt% (mass of oxygen per mass of ilmenite) may be achievable. Ilmenite occurs in abundances as high as 25 wt% in some lunar basalts.

Previous oxygen production experiments used lunar basalt 70035, which was crushed but not otherwise beneficiated. The sample produced 2.93 wt% oxygen in a 1,050 C hydrogen reduction experiment. Of the minerals in this rock, the most oxygen was extracted from ilmenite, with lesser amounts from olivine and pyroxene.

Oxygen can be produced from a wide range of unprocessed lunar soils, including those that contain little or no ilmenite. Oxygen yield from lunar soils is strongly correlated with initial iron content. The dominant iron-bearing phases in lunar soil are ilmenite, olivine, pyroxene, and glass. Each of these phases is a source of oxygen. Ilmenite and iron-rich glass react most rapidly and completely. Olivine is less reactive. Pyroxene is the least reactive iron-bearing phase in lunar soil.

The optimum feedstock for a lunar oxygen production process may be volcanic glass. At least 25 distinct glass compositions have been identified in the Apollo sample collection. The iron-rich species promise particularly high oxygen yields.



The production of oxygen from lunar materials is now a reality. Oxygen release by means of hydrogen reduction has been demonstrated in the laboratory with samples of lunar basalt, soil, and volcanic glass. Yields from soils are predictable, based solely on each sample's iron abundance. The reactions are rapid, with most of the release occurring in a few tens of minutes. All of the major iron-bearing phases in lunar soil release oxygen, though with differing degrees of efficiency. These data can support the design of an oxygen production plant at a future lunar base."

—Lunar scientist Carlton Allen at work in the Lunar Rock Laboratory at Johnson Space Center

Mining

Before we can hope to process the soil of the Moon into other materials, we will first have to dig it up and feed it into the processing plants. There are many concepts of how to do this, but all need to resolve the same issues that have faced mining companies on Earth for centuries. While there are problems on the Moon that are not a factor here on Earth, the mastery of this skill will require NASA to include the lessons of the mining industry in its planning. The U.S. Bureau of Mines and several universities have already begun to consider the requirements and options for lunar mining equipment.

Underground mines on the Earth often require remotely controlled equipment due to safety requirements and harsh conditions. On the Moon, excavation and hauling operations will need to be automated and teleoperated for the same reasons. Prior to mining operations, the topography will have to be mapped in great detail.

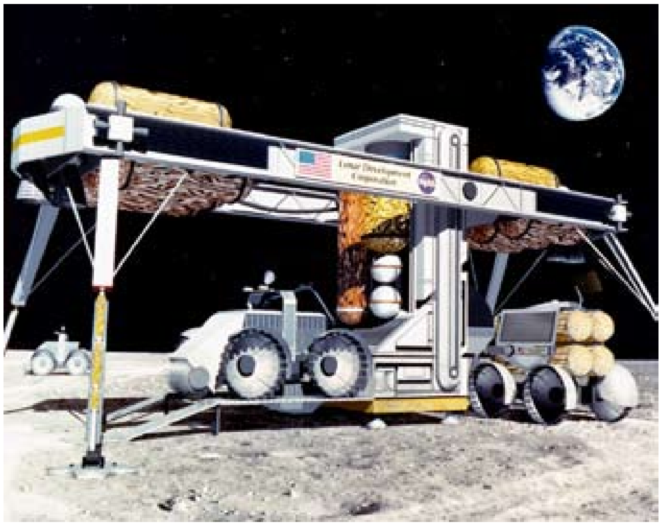
Front-end loaders will scoop up the regolith, drop it into haulers and bring it back to the processing site. Using inertial guidance, radar, laser ranging, electronic guideposts and satellite tracking, automated haulers could be operated from Earth or from lunar operators.

These haulers would be navigated back and forth from the mine in a programmed sequence. Many current toys and remotely controlled operations use this same technology of preprogrammed paths.

A lunar communications receiver, amplifier, transponder network and computer systems would be needed. The loaders and haulers themselves could be launched from Earth and assembled on the Moon.

The haulers would not need to be as structurally massive as Earth equipment. The loaders would be nearly the same since they need a counterweight when scooping up lunar regolith. These counterweights could be produced on the Moon. A simple bucket and reel system could replace front-end loaders. This system would pull the dirt up a ramp and into a hauler.

The Apollo astronauts had some difficulty extracting subsurface samples. While the top was powdery and soft, their attempts to drill into the surface resulted in drills seizing up; the drills had to be abandoned in place. It is thought that lunar soil is very dense under the soft surface, perhaps due to small repeated vibrations by distant meteor impacts over time, which densely packed soil particles.



Another concern is rubbing friction in a vacuum. The U.S. Bureau of Mines found that exposing lunar simulant to a vacuum long enough for nearly complete outgassing caused up to a 60-times increase in friction. Tools would need to be made from (or coated with) special materials to minimize friction. In preparation for their use on the Moon, experiments will be done using lunar simulants and tools in a vacuum. For a list of all the geology tools used for the Apollo missions, go to <http://www.hq.nasa.gov/alsj/tools/Welcome.html>. To review the sample collection processes used by the Apollo astronauts, visit <http://www.lpi.usra.edu/expMoon/Apollo11/A11_Samples_tools.html>.

Significant changes in lunar temperatures occur between shadowed and Sunlit areas on the lunar surface. Equipment will need to be designed to withstand very high temperatures (140 C) or Sunscreens can be used (possibly with foil mirrors to eliminate shadows). At night, mining equipment will need to be sheltered and heated perhaps, in tunneled garages.

Materials Processing

The top few meters of the lunar surface consist of a mix of materials, while lower depths may offer more uniform mineralogy from older magma oceans. The mix on the surface is due to the splashes of asteroid impacts that mixed materials from various distances. The surface is glassier due to heating of asteroid ejecta and subsequent quick cooling.

Volcanism on the Moon also produced glassy beads. Some proposed methods for materials processing on the Moon call for processing just one mineral, such as ilmenite. This would require separating the one mineral from the regolith mix or mining it deep under the surface, where it may be found in more abundance.

NASA experiments using simulated lunar soil have produced glass ceramics with “superior mechanical properties with tensile strengths in excess of 50,000 psi, which can be used as structural components of buildings in space or on the Moon.”

Natural glass is more common on the Moon due to the lack of water, which preserved it in its natural state from volcanic eruptions billions of years ago.

Clear pure silica glass (SiO_2) is readily manufactured from lunar materials. It can be made optically superior to that produced on the Earth because it can be made completely anhydrous (lacking in hydrogen). Anhydrous glass has been considered for use in structural components, because it has significantly better mechanical properties. Glass structural beams reinforced with asteroid nickel-iron steel could be used as structural beams to withstand a wide range of tension and compression.

Bulk fiberglass and hand ceramics can be made on the Moon using currently developed processes. The sintering technique for producing ceramics (used for casting molds) uses powdered material melted at very high temperatures and then slowly cooled to a solid. This routine process on Earth works even better in a vacuum where there is no oxygen, water or other molecules to create impurities. Solar ovens or microwaves could be used for sintering of lunar materials. The resulting material is low in density, can be cut and shaped fairly easily, holds small loads, and provides good thermal protection.

Glass ceramics that are highly resistant to abrasion and have a fairly good shock resistance can be made from basaltic rock. Techniques for cast basalt production have been around for over 50 years. They are used to produce tiles, pipes and other industrial products. Basalt is melted at about 1,350 C and poured into sand or metallic molds. The basalt solidifies at about 900 C.

For more about materials processing on the Moon, visit <http://science.nasa.gov/newhome/headlines/msad28apr98_1a.htm> from the NASA Marshall Space Flight Center.

Researchers at the University of Wisconsin's Center for Space Automation and Robotics believe the future of energy production lies with helium-3. One ton could supply the electrical needs of a city of 10 million people when combined in a fusion reactor with a form of hydrogen.

Lunar samples collected by Apollo astronauts show the resource is so plentiful that the Earth's energy needs could be accommodated for at least 1,000 years. However, a great deal of work needs to be done before helium-3-powered fusion plants become a reality. Although the university began its fusion program in 1963 and has since granted some 186 Ph.D.s in the field, no one has yet built a fusion reactor that releases more energy than it consumes. According to theory, fusion reactors operating with helium-3 would be superior to fission reactors because they would not generate high-level radioactive waste.

In one study, scientists determined that lunar helium-3, which originated from the Sun and was deposited on the Moon by the solar wind, could be mined and transported to Earth. Some early estimates place the value of helium-3 equivalent to buying oil at $7 a barrel.

Researchers also have studied possible mining sites. Based on U.S. experience during the Apollo 11 mission, they determined that the Sea of Tranquility was the prime target for initial investigations because it appeared to contain the potential for many tons of helium-3 below the surface. Backup targets include the vicinity of Mare Serenitatis sampled during Apollo 17.

Researchers designed solar-powered robotic equipment that would scoop up the top layer of lunar soil and place it into a robotic unit. The soil would be heated, thus separating the helium-3 from other lunar material. The spent material then would be dropped off the back of the moving robotic miner. Because the Moon has one-sixth the Earth's gravity, relatively little energy would be required to lift the material. Through this process, other products would also be produced, including nitrogen, methane, helium, water, carbon-oxygen compounds and hydrogen, all of which are vital to human existence in space.

Questions to think about

1. Of all the materials that could be manufactured on the Moon, which one has the most potential benefits for use solely on the Moon?
2. Which one has the most benefits for transferability to Earth? Why?
3. Which type of materials-processing facility would be the most interesting to design?
4. Which would be the most expensive?
5. Which would be the most cost effective?

Moon ABCs Fact Sheet			
Property	Earth	Moon	Brain Busters
Equatorial diameter	12,756 km	3,476 km	How long would it take to drive around the Moon's equator at 80 km per hour?
Surface area	510 million square km	37.8 million square km	The Moon's surface is similar to that of one of Earth's continents. Which one?
Mass	5.98×10^{24} kg	7.35×10^{22} kg	What percent of Earth's mass is the Moon's mass?
Volume	---	---	Calculate the volumes of the Earth and the Moon.
Density	5.52 g per cubic cm	3.34 g per cubic cm	Check this by calculating the density from the mass and volume.
Surface gravity	9.8 m/s^2	1.63 m/s^2	What fraction of the Earth's gravity is the Moon's gravity?
Crust	Silicate rocks. Continents dominated by granites. Ocean crust dominated by basalt.	Silicate rocks. Highlands dominated by feldspar-rich rocks and maria by basalt.	What portion of each body is crust?
Mantle	Silicate rocks dominated by minerals containing iron and magnesium.	Similar to Earth	Collect some silicate rocks and determine the density. Is the density greater or lesser than the Earth's/Moon's density? Why?

Source: Exploring the Moon—A Teacher's Guide With Activities, NASA EG-1997-10-113-HQ

Investigate the Geography and Geology of the Moon

Overview

For each mission to the Moon, a detailed study must be made to decide exactly where the mission will visit, and what will be studied. During this activity, team members will have the opportunity to learn more about the Moon and potential areas for a mission.

Lunar geology is the study of the Moons crust, rocks, strata, etc. Lunar geology tends to cover two broad areas of study: maria (and/or basins) and highlands. The two major lunar geologic disciplines are geochemistry and geophysics.

Geochemistry is the study of the sources, migrations and current resting places of individual chemical elements. Geophysics is the study of densities, temperatures and depths of boundaries of a planet's crust, mantle and core.

Purpose

Through a general study of lunar geography and geology, students will:

- Increase their knowledge of the Moon and its history.
- Increase their knowledge of lunar landmarks.
- Increase their knowledge of lunar composition.
- Increase their knowledge of lunar mining and manufacturing.
- Visualize and connect concepts for student landing sites using semantic mapping.

Preparation

1. Schedule an hour in a computer lab or for computer access; otherwise provide information about the Moon through books or articles. See Resources section for information.
2. Make copies of the Moon lithograph and Student Sheets.

Materials

Per student:

- Student Data Sheets (CD Location: Educator Resources/Guides/Student Guide)
- Computer (CD Location: The Moon/Lunar History, Lunar Geography, Lunar Resources, Seltect Landing Site)

Procedure

1. Distribute the "Investigate the Moon" Student Sheets to each group. Teams should complete the sheet and be prepared to share with the group.
2. Have each student view the Moon lithograph or provide hard copy Moon information to each team.
3. Discuss how the Moon was possibly formed.
4. Discuss the Moon's influence on Earth's tides.
5. Discuss the Moon's relationship with Earth as its only natural satellite.
6. Have each student complete the sections Lunar Geography and Lunar Resources on the Lunar Nautics CD.

Questions

1. What are the dark and light features of the Moon?
2. When was the Moon formed?
3. What is the powdery lunar soil called?
4. How was this powdery soil formed?
5. What country's spacecraft first visited the Moon?
6. What country's spacecraft first landed on the Moon?
7. Who was the first man to walk on the Moon? What was the date?
8. How much lunar rock and soil did Apollo astronauts return to Earth?
9. What is President George W. Bush's 2004 plan for lunar exploration?
10. Is there water on the Moon? If so, how do we know it could be there?
11. What do False Color Images tell us?

Answer Key/What is Happening?

1. Light areas are lunar highlands and dark areas are maria.
2. 4.5 billion years ago.
3. Regolith.
4. Meteorites and comets have struck the surface of the Moon, grinding up surface areas.
5. U.S.S.R. Spacecraft Luna 2 in 1959.
6. U.S. Spacecraft Surveyor 1 in 1966.
7. Neil Armstrong on July 20, 1969.
8. 381.925 kg.
9. Robotic exploration and then a human return to the Moon by the year 2018
10. Perhaps in dark, cold areas of the Moon. Clementine and Lunar Prospector spacecraft indicated water was possible.
11. It helps us determine different types of soil on the Moon.

Strange New Moon

Overview

Strange New Moon brings insight into the processes involved in learning about lunar exploration. This activity demonstrates how lunar features are discovered by the use of remote sensing techniques. It also demonstrates the progression of discovery by unmanned and manned missions to the Moon.

Purpose

Through participation in the demonstration, students will:

- Be engaged in making multisensory observations, gathering data and simulating spacecraft missions.

Preparation

1. Gather all materials.
2. Copy student data sheets.

Materials

- Student Data Sheets (CD Location: Educator Resources/ Guides/Student Guide)

Moons can be made from a combination of materials such as the following:

- Plastic balls, Styrofoam balls, or rounded fruit (e.g., cantaloupe, pumpkin, oranges, etc.).
- Modeling clay or Playdoh.
- Vinegar, perfume or other scents.
- Small stickers, sequins, candy, marbles or anything small and interesting.
- Toothpicks.
- Glue (if needed).
- Towels (to drape over Moons).
- Pushpins.
- Viewer material (e.g., sheet of paper, paper towel roll or toilet paper roll).
- 12.7 cm by 12.7 cm cellophane squares (one for each viewer) in blue plus other selected colors to provide other filters for additional information.
- Rubber bands (one for each viewer).
- Masking tape to mark the observation distances.

Procedure

1. Creating a Moon:

a. Form mission teams of four to five students.

b. Choose an object such as a plastic ball or fruit (e.g., cantaloupe, etc) that allows for multisensory observations.

c. Have each team decorate the object with stickers, scents, etc. to make the object interesting to observe. Some of these materials should be placed discreetly, so they are not obvious upon brief or distant inspection. Some suggestions for features are:

1. Carve channels or craters.
2. Attach modeling clay or Playdoh to create mountains.
3. Affix small stickers or embed other objects into the Moon.
4. Apply scent sparingly to a small area.
5. Have the team describe their Moons on the student data sheets.
6. Place the completed objects (Moons) on a desk or table in the back of the room.
7. Cover the objects with towels when completed.
8. Assign each team to observe an object that another team created.
9. Brief students on their task — to explore a strange new Moon.

   d. Students can construct viewers out of loose-leaf paper by rolling the shorter side into a tube. They can also use a toilet paper roll or paper towel roll. These viewers should be used whenever observing the Moon. Encourage use of all senses except taste, unless specifically called for.

2. **Prelaunch reconnaissance:**
   a. This step simulates Earth-bound observations. Arrange students against the sides of the room by teams. These areas will be referred to as Mission Control.
   b. To simulate Earth's atmosphere, a blue cellophane sheet could be placed on the end of the viewers, taped or held in place by a rubber band. This helps to simulate the variation that occurs when viewing objects through the Earth's atmosphere.
   c. Remove the towel. Teams observe the Moon(s) using their viewers for 1 minute.
   d. Replace the towel. Teams can discuss and record their observations of the Moon. At this point, most of the observations will be visual and will include color, shape, texture and position.
   e. Teams should write questions to be explored in the future missions to the Moon.
3. **Mission 1: The Flyby (e.g., Luna, Pioneer, Ranger, Zond (1959 to 1966) and Hiten (1990)):**
   a. Each team will have a turn at walking quickly past one side of the Moon while the other side remains draped under a towel. A distance of 1.524 m from the Moon needs to be maintained.
   b. Teams then reconvene at the sides of the room (Mission Control) with their backs to the Moon while the other teams conduct their flyby.
   c. Replace towel over the Moon once all the flybys have taken place.
   d. Teams record their observations and discuss what they will be looking for on their orbit mission.
4. **Mission 2: The Orbiter (e.g., Luna Spacecraft, Lunar Orbiter Spacecraft, 1966 to 1974; Apollo 8, 1968; Hiten, 1990; Clementine, 1994; Lunar Prospector, 1998; SMART 1, 2003):**
   a. Each team takes 2 minutes to orbit (circle) the Moon at a distance of 0.61 m. They observe distinguishing features and record their data back at Mission Control.
   b. Teams develop a plan for their landing expedition onto the Moon's surface. Plans should include the landing spot and features to be examined.
5. **Mission 3: The Lander (e.g., Surveyor Spacecraft, 1966 to 1968; Apollo 11, 12, 14, 15, 16 and 17 1969 to 1972)**:
   a. Each team approaches their landing site and marks it with a pushpin or masking tape if Moon will pop using a pin.
   b. Team members take turns observing the landing site with the viewers. Field of view is kept constant by team members aligning their viewers with the pushpin located inside and at the top of their viewers.
   c. Within the field of view, students enact the mission plan.
   d. After 5 minutes, the team returns to Mission Control to discuss and record their findings.
6. **Presentation**:
   a. Each student should complete a student data sheet.
   b. Each team shares their data with the class in a team presentation.

Questions

1. As a class, compile a list of all information gathered by the teams to answer the question, "What is the Moon (or each Moon, if multiple Moons are used) like?"
2. Have the class vote on a name of the newly discovered Moon or the geologic features discovered using the rules for naming a Moon (lunar nomenclature) that is located at the USGS Web site: <http://arizona.usgs.gov/Flagstaff>.
3. Teams critique their depth of observations and ability to work together.

Answer Key/What is Happening?

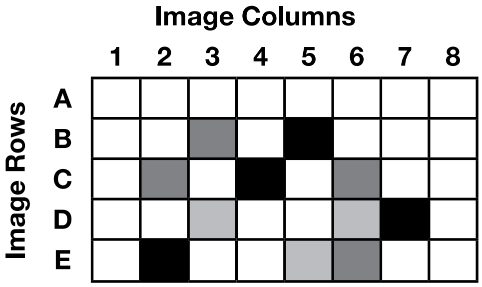
N/A

Adapted from ASU Mars K-12 Education Program 6/99 and NASA Education Brief "EB-112: How to Explore a Planet" 5/93

Digital Imagery

Overview

Digital images are made up of hundreds of small dots called pixels. The more pixels there are per inch (ppi) the higher the resolution and the better the image quality. The Web requires a resolution of at least 72 dots per inch (dpi), but printed materials require more; for example, magazine images require at least 300 dpi. The dimensions of the picture may also affect the quality of the image. Digital images are often used by astronauts or satellites to send information back to scientists and the public back on Earth.



Purpose

To investigate how digital images are created, sent and received.

Preparation

This activity requires students to work with a partner. Divide students in pairs prior to starting the activity.

Materials:

Per team:

- Student Data Sheets (CD Location: Educator Resources/Guides/Student Guide)
- Graph paper
- Color markers or pencils

Procedure

1. Discuss how digital images are recorded and transferred as pixels.
2. Divide students into pairs and distribute the Student Sheets.
3. Choose one student to be the sender. The other will be the receiver.
4. Go over the procedure as a class. Answer any questions the students may have.
5. Allow time for students to complete the activity.
6. Have students share their sender and receiver images with the class and compare them. Discuss answers from Student Sheets.
7. Ask students what benefits sending images in this way could offer for the future.
8. Have students create colored drawings; repeat the activity using the colored drawings. Remind students that they would have to assign every color used with a number code.
9. Display color-coded messages.
10. Have students make a picture and then write the code out on paper. This code could then be shared with the class, and students could use it to make images.

Answer Key/What is Happening?

N/A

Imagery from Space

An image is a picture created by a camera on photographic film (called a photograph) or by a remote sensing detector displayed on a screen or on paper. A camera takes light energy and records it chemically on film. The film is then processed and the image transferred to paper where we can look at it. This is called a photographic image. Most films have chemicals that are sensitive to visible light energy. This means it will record the same images a human eye can see. Camera film can also be chemically sensitive to the invisible IR energy, recording images on the film that the human eye cannot see.

Scientists have created very complex detectors that can sense many different wavelengths in the electromagnetic spectrum. These sensitive instruments record the reflected energy as numbers or digits. Digital images are recorded and transferred as pixels; the more pixels that are used, the better or clearer the image. This is often referred to as resolution.

This digital information is often recorded on magnetic tape, like in a tape recorder or videocassette, or radioed back to Earth. Computers then put these numbers together and make pictures. To do this, they use binary numbers, which are either 0s or 1s (think of them as a switch that is either off or on, with nothing in between). A more complex use of the binary system allows computers to determine shades between black and white and color.

In a color analog television, each line is a continuous signal that is shot onto the screen by a system of three electron guns. The electron guns shoot electrons at red, green and blue phosphors that are arranged in dots or stripes. When electrons hit the phosphors that coat the screen, light will be emitted. There are magnets on each side of the tube that move the electrons across the screen. There are also magnets on the top and bottom of the screen that can move the electrons up or down rows.

High-Definition Television (HDTV) is more lines of resolution both horizontally and vertically plus digital audio. The basic concept behind HDTV is actually not to increase the definition per unit area, but rather to increase the percentage of the visual field contained by the image. It takes more lines of resolution to achieve this wider field of vision, and this wider field of vision engages the viewer significantly more than does the old standard.

Portable ultrasound machines that can send images to doctors also use a similar concept. These machines have been tested on the International Space Station. While in space, the images from the ultrasound were transmitted to doctors on the ground. This will be useful on long-distance missions when astronauts are more likely to develop illnesses that need medical attention.

Source: NASA Explores

Impact Craters

Overview

Impact craters are formed when pieces of asteroids or comets strike the surface of a planetary body. Craters are found on all the terrestrial planets, on the Earth's Moon and on most satellites of planets.

Various geological clues and studies of the lunar rocks returned by the Apollo missions indicate that asteroid-size chunks of matter were abundant in the solar system about 3.9 billion years ago. This was a time of intense bombardment of the young planet, affecting Earth by breaking up and modifying parts of the crust. Mountain building, plate tectonics, weathering and erosion have largely removed the traces of Earth's early cratering period. But the near absence of weathering on the Moon has allowed the evidence of this ancient time to be preserved.

Purpose

Through participation in this demonstration, students will:

- Model impact craters in the lab.
- Identify various structures caused by the cratering process.
- Manipulate the conditions that control the size and appearance of impact craters.
- State the relationships between the size of the crater, size of the projectile and velocity.
- Demonstrate the transfer of energy in the cratering process.

Preparation

Preparations for Activity A are as follows:

1. Assemble materials.
2. Practice mixing plaster of paris to get a feel for the hardening time under classroom or outdoor conditions. Plaster for classroom use should be mixed at time of demonstration.
3. Copy one Student Impact Crater Data Chart.
4. Prepare plaster.
   a. Mix the plaster of paris. A mixture of two parts plaster of paris to one part water works best. (REMINDER: The plaster hardens in 10 minutes to 20 minutes, so you must work quickly. Have Data Chart complete and all materials assembled before plaster is mixed.)
   b. Pour a 5 cm or more layer of plaster in a small, deep, disposable container.
   c. Optional: Using a kitchen strainer or a shaker, sprinkle a thin layer of powdered tempera paint over the plaster (use a dust mask and do not get paint on clothes).

Preparations for Activity B are as follows:

1. Assemble equipment.
2. Prepare projectile sets and label.
3. Copy one Student Impact Crater Data Chart.
4. Prepare target trays of dry material and paint.
   a. Place an even layer (3-cm thick) of dry material in the bottom of the tray (or box).
   b. Sprinkle a thin layer of red powdered tempera paint over the dry material with a kitchen strainer.
   c. Place another very thin (2-mm to 3-mm), even layer of dry material on top of the tempera paint, just enough to conceal paint.
   d. Optional: Sprinkle another layer of blue powdered tempera paint on top of the second layer of dry material. Repeat step 4.c. (Very fine craft glitter can be used instead of tempera for "sparkle" effect.)

Materials

- Student Data Sheets (CD Location: Educator Resources/Guides/Student Guide)

Materials for Activity A are as follows:

- Plaster of paris.
- 1 large, disposable pan or box (if used as a whole class demonstration) or three to four small, deep containers such as margarine tubs or loaf pans (for individuals or groups).
- Mixing container.
- Stirring sticks.
- Water (one part water to two parts plaster).
- Projectiles (e.g., marbles, pebbles, steel shot, lead fishing sinkers, ball bearings, etc.).
- Red or blue dry tempera paint (optional) (enough to sprinkle over the surface of the plaster) or substitute baby powder, flour, corn starch, fine-colored sand, powdered gelatin or cocoa.
- Strainer, shaker or sifter to distribute paint evenly.
- Meter stick.
- Dust mask.
- Data Charts (one per group).

Materials for Activity B are as follows:

- Large tray or sturdy box 8-cm to 10-cm deep and about 0.5 m on each side (a cat litter pan works nicely), two per class or one per group .
- Baking soda (two to three 1.8-kg boxes) per tray, or flour (two 2.26-kg bags), or fine sand (sandbox sand, 3 kg per tray).
- Red or blue dry tempera paint (enough for a thin layer to cover the dry material surface). (Very fine craft glitter may be used as one color.) **A nose and mouth dust mask should be used when sprinkling paint**. Suggested substitutes for paint may be found in the materials list for Activity A.
- Projectiles. (Provide one set of either type for each group of students.)
  - Set A: four marbles, ball bearings or large sinkers of identical size and weight (per group).
  - Set B: three spheres of equal size but different materials so that they will have different mass (e.g., glass, plastic, rubber, steel or wood). (Provide one or two sets per class.)
- Strainer, shaker or sifter to distribute the paint.
- Metric rulers and meter sticks.
- Lab balance (one per class).
- Data chart (per group).

Procedure

The procedure for Activity A is as follows:

1. Discuss background before or during activity.
2. Students work in small groups or conduct classroom demonstration.
3. Discuss questions.

The procedure for Activity B is as follows:

Note: This procedure is for small groups. It must be modified if the entire class will act as a single group.

1. Students should work in small groups. Each group should choose at least three projectiles from Set A or Set B.
2. Write a description of each projectile on your data chart.
3. Measure the mass and dimensions of each projectile and record on the data chart.
4. Drop projectiles into the dry material.
   a. Set A: Drop all projectiles from the same height or several series of experiments may be conducted from different heights. Record data and crater observations.
   b. Set B: Drop the projectiles from different heights (suggest 2 m to 3 m). Record all height data and crater observations.
5. Discuss the effects caused by the variables.

Questions

Questions for Activity A are as follows:

1. Where do you find the thickest ejecta?
2. How do you think the crater rim formed?
3. The powder represents the planet's surface. Material beneath the top layer must have formed at an earlier time, making it physically older. If you were to examine a crater on the Moon, where would you find the older material? Where would you find the younger material? Why?
4. What effect did the time intervals have on crater formation? Why?
5. If different projectiles were used, what effect did different projectiles have on crater formation? Why?
6. Since large meteorites often explode at or near the surface, how would the explosion affect the formation of impact craters?
7. How does the increased drop height affect crater formation? Why?

Questions for Activity B are as follows:

1. What evidence was there that the energy of the falling projectile was transferred to the ground?
2. How does the velocity of a projectile affect the cratering process?
3. How does the mass of a projectile affect the cratering process?
4. If the projectile exploded just above the surface, as often happens, what changes might you see in the craters?

Answer Key/ What is Happening?

The transfer of energy from a moving mass (meteorite) to a stationary body (planet) forms impact craters. Kinetic energy is the energy of motion. It is defined as one-half the mass of an object, times the velocity of the object squared ($K.E. = 0.5 Mv^2$). Objects in space move very fast, so this can be a huge amount of energy. In an impact, the kinetic energy of a meteorite is changed into heat that melts rocks and energy that pulverizes and excavates rocks. Simplified demonstrations of this transfer of energy can be made by creating impacts in powdered materials.

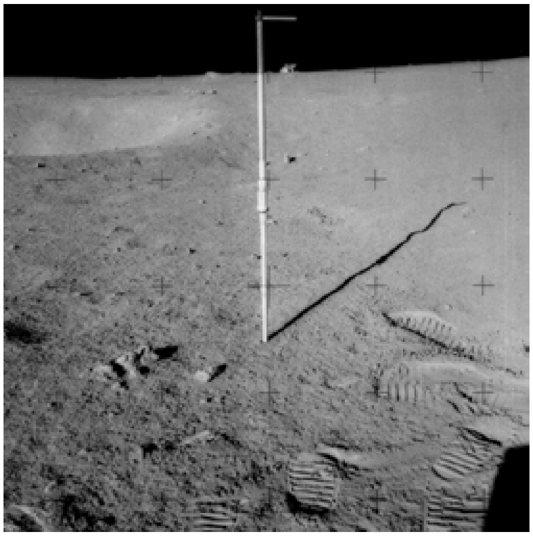
If identical objects are impacted into powdered materials from different heights or using different propulsion systems to increase velocities, then students can determine the effect velocity has on the cratering process. Likewise, if projectiles of different masses are dropped from the same height and the same velocity, students will be able to identify the relationship of mass to crater formation.

The high-velocity impact and explosion of an iron meteorite about 30 m in diameter could make a crater over 1-km wide. This is how Meteor Crater in Arizona was formed. In the classroom, the low velocities and low masses will make craters much closer in size to the impacting bodies.

Source:: Impact Craters-Holes in the Ground! NASA EG-1997-08-104-HQ

Lunar Core Sample

Overview



Lunar materials may yield new resources for living on the Moon, to send to Earth or for use in further space travel to Mars and beyond. It is important to understand what useful materials are below the surface of the Moon. One easy method of physically recovering material from below the surface of the Moon is by making core samples. A core sample can be made by a hollow drill bit operated by astronauts on the Moon. Another method for obtaining a core sample would use a lunar robotic arm onboard a mining vehicle to drill down approximately 0.5 meter into the lunar surface. A third core sampling method would use a lunar long-range rover that can drill core samples in selected rocks for a sample of lunar surface materials to return to Earth.

Purpose

Through participation in this demonstration, students will:

- Learn how an unknown core sample can be identified by matching it with a known sample.
- Discover how surface core samples can tell us about the history and makeup of the Moon.
- Consume the core sample at the end of the exercise.

Preparation

Prepare materials for each student as follows:

Materials

For each student:

- Student Data Sheets (CD Location: Educator Resources/Guides/Student Guide)
- "Fun or bite size" candy bar (e.g., Snickers, Milky Way, Mounds, Reeses Peanut Butter Cup, etc.)
- 2 7.62-cm long sections of clear plastic soda straw
- Paper plate.
- Plastic knife
- Graph paper or small ruler
- Wet wipes (optional for hand clean-up prior to activity, since edible material is involved)

Procedure

1. Distribute one candy bar to each student (use candy at room temperature or a bit warmer). Instruct students not to show their brand to anyone else. Ask each student to unwrap their bar and record observations about its surface (e.g., color, texture, composition, etc.).
2. Have students take a core sample by carefully and steadily drilling a straw into their candy bar. The core sample can be cut out with a knife and pressed out the end using the back edge of the knife. Then ask them to record the number and thickness of layers and color and texture of layers. What are the layers made of? Any repeated layers?
3. Have the students use knives to cut candy in two, so the layers can be viewed more easily in a cross section. Discuss which layers were made first. How were the layers made?
4. Have the students make a second core sample using the other straw. Two students then exchange core samples. Can they identify a new sample by comparing it with one that is known?
5. Finally, allow the students to consume the samples.

Questions

1. Describe the color of your lunar sample. Have the students observe the exact color of the surface. Is it milk chocolate color, dark chocolate, etc.? Have them define in word variations to more distinctly describe what they are seeing.
2. Describe the surface features of your lunar sample. Is it smooth, wavy, lined, bumpy, speckled, etc.? Can they see different colors integrated into the surface?
3. Draw a picture of any surface features you see on your lunar sample.
4. What is your hypothesis (scientific guess) about the cause of any texture you see on your lunar sample? If this was a lunar sample, what physical process could have caused the textures or features you are seeing (e.g., water erosion (fluvial), wind erosion (aeolian), impacts, etc.)?
5. How many layers does your lunar core sample contain? This will vary, depending upon the candy bar.
6. Draw a picture showing the layers of your lunar core sample.
7. Which layers were made first and why? The chocolate covering would be the surface, the youngest area of deposit. The stratigraphy (the order of the layers) would grow older as they go down the straw, towards the bottom. This would generally be true, barring any unusual events, like earthquake faulting or magma (liquid rock) intrusion.
8. Draw a picture of the second core sample showing any layers and surface features.
9. Compare the two core samples and list any similarities or differences from your lunar core sample. Unless the student got an identical core sample in the exchange, there should be some change. Compare the thickness of the top layers, colors, textures, smells, number of layers, sizes of layers, softness, hardness, etc.
10. Would a lunar core sample be important to the study of the Moon? Why? A core sample would be very important to the study of the Moon. Most of our science observations have been of surface features. To have a better understanding of the processes that formed the lunar features, seeing the subsurface would be very important. There are also many unanswered questions the scientists are trying to find answers for:
    a. Is there water in the subsurface that a human mission to the Moon could access (lunar microprobes)?
    b. How many layers are there and how thick are the layers in the subsurface?
    c. Are there different rocks underground than there are on the surface of the Moon?
    d. What can we tell about the climatic history of the Moon from these layers?
11. Where would be the best place to study a lunar core sample, on Earth or on the Moon? Why? Earth would probably have better, more sensitive science equipment available, since spacecraft equipment is somewhat limited due to space/cost/sensitivity factors. Studying the sample on the Moon would allow the scientist to observe the actual site and surroundings of the core sample. Was this sample typical of the rest of the terrain, or an unusual occurrence? A field study could be better conducted on the Moon.
12. What would account for the samples being different, if both come from the Moon? The core samples may have been taken from different sites or different places on the planet. Remember, one sample does not necessarily translate to the whole planet being like the sample. (A good story is the "The Blind Men and the Elephant", where the blind men all feel a different part of the elephant and think they know what the whole elephant is like.)

Answer Key/What is Happening?

Source: This activity is adapted from Mission to Mars materials from the Pacific Science Center in Seattle, WA, and Adler Planetarium. Submitted to Live From Mars by April Whitt and Amy Singel, Adler Planetarium. Teacher's Edition created by ASU Mars K-12 Education Outreach Program.

Edible Rock Abrasion Tool

Overview

How do planetary geologists study rocks on a planet that no human has ever visited and that is as much as 80.5 million km away? NASA uses robotic rovers to do this type of study on the surface of the Moon and Mars. To observe a pristine (or fresh) sample of rock, geologists on Earth would break the rock open with a rock hammer. Instead of breaking the rock open with a hammer, a rover will have a special tool called the rock abrasion tool (RAT), to remove outer layers of rock and expose underlying material for examination by the Microscopic Imager (which is like a geologist's hand lens) or Pancam (the rover camera).

Purpose

Through participation in this demonstration, students will:
Learn to make scientific observations using an edible RAT.

Preparation

Prepare materials for students.

Materials

For each student:

- Student Data Sheets (CD Location: Educator Resources/Guides/Student Guide)
- 1 fig bar-type cookie that you can get in a variety of flavors
- 1 cup cinnamon and sugar mixture (mixture to use for entire class: 1/3 cup cinnamon, 2/3 cup sugar)
- 1 jumbo pretzel stick (about 0.635 cm in diameter) — RAT tool
- 1 paper baking cup (muffin liner)
- 1 Popsicle or craft stick
- 1 ruler (metric)
- 1 pencil

Procedure

1. Have the students work in teams of two.
2. Sprinkle the bottom of the muffin liner with the cinnamon-sugar mixture.
3. Place a fig bar in each mixture-sprinkled muffin liner. Use different flavors of fig bars if you have them available. Take the fig bar and press each exposed fig side of the bar into the cinnamon-sugar mixture to cover the exposed filling on the sides of the cookie. (Note: If a variety of fig bar flavors are being used, this task can be done by the teacher prior to the distribution of the fig bars to the students to add more of a discovery component to the lesson. Just do not do this too far in advance unless you cover the cookies or the cookies will dry out and be hard to drill.)
4. Sprinkle the top of the fig bar with the cinnamon-sugar mixture so the top surface of the cookie is also covered with the mixture (lunar dust).
5. Give each student team a pretzel. This is their RAT.
6. Each student will observe the undisturbed rock before the RAT drilling begins and record observations such as color, texture, size and surface features of the rock on the student activity sheet.
7. In determining the size of the sample, students should use the craft stick and a pencil to mark off the dimensions (i.e., length, width and height) of their rock sample. Students can then use their ruler to measure their marked stick and record these measurements on their RAT Student Activity Sheet.

8. Students will then take their RAT and gently place it on the top surface of their rock. Have them rotate the RAT a few times on the surface of the cookie, applying a very slight amount of pressure. The cinnamon mixture should erode away readily, exposing the surface of the cookie portion of the fig bar.
9. Each student should observe the newly exposed region and record their observations. How is it different from the original surface?
10. Notice how the lunar dust (cinnamon mixture) builds up along the edge of the drilled area, along with some of the rock surface (cookie crumbs). Students should brainstorm how they could keep the dust from the RAT hole from contaminating the freshly drilled rock sample.
11. Have students apply slightly more pressure to the pretzel and rotate several more times to dig slightly deeper into the sample (the real RAT will only penetrate approximately 5 mm into the rock and drill a diameter of approximately 2 cm). Remove the pretzel. The students should observe the filling of the fig bar (the interior of the rock). This is representative of the pristine (fresh) rock sample in its original form. Each student should observe this new material and record their observations on the RAT student activity sheet.
12. Again, using the craft stick, students should measure the depth and diameter of their "RAT hole" and record their observations on the RAT student activity sheet.
13. Students should brainstorm as to what type of rock this might be (i.e., igneous, metamorphic or sedimentary) and justify why they think so. Here are some simple definitions of the three types of rocks, or you may use your own:
    a. Igneous rocks are rocks that are made from molten materials that well up from inside a planetary body and cool to solidify into rock.
    b. Metamorphic rocks are rocks that have been changed by temperature and/or pressure.
    c. Sedimentary rocks are rocks that have been eroded away from their original rock type and have been deposited and accumulated to solidify into new rock.

Questions

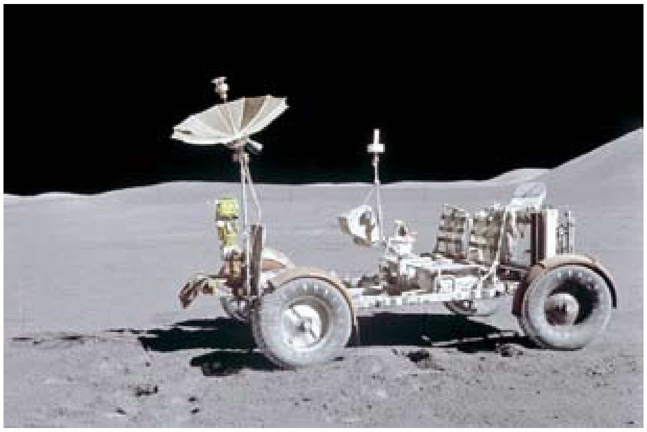
N/A

Answer Key/ What is Happening?

N/A

Source: ASU Mars K-12 Education Program

Lunar Missions



In this section, students discover past, present and future space exploration missions and their spacecraft.

Recap: Apollo

Stepping Stone to Mars

Takes a look at missions to the Moon as a next step before going to Mars.

Investigate Lunar Missions

Takes a look at space science missions on the Internet for a general understanding of missions that have been, are going or will go to destinations in our solar system.

The Pioneer Missions

Edible Pioneer 3 Spacecraft

Uses a variety of candies and cookies to design a model of the Pioneer spacecraft.

The Clementine Mission

Edible Clementine Spacecraft

Uses a variety of candies and cookies to design a model of the Clementine spacecraft.

Edible Lunar Rover

Lunar Prospector

Edible Lunar Prospector Spacecraft

Uses a variety of candies and cookies to design a model of the Lunar Prospector spacecraft.

Lunar Reconnaissance Orbiter

Challenges students to think of robot systems and instruments and their human counterparts.

Robots Versus Humans

The Definition of a Robot

Lunar Reconnaissance Orbiter Edible Spacecraft

Recap: Apollo

"At that moment when that pyramid of fire rose to a prodigious height into the air, the glare of the flame lit up the whole of Florida; and for a moment day superceded night over a considerable extent of the country."

—Jules Verne, ("From the Earth to the Moon," 1865)

The Soviet spacecraft Luna 2 visited the Moon first in 1959. The Moon is the only extraterrestrial body to have been visited by humans. The first human landing on the Moon occurred on July 20, 1969; the last was in December 1972. The Moon is also the only body from which samples have been returned to Earth. Let us start by reviewing the timeline of the Moon.

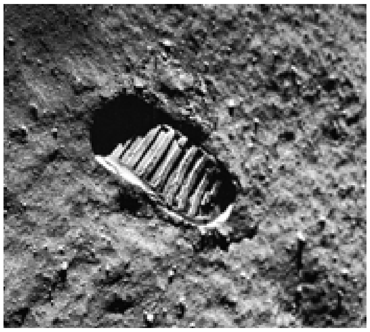
The Decision to Go to the Moon

"I believe this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the Moon and returning him safely to the Earth. No single space project in this period will be more impressive to mankind, or more important for the long-range exploration of space, and none will be so difficult or expensive to accomplish."

—President John F. Kennedy, speech to U.S. Congress, May 25, 1961.

President Kennedy's speech to Congress was made in the context of the Cold War between the United States and the Soviet Union. At that time, the U.S. feared that it was falling behind the Union of Soviet Socialist Republics (U.S.S.R.) both in technological advances and international prestige. The U.S.S.R. launched the first artificial satellite into Earth orbit in October 1957. On April 12, 1961, just 6 weeks before Kennedy's speech, the Soviets launched the first human into Earth orbit.

Although the U.S. launched astronaut Alan Shepard on a brief, suborbital flight on May 5, 1961, they did not put an astronaut in orbit until February 1962. The failure of the U.S.-backed invasion of the Bay of Pigs, Cuba, in April 1961 added to this space race mentality. President Kennedy sought an inspirational goal to rally the country. With the advice of Vice President Lyndon Johnson and the nation's scientific leadership, Kennedy settled on a manned lunar journey as a goal dramatic enough to capture the world's attention. The difficulty of reaching this goal ensured that it could not be achieved quickly, allowing the U.S. time to overcome the Soviet Union's lead in space exploration.



NASA quickly turned its aim toward reaching the Moon. Project Mercury, already under way at the time, provided the U.S. its first experience with humans in space. In 1965 and 1966, Project Gemini provided experience in three areas that were crucial to reaching the Moon: long-duration spaceflight, extravehicular activity (EVA) and rendezvous and docking of spacecraft.

Unmanned programs also contributed to the cause. Project Ranger provided our first close-up images of the Moon. Project Surveyor provided images from the Moon's surface and analyses of the chemical composition and mechanical properties of the

Moon's soil. The Lunar Orbiter photographed the entire Moon from low-altitude orbit, with particular emphasis on locating landing sites for the Apollo Program. To explore all of the unmanned missions to the Moon, review the Lunar Exploration Timeline at <http://nssdc.gsfc.nasa.gov/planetary/lunar/lunartimeline.html>.

The tragic Apollo 1 launch pad fire in January 1967 killed the three-man crew (Edward H. White II, Virgil I. "Gus" Grissom and Robert B. Chaffee).

The accident delayed the Apollo program while the spacecraft was redesigned for greater safety. Between October 1968 and May 1969, Apollo 7 through Apollo 10 tested the various components of the Apollo system. Apollo 7 tested the Command and Service Modules in Earth orbit. Apollo 8 was mankind's first trip beyond Earth orbit, a dramatic Christmas trip to the Moon. Apollo 9 tested the Lunar Module in Earth orbit. Apollo 10 was a final dress rehearsal in lunar orbit, clearing the way for Apollo 11's historic flight

Throughout this time, the Soviet Union continued planning for the Moon. Although they did not publicly announce their plans at the time, they too were planning a manned lunar voyage, which never actually occurred due to repeated failures of their giant booster rocket. However, they did attempt to steal Apollo 11's thunder by returning a small sample of lunar soil with the Luna 15 spacecraft just a few days prior to Apollo 11. This effort also failed when Luna 15 crashed on the Moon's surface on July 21, 1969. President Kennedy's goal was finally achieved when Apollo 11 landed on the Moon on July 20, 1969 and returned to Earth on July 24, 1969.

While Apollo 11 was the political culmination of the Apollo program, six more increasingly sophisticated missions were flown to the Moon prior to the end of Apollo.

Apollo 13 was a near-fatal disaster due to the explosion of an oxygen tank in the Service Module. Apollo 12 and Apollo 14 through Apollo 17 were successful and provided much of the data on which our current scientific understanding of the Moon is built. Since the end of Apollo 17 in December 1972, no human has walked on the surface of the Moon. For more details on the missions visit the Apollo Lunar Surface Journal at <http://www.lpi.usra.edu/expmoom/decision.html>.

Top Ten Scientific Discoveries Made During Apollo Exploration of the Moon

1. **The Moon did not exist at the beginning of creation. It is an evolved terrestrial planet with internal zoning similar to that of Earth.**

   Before Apollo, the state of the Moon was a subject of almost unlimited speculation. We now know that the Moon is made of rocky material that has been variously melted, erupted through volcanoes and crushed by meteorite impacts.

The Moon possesses a thick crust (60 km), a fairly uniform lithosphere (60 km to 1,000 km) and a partly liquid asthenosphere (1,000 km to 1,740 km); a small iron core at the bottom of the asthenosphere is possible but unconfirmed. Some rocks give hints for ancient magnetic fields, although no planetary field exists today.

2. **The Moon is ancient and still preserves an early history (the first billion years) that is assumed to be common to all terrestrial planets.**

   The extensive record of meteorite craters on the Moon, when calibrated using absolute ages of rock samples, provides a key for unraveling time scales for the geologic evolution of Mercury, Venus and Mars based on their individual crater records. Photogeologic interpretation of other planets is based largely on lessons learned from the Moon. However, before Apollo, the origin of lunar impact craters was not fully understood and the origin of similar craters on Earth was highly debated.

3. **The youngest Moon rocks are virtually as old as the oldest Earth rocks. The earliest processes and events that probably affected both planetary bodies can now only be found on the Moon.**

   Moon rock ages range from about 3.2 billion years in the maria (dark, low basins) to 4 billion to 5 billion years in the terrae (light, rugged highlands). Active geologic forces, including plate tectonics and erosion, continuously repave the oldest surfaces on Earth; whereas old surfaces persist with little disturbance on the Moon.

4. **The Moon and Earth are genetically related and formed from different proportions of a common reservoir of materials.**

   Oxygen isotopic compositions of Moon rocks and Earth rocks clearly show common ancestry. Relative to Earth, however, the Moon was highly depleted in iron and in volatile elements that are needed to form atmospheric gases and water.

5. **The Moon is lifeless; it contains no living organisms, fossils or native organic compounds.**

   Extensive testing revealed no evidence for life, past or present, among the lunar samples. Even nonbiological organic compounds are amazingly absent; traces can be attributed to contamination by meteorites.

6. **All Moon rocks originated through high-temperature processes with little or no involvement with water. They are roughly divisible into three types: basalts, anorthosites and breccias.**

   Basalts are dark lava rocks that fill mare basins; they generally resemble, but are much older than, lavas that comprise the oceanic crust of Earth.

   Anorthosites are light rocks that form the ancient highlands; they generally resemble, but are much older than, most ancient rocks on Earth.

   Breccias are composite rocks formed from all other rock types through crushing, mixing and melting during meteorite impacts. The Moon has no sandstones, shales or limestones such as testify to the importance of water-borne processes on Earth.

7. **Early in its history, the Moon was melted to great depths to form a magma ocean. The lunar highlands contain the remnants of early, low-density rocks that floated to the surface of the magma ocean.**

   The lunar highlands were formed about 4.4 billion to 4.5 billion years ago by flotation of an early, feldspar-rich crust on a magma ocean that covered the Moon to a depth of many tens of kilometers or more. Innumerable meteorite impacts through geologic time reduced much of the ancient crust to curved mountain ranges between basins.

8. The lunar magma ocean was followed by a series of huge asteroid impacts that created basins that were later filled by lava flows.

The large, dark basins such as Mare Imbrium are gigantic impact craters, formed early in lunar history, that were later filled by lava flows about 3.2 million to 3.9 billion years ago. Lunar volcanism occurred mostly as lava floods that spread horizontally; volcanic fire fountains produced deposits of orange and emerald-green glass beads.

9. The Moon is slightly asymmetrical in bulk form, possibly as a consequence of its evolution under Earth's gravitational influence. Its crust is thicker on the far side, while most volcanic basins and unusual mass concentrations occur on the near side.

Mass is not distributed uniformly inside the Moon. Large mass concentrations (mascons) lie beneath the surface of many large lunar basins and probably represent thick accumulations of dense lava. Relative to its geometric center, the Moon's center of mass is displaced toward Earth by several kilometers.

10. A rubble pile of rock fragments and dust (the lunar regolith) that contains a unique radiation history of the Sun covers the surface of the Moon, which is of importance to understanding climate changes on Earth.

The regolith was produced by innumerable meteorite impacts through geologic time. Surface rocks and mineral grains are distinctively enriched in chemical elements and isotopes implanted by solar radiation. As such, the Moon has recorded 4 billion years of the Sun's history to a degree of completeness that we are unlikely to find elsewhere.

Scientists now believe that the Moon formed as a result of a collision between early Earth and a Mars-sized planet. This smaller planet was destroyed in the collision, about 4.5 billion years ago. The giant impact sprayed vaporized material into a disk that orbited Earth. This vapor cooled into droplets that coalesced into the Moon. Moon research continues, and more than 60 research laboratories throughout the world continue studying the Apollo lunar samples today. Many new analytical technologies, which did not exist when the Apollo missions were returning lunar samples, are now being applied by the third generation of scientists. The deepest secrets of the Moon remain to be revealed.

Recent Missions

The Galileo spacecraft obtained some imagery of the Moon during brief lunar flybys in 1990 and 1992. The Clementine spacecraft obtained detailed images and mapped the topography of the Moon from orbit in 1994. The Lunar Prospector spacecraft made an orbital survey of the Moon's chemical composition and gravitational and magnetic fields in 1998 and 1999.

The results from Clementine and Lunar Prospector contributed to a renaissance in lunar geology and geophysics studies during the last half of the 1990s. The possibility that there may be water on the Moon was suggested by the results of both these spacecrafts' findings.

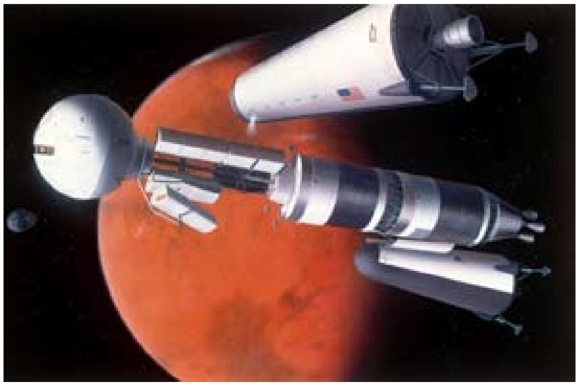
Selene Lunar Orbiter

Several future missions are under consideration by various governments at this time. SMART, Lunar-A and Selene are scheduled for launch within the next few years. LunarSat, a lunar microorbiter, will, for the first time, be a spacecraft primarily designed and built by young professionals and students. Its goal is to investigate the Moon's suitability for an extraterrestrial outpost.

Apollo produced a wealth of new knowledge about the Moon, but our nearest neighbor in space remains an attractive target of exploration, both because of its scientific interest and as a test bed for developing techniques for exploring farther into the solar system.

Stepping Stone to Mars

"Anything one man can imagine,
other men can make real."
—Jules Verne



Future generations of space explorers will have to relearn how to work and live on other planetary surfaces for months and years at a time. Even now, astronauts are being trained for geological sciences on other worlds in preparation for these trips. Because of its closeness to Earth, the Moon has much to offer as a first step in the exploration of other worlds such as Mars.

The Moon can be used as a test bed for the new technologies and equipment needed for Mars exploration, because of the similarities in the two environments. It can serve as a base for training human crews in long-duration space voyages and ways of living on other worlds. In addition, continued exploration of the Moon would help us to answer many remaining questions about the Moon's origin and composition.

Using the Moon (which is only 3 days away) as a stepping-stone before we attempt long voyages to other worlds such as Mars has certain advantages, including the possibility of a life-saving rescue, the possibility of fast resupply of necessary or emergency equipment, the testing of systems in a similar environment (e.g., low gravity, alien surroundings, dust, radiation exposure, etc.), and the possibility of a fast return to Earth in case of illness or emergency. Developing lunar resources, such as lunar oxygen from regolith (soil) or water from south pole ice deposits, increases our motivation to return to the Moon and could significantly enhance the economics and feasibility of future lunar bases.

This initiative, known as the Space Exploration Initiative, marked a new direction for the nation and an investment in the future. Download the report from <http://history.nasa.gov/sei.htm>.

The Apollo missions demonstrated that no problem exists for adaptation to low gravity for short periods. Modern lunar exploration would extend stay time on the lunar surface.

Coupled with long duration in weightlessness in Earth orbit, data could be efficiently accumulated to predict how humans would perform on a Mars mission.

The effects of galactic cosmic rays and solar radiation on the crews could be measured. Psychological issues raised by long duration in isolation could also be studied.

The predecessors of interplanetary spacecraft would gather operational time in an Earth-Moon transportation system. Data would be taken on system reliability, maintenance and performance. Lunar surface life support systems could evolve into their martian counterparts. Power, transportation, communication, construction and resource utilization can all be elements of a lunar base that would be applicable to a Mars mission.

A heavy lift launch vehicle is a natural element of a lunar program, but the demands on performance and launch rate are not as high as in a Mars program. In fact, they provide a natural training ground for operations personnel and management and a chance to make improvements in launch vehicles. Maintaining, refueling and refurbishing vehicles on orbit provide the experience from which to build an operations team for future assembly of Mars spacecraft.

Because the Moon is close to the Earth and because it is possible to launch small payloads to it with relatively small rockets, the opportunity arises to involve students in the exploration experience using robotics, telepresence and the Internet. Students could accumulate data from instruments on the Moon and even direct some of the instruments. It could provide for real interaction between the scientists of tomorrow and the lunar explorers of today.

While a program to land humans on Mars is possible, the required advances in operational and technical capability are large due to present significant risks for program failure, as outlined above.

An immediate commitment to piloted missions to Mars runs the risk of revisiting Apollo, a crash program created by the political system that was cancelled when the effort seemed no longer relevant. In the process of human exploration of the solar system, the establishment of a permanent presence on the Moon is a necessary step in the steady progress of technology, experience and the understanding of human capabilities in space. A lunar program provides the opportunity to build up space capability in a sequential way.

During the late 1960s and early 1970s, the Apollo program demonstrated American technical strength in a race against the Soviet Union to land humans on the Moon. Today, NASA's plans for a return to the Moon are not driven by Cold War competition, but by the need to test new exploration technologies and skills on the path to Mars and beyond.

As a stepping stone to Mars and beyond, NASA will begin its lunar test bed program with a series of robotic missions beginning with a Lunar Reconnaissance Orbiter scheduled to be launched in 2008. The Moon provides a convenient location in which to develop and test a variety of exploration tools and techniques. NASA will advance lunar science and use the Moon to perform the following:

- Test and develop hardware, software and various systems and components to determine how they operate in harsh space environments.
- Provide the opportunity to understand how crews adapt and perform in a partial-gravity environment.
- Test the autonomy of essential systems before they are used in more distant destinations.
- Test and enhance interactions between human explorers and robots.
- Explore the possibility of using resources already present on the Moon for power generation, propulsion and life support.

A robotic landing is scheduled to follow in the 2009 to 2011 time period to begin demonstrating capabilities for sustainable exploration of the solar system. Additional missions are planned to demonstrate new capabilities such as robotic networks, reusable planetary landing and launch systems, prepositioned propellants, and resource extraction. A human mission will follow as early as 2015.

Questions to Think About:

1. You are too young to remember the lunar landings. How do you feel about sending a crew back to the Moon?
2. Would you be more excited about a human mission to Mars? Why?
3. Would you like to participate in a student program using telepresence on another world? What type of tasks would you like to do?

Source: Stepping Stone to Mars at <http://aerospacescholars.jsc.nasa.gov/HAS/Cirr/EM/6/9.cfm>.

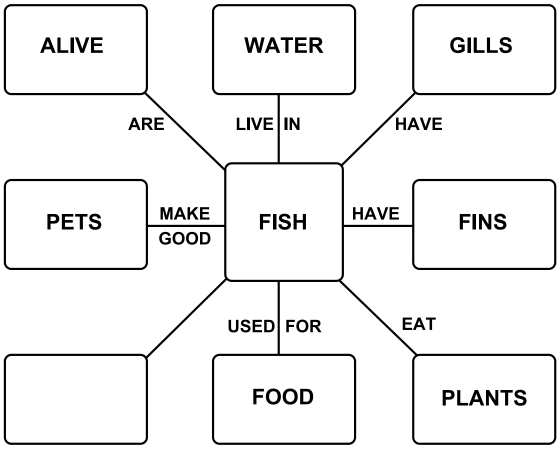
Investigate Lunar Missions

Overview
Spacecraft systems and materials are carefully chosen and designed for a specific mission to the Moon. The distance to the Moon and the environment and mission objectives help determine what systems and materials are used. During this activity, team members will have the opportunity to learn more about spacecraft that have been, are going or will go to the Moon.

Purpose
Through a study of past, present and future spacecraft and their missions, students will:
- Increase their knowledge of our unmanned and manned lunar missions.
- Increase their knowledge of spacecraft systems.
- Visualize and connect concepts for student mission scenarios using semantic mapping.

Preparation
1. Schedule an hour in a computer lab or for computer access. Alternatively, provide hard copy information about unmanned space missions and spacecraft through books or articles. See Resources section for information.
2. Make copies of the Pioneer, Lunar Reconnaissance Orbiter, Apollo, Clementine, Lunar Prospector, Selene Mission fact sheets and Let's Investigate Lunar Missions Student Sheets.
3. If the class has never worked with semantic mapping, create one together as a class to familiarize them with the concept. In the example below, the column on the left represents the list the students came up with during the brainstorm. The example below shows how they should place their information into a semantic map. The main concept is in the center; the brainstormed ideas are placed in rectangles and connected to the main idea with a line to represent the relationship between the two.

Ideas and Concepts for Fish
Examples:
- Live in water
- Have gills
- Have fins
- Make good pets
- Eat plants
- Used for food
- Are alive



Materials
Per team:
- Student Data Sheets (CD Location: Educator Resources/Guides/Student Guide)
- Computer access or hard copy information on space missions
- Let's Investigate Lunar Missions Student Sheets

Procedure

1. Have each student pull up the Lunar Nautics Lunar Exploration Timeline activity. Alternatively, distribute hard copies of unmanned space mission and spacecraft information to each team.
2. Discuss the difference between manned and unmanned spacecraft and satellites.
3. Discuss what the Exploration Systems Mission Directorate is.
4. Distribute the Let's Investigate Lunar Missions Student Sheets to each group. Teams should complete the sheet and be prepared to share with the group.
5. Have each student brainstorm words or ideas related to their Lunar Nautics Space System, Inc. mission. These lists may not be very long. The students should place these words or ideas on the semantic map provided.

Questions

1. Name a past, present or future lunar mission. Identify the mission's specific destination. Describe the mission's spacecraft.
2. Who can describe a currently operating mission? (Where was or is it going? What are its objectives? What is its timeline?)
3. Who can describe a future or in-development mission? (Where is it going? What are its objectives? What is its timeline?)
4. Who can describe an under-study mission? (Where is it going? What are its objectives? What is its timeline?)

Answer Key/What is Happening?

Semantic mapping powerfully establishes the connection of concepts and words to each other. It also reinforces or introduces specific vocabulary. Finally, it promotes retention of content.

The Pioneer Missions

The picture on the right shows Pioneer spacecraft 6 through 13. Pioneer 6, 7, 8 and 9 spacecraft are shown in the upper left corner of the picture. A picture of the Pioneer 10 and 11 spacecraft is second from the left. A picture of the Pioneer Venus Orbiter (Pioneer 12) spacecraft is third from the left. In the lower right corner is the Pioneer Venus Multiprobe (Pioneer 13) spacecraft.

The Pioneer 6 to 9 Missions

The spacecraft measures 93.98 cm in diameter by 88.9 cm high (main body). The horizontal booms are 208.28-cm long. The antenna mast (pointing down in the picture) is 132.08-cm long. The weight is approximately 68.04 kg. The spacecraft is spin-stabilized at approximately 60 rpm, with the spin axis perpendicular to the ecliptic plane.

Pioneer 6 was launched on a Thor-Delta launch vehicle on December 16, 1965 into a circular solar orbit with a mean distance of 0.8 Astronomical Units (AUs) from the Sun. (The mean distance from the Earth to the Sun is 1.0 AU).

Pioneer 7 was launched on August 17, 1966 into solar orbit with a mean distance of 1.1 AUs from the Sun.

Pioneer 8 was launched on December 13, 1967 into solar orbit with a mean distance of 1.1 AUs from the Sun.

Pioneer 9 was launched on November 8, 1968 into solar orbit with a mean distance of 0.8 AUs from the Sun.

Pioneers 6 to 9 demonstrated the practicality of spinning a spacecraft to stabilize it and to simplify control of its orientation. Measurements made by these spacecraft greatly increased our knowledge of the interplanetary environment and the effects of solar activity on Earth. New information was gathered about the solar wind, solar cosmic rays, the structure of the Sun's plasma and magnetic fields, the physics of particles in space, and the nature of storms on the Sun, which produce solar flares.

Originally designed to operate in space for at least 6 months, the Pioneers have proved to be remarkably reliable. Pioneer 9 failed in 1983. Pioneer 8 was last tracked successfully on August 22, 1996, after being commanded to the backup transmitter tube (TWT). Pioneer 7 was last tracked successfully in March 1995. Pioneer 6, the oldest operating spacecraft ever, had a track on the 70-meter Deep Space Station 43 in Australia on October 6, 1997. The spacecraft had been commanded to the backup TWT in July 1996. The prime TWT apparently had failed some time after December 1995. The MIT and ARC Plasma Analyzers and the cosmic ray detector from the University of Chicago were turned on and still worked after almost 32 years. Limited availability of NASA's Deep Space Tracking Network antennas and the greater scientific value of newer space missions led to a discontinuance of the tracking of these spacecraft. However, to mark its 35 years in orbit as the oldest extant NASA spacecraft, one last contact was successfully completed on the 70-meter Deep Space Station 14 at Goldstone, near Barstow, California, on December 8, 2000.

Pioneer 6 was featured on the Star Date Radio broadcast by the University of Texas McDonald Observatory on December 16, 2000—the 35th anniversary of its launch.

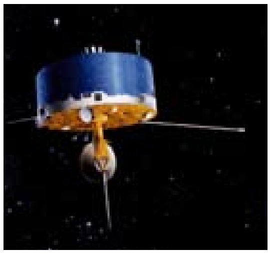
Source: Pioneer Project at <http://www.nasa.gov/centers/ames/missions/archive/pioneer.html>.

The Pioneer 10 and 11 Missions

For a complete description of the Pioneer 10 and 11 missions, see the Pioneer Home Page and the Missions Descriptions Page at <http://msl.jpl.nasa.gov/QuickLooks/pioneer10QL.html>.

The Pioneer Venus Orbiter Mission

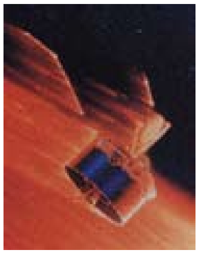
The Pioneer Venus Orbiter (Pioneer 12) spacecraft is shown in its normal flight attitude (upside down).



The Orbiter was launched on May 20, 1978 on an Atlas-Centaur launch vehicle. On December 4, 1978, the Orbiter was injected into a highly elliptical orbit around Venus. The periapsis, or low orbital point, of the orbit was about 150 km above the surface of the planet. The apoapsis, or highest orbital point, was 66,000 km from the planet. The orbital period was 23 hours 11 minutes.

The orbit permitted global mapping of the clouds, atmosphere and ionosphere; measurement of upper atmosphere, ionosphere and solar wind-ionosphere interaction; and mapping of the planet's surface by radar. For the first 19 months of the mission, the periapsis was maintained at about 150 km by periodic maneuvers. As propellant began to run low, the maneuvers were discontinued and solar gravitational effects caused the periapsis to rise to about 2,300 km. By 1986, the gravitational effects caused the periapsis to start falling again, and the Orbiter instruments could again make direct measurement within the main ionosphere.

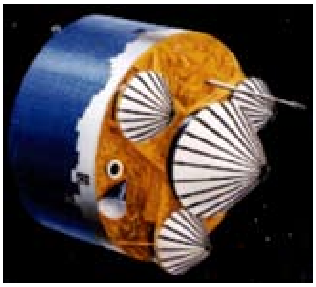
During the Orbiter's mission, opportunities arose to make systematic observations of several comets with the Ultraviolet Spectrometer (OUVS). The comets and their date of observation were: Encke April 13 through April 16, 1984; Giacobini-Zinner, September 8 through 15, 1985; Halley, December 27, 1985 to March 9, 1986; Wilson, March 13 to May 2, 1987; NTT, April 8, 1987; and McNaught, November 19 through 24, 1987. For Halley, the results showed that the water evaporation rate was about 40 tons per second near perihelion.



Starting in September 1992, controllers used the remaining fuel in a series of maneuvers to keep raising periapsis altitude for as long as possible. On October 8, 1992, its fuel supply exhausted, the Orbiter ended its mission, becoming a meteor flaming through the dense atmosphere of Venus, producing a glowing tail like a large meteorite. The artist's rendering at right shows the spectacular end of the Orbiter's 14-year mission.

Spacecraft Description

The main body of the spacecraft was a flat cylinder 2.5 m in diameter and 1.2-m high. A circular equipment shelf was in the upper or forward end of the cylinder. All the spacecraft's scientific instruments and electronic subsystems were on this shelf. Below the shelf, 15 thermal louvers controlled heat radiation from an equipment compartment that was between the shelf and the top of the spacecraft. On top of the spacecraft was a 1.09-m diameter, despun, high-gain, parabolic dish antenna. The despun design allowed the antenna to be mechanically directed to continuously face the Earth from the spinning spacecraft.



The spacecraft also carried a solid-propellant rocket motor with 18,000 N of thrust. This thrust would decelerate the spacecraft by 3,816 km/hr and place it into an orbit around Venus. The spacecraft's launch weight of 553 kg included 45 kg of scientific instruments and 179 kg of rocket propellant.

Beneath the equipment compartment were two conical hemispheric propellant tanks. These tanks stored 32 kg of hydrazine propellant for three axial and four radial thrusters. These thrusters were used to change the attitude, velocity or orbital period and spin rate during the mission.
Additional information about Pioneer Venus can be found at the following locations:

- The National Space Science Data Center (NSSDC) has a description of the Pioneer Venus missions and science data sets at < http://nssdc.gsfc.nasa.gov/planetary/pioneer_venus.html>.
- The Center for Space Research at MIT has a science data set from the Radar Mapper instrument on the Orbiter at < http://www.nasa.gov/centers/ames/missions/archive/pioneer.html>.

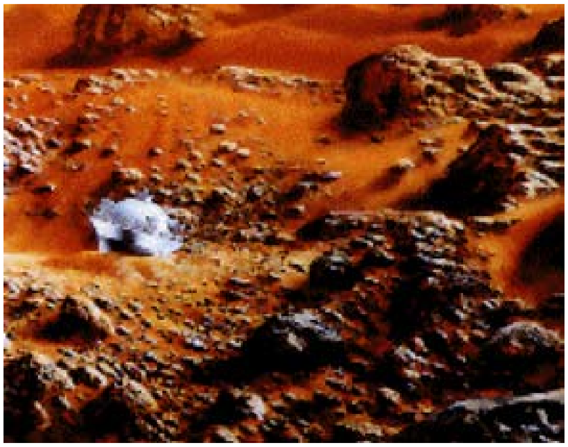
The Pioneer Venus Multiprobe Mission

On August 8, 1978 (slightly less than 3 months after the Orbiter left Earth), the Multiprobe spacecraft (Pioneer 13) was launched from the Kennedy Space Center on an Atlas-Centaur launch vehicle. On November 16, 1978, the large probe was released from the bus toward an entry near the equator on the day side of Venus. Four days later, on November 20, 1978, the three small probes were released from the bus. Two of the probes were targeted to enter on the night side and one was targeted to enter on the Venus day side. On December 9, 1978 the bus, with its instruments, was retargeted to enter Venus' day side.

When the probes separated from the Multiprobe bus, they went off the air because they did not have sufficient on-board power or solar cells to replenish their batteries. Preprogrammed instructions were wired into them and their timers had been set before they separated from the bus. The on-board countdown timers were scheduled to bring each probe into operation again 3 hours before the probes began their descent through the Venusian atmosphere. On December 9, 1978, just 22 minutes before entry, the large probe began to transmit radio signals to Earth. Only 17 minutes before hurtling into the Venusian atmosphere at almost 42,000 km/hr, all the small probes started transmitting.

All four probes were designed for a descent time of approximately 55 minutes before impacting the surface. None were designed to withstand the impact. However, one small probe (the Day Probe) did survive and sent data from the surface for 67 minutes. Engineering data radioed back from the Day Probe showed that its internal temperature climbed steadily to a high of 126 C. Then its batteries were depleted, and its radio became silent.

At right is an artist's illustration of how a Pioneer Venus probe might have looked on the hot surface of Venus.



The Bus

The Pioneer Venus Multiprobe spacecraft consisted of a basic bus similar to the Orbiter's, a large probe and three identical small probes. It did not carry a despun, high-gain antenna. The weight of the Multiprobe was 875 kg including 32 kg of hydrazine. The Multiprobe used this propellant to correct its trajectory and orient its spin axis. The total weight of the four probes it carried was 585 kg. The bus itself weighed 290 kg. The Multiprobe's basic bus design was similar to the Orbiter's design. It also used a number of common subsystem designs. The spacecraft diameter was 2.5 m. From the bottom of the bus to the top of the large probe mounted on it, the Multiprobe measured 2.9 m.

During their flight to Venus, the four probes were carried on a large inverted cone structure, and three equally spaced circular clamps surrounded the cone. Bolts held these attachment structures to the control thrust tube. This thrust tube formed the structural link to the launch vehicle. The large probe was centered on the spin axis. A pyrotechnic-spring separation system launched the probe from the bus toward Venus. The ring support clamps that attached the small probes were hinged. To launch the small probes, the Multiprobe first spun up to 45 rpm; then explosive nuts fired to open the clamps on their hinges. This sequence allowed the probes to spin off the bus tangentially.

The Probes

The probes' designers faced a number of tremendous challenges: the high pressure in the lower regions of Venus' atmosphere, which is 100 times greater than the pressure on Earth; the high temperature of about 480 C at the surface (hot enough to melt lead); and corrosive constituents of the clouds, such as sulfuric acid. Moreover, the probes had to enter the atmosphere at a speed of about 41,600 km/hr. The large and small probes were similar in shape. The main component of each probe was a spherical pressure vessel. Machined from titanium, the vessels were sealed against the vacuum of space and the high pressure of Venus' atmosphere. A conical aeroshell deceleration module and heat shield protected the probes from the heat of high-speed atmospheric entry.

The large probe weighed about 315 kg and was about 1.5 m in diameter. The probe was equipped with a parachute to slow its entry into the atmosphere. The forward heat shield and aft cover of the deceleration module were designed to separate from the pressure vessel. There were a total of seven scientific instruments on the large probe. Four scientific instruments used nine observation windows through pressure vessel penetrations. Eight of the windows were made of sapphire and one was made of diamond. There were three pressure vessel penetrations as inlets for direct atmospheric sampling by a mass spectrometer, a gas chromatograph and an atmospheric structure instrument.

The three small probes were identical. In contrast to the large probe, they did not carry parachutes. Aerodynamic braking slowed them down. Like the large probe, each small probe consisted of a forward heat shield, a pressure vessel and an afterbody. The heat shield and the afterbody remained attached to the pressure vessel all the way to the surface. Each probe was 0.8 m in diameter and weighed 90 kg. The small probes were equipped with a mechanism that deployed two 2.4-m cables and weights as a yo-yo despin system 5 minutes before atmospheric entry. The cables and weights reduced the spin rate of the probes from 48 rpm to 15 rpm. The weights and cables were then jettisoned. Each small probe carried three scientific instruments.

Spaceprojects
Ames Research Center
Project Manager: Dr. Lawrence Lasher

Edible Pioneer 3 Spacecraft

Overview

Students work individually to build the Pioneer 3 spacecraft from edible treats.

Purpose

Through a study of the Pioneer 3 spacecraft, students will:
- Build an edible model of the Pioneer 3 spacecraft.
- Identify the findings of the Pioneer 3 spacecraft.

Preparation

1. Reproduce the Pioneer 3 information from this link <http://msl.jpl.nasa.gov/QuickLooks/pioneer3QL.html> for each student.
2. Fill a baggie of the materials listed below for each student.

Materials

Per student:
- Student Data Sheets (CD Location: Educator Resources/Guides/Student Guide)
- 1 sugar cone
- 1 2-oz package of Airhead Extreme Sour Belts
- 2 HERSHEY'S KISSES
- Marshmallow crème or cake icing (small containers or shared jar)
- 1 small plastic/paper plate
- 1 plastic knife
- Paper towels
- Wet wipes
- Construction paper
- Toothpicks
- Scissors
- Plastic gloves (optional)

Note: Ask or tell students what each part represents on the spacecraft.

Procedure

1. Review Pioneer mission (see <http://msl.jpl.nasa.gov/QuickLooks/pioneer3QL.html> to create fact sheets).
2. Distribute copies of the fact sheet to each student.
3. Distribute the materials. Tell the teams they will build a model of the Pioneer 3 spacecraft with the furnished materials.
4. Students can use a diagram of the spacecraft and some imagination to add instruments and engineering components onto their spacecraft.
5. Once the spacecraft is built, they will need to label the parts using toothpicks and construction paper labels.
6. Have the teams share their spacecraft models. Each group should explain one part and its function to the class.
7. Direct students to clean up supplies.

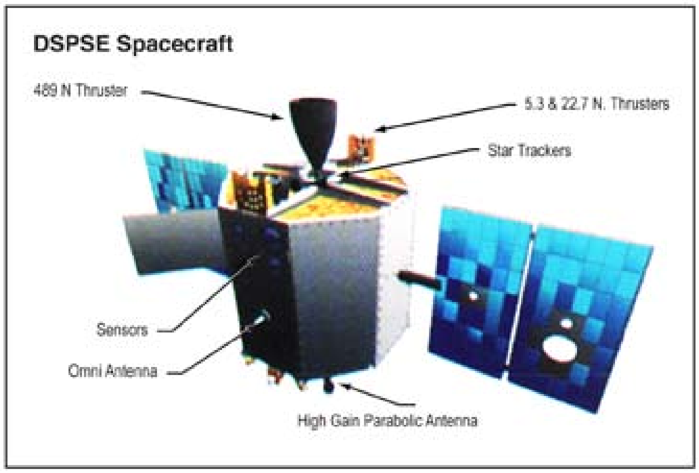
Questions

1. What did you learn about the Pioneer 3 spacecraft that you found interesting?
2. What are the major parts of the spacecraft?
3. What does each part do?
4. What was difficult about making the model?
5. What do you like best about your model?
6. Are there more instruments to do the science or to operate the spacecraft? Why is that?

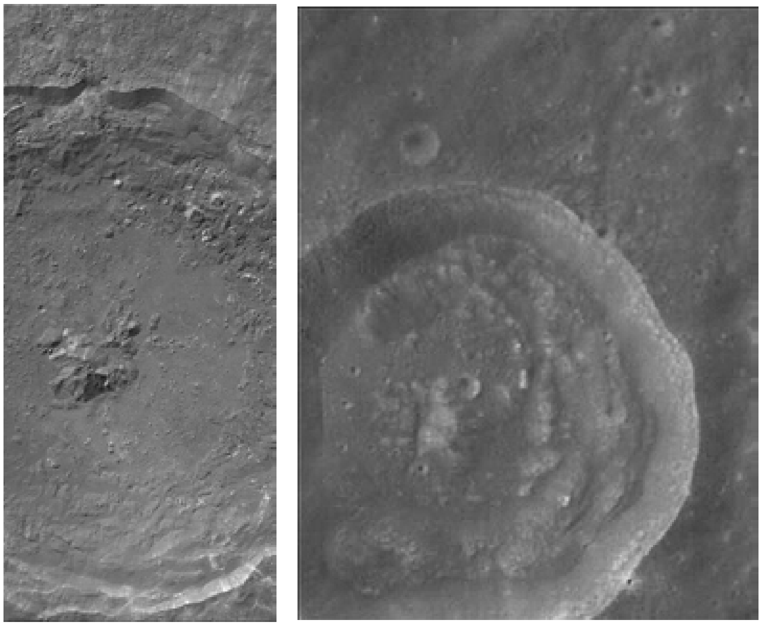
Answer Key/What is Happening?

N/A

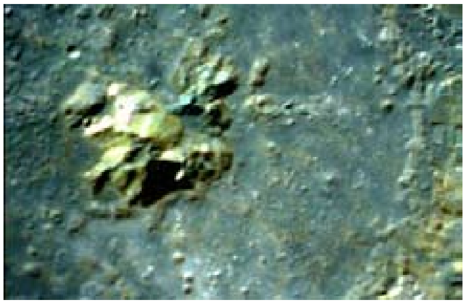
The Clementine Mission



The Clementine mission mapped most of the lunar surface at a number of resolutions and wavelengths from UV to IR. The spacecraft was launched on January 25, 1994. The nominal lunar mission lasted until the spacecraft left lunar orbit on May 3, 1994. Clementine had five different imaging systems on-board. The UV/Visible camera had a filter wheel with six different filters, ranging from 415 nm to 1,000 nm, including a broadband filter covering 400 nm to 950 nm. The Near IR camera also had a six-filter wheel, ranging from 1,100 nm to 2,690 nm. The Long-wave IR camera had a wavelength range of 8,000 nm to 9,500 nm. The Hi-Res imager had a broadband filter from 400 nm to 800 nm and four other filters ranging from 415 nm to 750 nm. The Star Tracker camera was also used for imaging.



The first image at left shows Tycho crater (43S, 12W) from the UV/Visible camera with the 1,000-nm filter. The image was taken on Orbit 40 on Feb. 28, 1994 at an altitude of 425 km. The second image shows Chant crater (40S, 109W, diameter 45 km) from the UV/Visible camera at 900 nm. It was taken on orbit 76 on Mar 8, 1994 at an altitude of 444 km. North is upward in both images.



Color ratio image of the center of Tycho crater.

Source: Clementine (1994) at <http://nssdc.gsfc.nasa.gov./planetary/lunar/clementine1.html>.

Edible Clementine Spacecraft

Overview

Students work individually to build a Clementine spacecraft from edible treats. Each student becomes a specialist, researching the function of each part of the spacecraft.

Purpose

Through a study of the Clementine spacecraft, students will:
- Build an edible model of the Clementine spacecraft.
- Identify the technology used aboard the Clementine spacecraft.

Preparation

1. The day before this activity, have students complete a one-page research summary on the Clementine spacecraft as homework. Access <http://nssdc.gsfc.nasa.gov/planetary/lunar/clementine1.html>.
2. Copy the Clementine photo sheets (see link above) for each student.
3. Fill a baggie with the edible materials listed below for each student.

Materials

Per student:
- Student Data Sheets (CD Location: Educator Resources/Guides/Student Guide)
- 2 figbar type cookies
- 4 Crème Wafers
- 3 jumbo marshmallows
- 10 toothpicks
- 5 gumdrops
- 1 Blow Pop
- 1 small plastic plate
- 1 plastic knife
- Paper towels
- Wet wipes

Procedure

1. Return the Clementine research summaries to each student.
2. Distribute materials. Tell the teams that they will now build a model of the Clementine spacecraft with the furnished materials.
3. Students can use a diagram of the spacecraft and some imagination to add instruments and engineering components onto their spacecraft.
4. Direct students to clean up supplies.

Questions

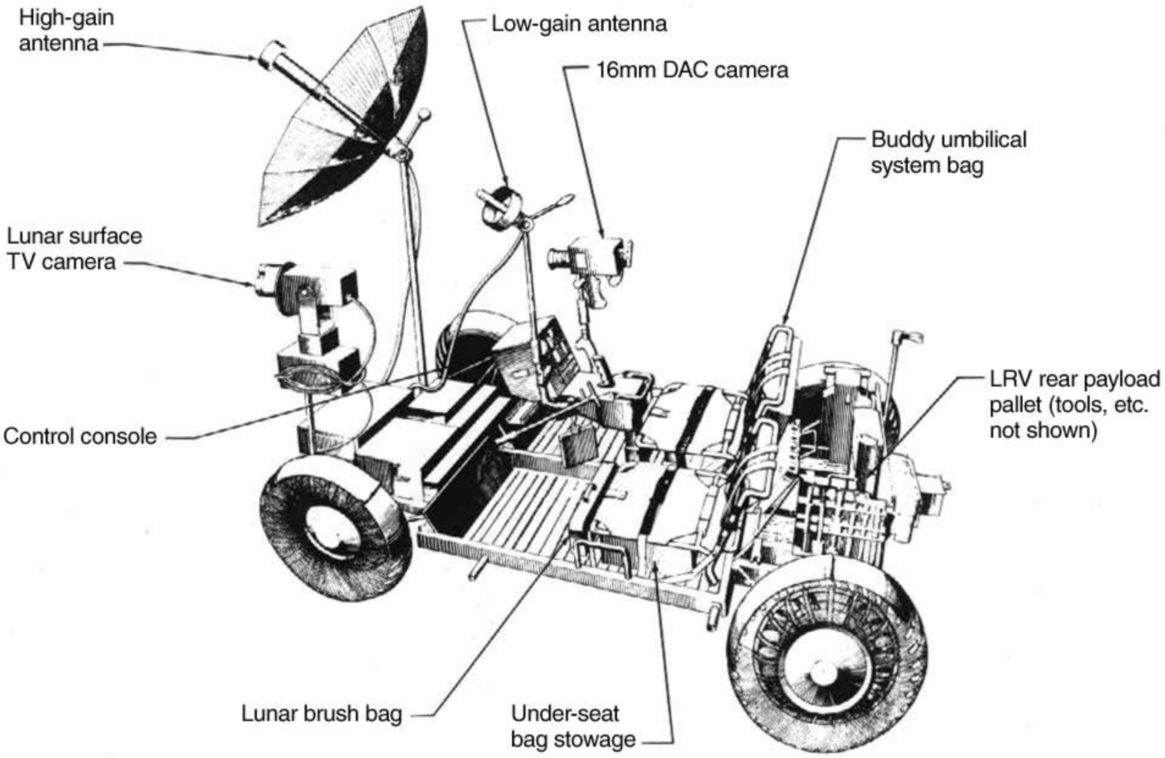
1. What did you learn about the Clementine spacecraft that you found interesting?
2. What are the major parts of the spacecraft?
3. What does each part do?
4. What was difficult about making your model?
5. What do you like best about your model?

Answer Key/What is Happening?

N/A

Lunar Rover

The Apollo Lunar Roving Vehicle (LRV) was an electric vehicle designed to operate in the low-gravity vacuum of the Moon and to be capable of traversing the lunar surface, allowing the Apollo astronauts to extend the range of their surface extravehicular activities. Three LRVs were driven on the Moon, one on Apollo 15, one on Apollo 16 and one on Apollo 17.



Usage

Each rover was used on three traverses, one per day over the 3-day course of each mission. An operational constraint on the use of the LRV was that the astronauts must be able to walk back to the Lunar Module if the LRV were to fail.

Weight and Payload

The LRV had a weight of 201.01 kg and was designed to hold a payload of an additional 489.88 kg on the lunar surface. The frame was 3.05-m long with a wheelbase of 2.29 m. The maximum height was 1.14 m. Fully loaded the LRV had a ground clearance of 35.56 cm. The Lunar Rover had a max payload 3 times that of a family car!

Navigation

Navigation was based on continuously recording direction and distance through use of a directional gyro and odometer and inputting this data to a computer that would keep track of the overall direction and distance back to the LM. There was also a Sun-shadow device that could give a manual heading based on the direction of the Sun, using the fact that the Sun moved very slowly in the sky.

Source: http://en.wikipedia.org/wiki/Lunar_rover

Edible Lunar Rover

Overview

Students work individually to build a Lunar Rover from edible treats. Each student becomes a specialist, researching the function of each part of the rover.

Purpose

Through a study of the Lunar Rover, students will:

- Build an edible model of the Lunar Rover.
- Identify the technology used aboard the Lunar Rover.

Preparation

1. The day before this activity, have students complete a one-page research summary on the Lunar Rover. Access < http://fi.edu/pieces/schutte/LRV.html >.
2. Copy the Lunar Rover photo sheets (see link above) for each student.
3. Fill a baggie with the edible materials listed below for each student.

Materials

Per student:

- Student Data Sheets (CD Location: Educator Resources/Guides/Student Guide)
- 2 sheets of graham crackers (four crackers total)
- 4 Oreos
- 2 jumbo marshmallows
- 4 regular-size marshmallows
- 4 toothpicks
- 2 Starburst fruit chews
- Marshmallow crème or cake icing (small containers or shared jar)
- 1 small plastic plate
- 1 plastic knife
- Paper towels
- Wet wipes
- 2 pretzel rods
- 4 miniature Tootsie Rolls
- 5 gumdrops
- 6 Crème Wafers

Procedure

1. Return the Lunar Rover research summaries to each student.
2. Distribute the materials. Tell the teams that they will now build a model of the Lunar Rover with the materials provided.
3. Students can use a diagram of the Lunar Rover and some imagination to add instruments and engineering components onto their Lunar Rover.
4. Direct students to clean up supplies.

Questions

1. What did you learn about the Lunar Rover that you found interesting?
2. What are the major parts of the Lunar Rover?
3. What does each part do?
4. What was difficult about making your model?
5. What do you like best about your model?

Answer Key/What is Happening?

N/A

Lunar Prospector

Launch Date: January 6, 1998
Launch Vehicle: Athena II
Launch Site: Kennedy Space Center
Launch Mass: 296 kg (fully fueled), 158 kg (dry)
Power System: Body mounted 202-W solar cells and 4.8-amp-hr NiCd Battery

No water was detected from the July 31 crash of Lunar Prospector into the Moon.

The Lunar Prospector was designed for a low-polar orbit investigation of the Moon, including mapping of surface composition and possible polar ice deposits, measurements of magnetic and gravity fields, and study of lunar outgassing events. Data from the 19-month mission allowed construction of a detailed map of the surface composition of the Moon and improved our understanding of the origin, evolution, current state and resources of the Moon. The spacecraft was a graphite-epoxy drum, 1.37 m in diameter and 1.28-m high with three radial instrument booms. It was spin-stabilized and controlled by six hydrazine monopropellant 22-N thrusters. Communications were through two S-band transponders and a slotted, phased-array, medium-gain antenna and omnidirectional, low-gain antenna. There was no on-board computer; ground command was through a 3.6-kbps telemetry link. Total mission cost was about $63 million. After launch, the Lunar Prospector had a 105-hour cruise to the Moon, followed by insertion into a near-circular 100-km altitude lunar polar orbit with a period of 118 minutes. In December 1998, the orbit was lowered to 40 km. The nominal mission ended after 1 year, at which time the orbit was lowered to 30 km. On July 31, 1999, Lunar Prospector impacted the Moon near the south pole in a controlled crash to look for evidence of water ice — none was observed.

Scientific Investigations

Gamma Ray Spectrometer (GRS): G. Scott Hubbard, NASA Ames
Neutron Spectrometer (NS): William Feldman, Los Alamos

The GRS and NS returned global data on elemental abundances, which were used to help understand the evolution of the lunar highland crust and the duration and extent of basaltic volcanism and to assess lunar resources. The NS also located any significant quantities of water ice that existed in the permanently shadowed areas near the lunar poles.

Magnetometer (MAG): Mario Acuna, NASA Goddard; Lon Hood, Univ. of Arizona LPL
Electron Reflectometer (ER): Robert Lin, UC Berkeley SSL

The MAG/ER experiments returned data on the lunar crust's magnetic field and the lunar-induced magnetic dipole. These data helped provide an understanding of the origin of lunar paleomagnetism and the degree to which impacts can produce paleomagnetism. They will also allow constraints on the size and composition of the (possible) lunar core.

Alpha Particle Spectrometer (APS): Alan Binder, Lockheed

The APS instrument was used to find radon outgassing events on the lunar surface by detecting alpha particles from the radon gas itself and its decay product, polonium. Observations of the frequency and locations of the gas release events helped characterize one possible source of the tenuous lunar atmosphere. Determination of the relationship of outgassing sites with crater age and tectonic features was possible. This was, in turn, used to characterize the current level of lunar tectonic activity.

Doppler Gravity Experiment (DGE): Alex Konopliv, NASA Jet Propulsion Laboratory (JPL)

This investigation used doppler tracking of S-band radio signals to characterize the spacecraft orbit and determine the lunar gravity field. This data provided information on the lunar interior and, combined with lunar topographic data, allowed modeling of the global crust's asymmetry, structure and subsurface basin structure. It was also used for planning future lunar missions.

Source: Lunar Prospector at <http://nssdc.gsfc.nasa.gov/planetary/lunarprosp,html>.

Lunar Prospector: Mission Profile

On January 6, 1998, Lunar Prospector blasted off to the Moon aboard a Lockheed Martin solid-fuel, three-stage rocket called Athena II. It was successfully on its way to the Moon for a 1-year, polar orbit, primary mission dedicated to globally mapping lunar resources, gravity and magnetic fields, and even outgassing events. About 13 minutes after launch, the Athena II placed the Lunar Prospector payload into a parking orbit, 115 miles above the Earth. Following a 42-minute coast in the parking orbit, the Prospector's Trans Lunar Injection (TLI) stage successfully completed a 64-second burn, releasing the spacecraft from Earth orbit and setting it on course to the Moon, a 105-hour coast. The official mission timeline began when the spacecraft switched on 56 minutes, 30 seconds after liftoff. Shortly after turning the vehicle on, mission controllers deployed the spacecraft's three extendible masts, or booms. Finally, the spacecraft's five instruments—the gamma-ray spectrometer, alpha particle spectrometer, neutron spectrometer, magnetometer and electron reflectometer—were turned on. On January 11, 1998, Lunar Prospector was successfully captured into lunar orbit, and a few days later began its mission to globally map the Moon.

Lunar Prospector was a small, 1.3-m wide × 1.4-m tall bus with three 2.5-m science masts carrying its five science instruments and isolating them from the spacecraft's electronics. It was a spin-stabilized spacecraft in a polar orbit with a period of 118 minutes at a nominal altitude of 100 km. Since the Moon rotated a full turn beneath the spacecraft every lunar cycle (≈27.3 days) as it zipped around the Moon every 2 hours, Prospector visited a polar region every hour and completely covered the lunar surface twice a month. Prospector's 1-year-long primary mission with an optional extended mission of a further 6 months at an even lower altitude enabled large amounts of data to collect over time. For some science instruments, a significant amount of time was required to obtain high-quality usable data. Thus, Prospector's polar orbit and long-mission time rendered it ideal from the standpoint of globally mapping the Moon.

Source; Mission Profile at <http://lunar.arc.nasa.gov/printerready/science/newresults/mission.html>.

Lunar Prospector Scientific Goals

As a Discovery-class mission, Prospector's scientific goals were carefully chosen to address outstanding questions of lunar science both efficiently and effectively. In the Post-Apollo era, NASA convened the Lunar Exploration Science Working Group (LExSWG) to draft a list of the most pressing, unanswered scientific riddles still facing the lunar-science community. In 1992, LExSWG produced a document, entitled "A Planetary Science Strategy for the Moon." The following lunar science objectives were listed:

- How did the Earth-Moon system form?
- How did the Moon evolve?
- What is the impact history of the Moon's crust?
- What constitutes the lunar atmosphere?
- What can the Moon tell us about the history of the Sun and other planets in the solar system?

Lunar Prospector mission designers carefully selected a set of objectives and a payload of scientific instruments that would address as many of LExSWG's priorities as possible, while remaining within the tight budget confines of NASA's Discovery Program.

Lunar Prospector's identified critical science objectives were:

- Prospect the lunar crust and atmosphere for potential resources, including minerals, water ice and certain gases.
- Map the Moon's gravitational and magnetic fields.
- Learn more about the size and content of the Moon's core.

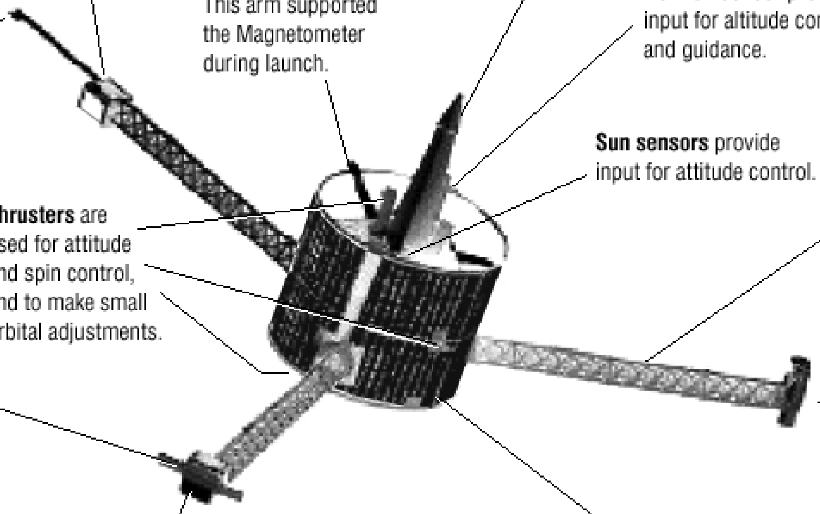
The six experiments (five science instruments) that addressed these objectives were designed to:

- Neutron Spectrometer (NS): Map hydrogen at several signature energies and thereby infer the presence or absence of water.
- Gamma Ray Spectrometer (GRS): Map 10 key elemental abundances, several of which offered clues to lunar formation and evolution.
- Magnetometer/Electron Reflectometer (Mag/ER): These two experiments combined to measure lunar magnetic field strength at the surface and at the altitude of the spacecraft and thereby greatly enhanced understanding of lunar magnetic anomalies.
- Doppler Gravity Experiment (DGE): Make an operational gravity map of the Moon by mapping gravity field measurements from changes in the spacecraft's orbital speed and position.
- Alpha Particle Spectrometer (APS): Map outgassing events by detecting radon gas (current outgassing events) and polonium (tracer of recent events, i.e., 50 years).

Source: Lunar Prospector Scientific Goals at <http://lunar.arc.nasa.gov/NewResults/scientific_goals.html>.

The Lunar Prospector Spacecraft

Lunar Prospector circles the Moon in a polar orbit 100 km above the lunar surface. Traveling about 5,500 km/hr, the craft completes one full trip around the Moon every two hours. Due to the Moon's 28-day rotation, the lunar surface drifts about 26km between each orbit, measured at the equator. Over time, this permits Prospector to collect data from the entire lunar surface. The polar regions shift very little below Prospector's polar orbit.



The Electron Reflectometer is a remote sensing instrument which measures solar electrons reflected from local surface magnetic fields. Combined mass of the Magnetometer and Electron Reflectometer is about 5 kilograms. Together, the two instruments use 4.5 watts of power, and produce 670 bits of data per second.

The Magnetometer is a direct-sensing instrument which measures magnetic fields in the vicinity of the spacecraft. Its location at the end of a boom helps isolate it from the magnectic fields generated by the spacecraft's own electronics.

This arm supported the Magnetometer during launch.

Thrusters are used for attitude and spin control, and to make small orbital adjustments.

The Neutron Spectrometer detects "cool" neutrons: those that have bounced off hydrogen atoms on the lunar surface, providing evidence of water. The instrument's mass is 3.9 kilograms; it consumes 2.5 watts of power and produces 49 bits of data per second.

The Alpha Particle Spectrometer detects alpha particles emitted by radioactive gases, such as radon and polonium, leaking ou of the lunar interior. The instrument's mass is 4 kilograms; it consumes 7 watts of power and produces data at a rate of 181 bits per second.

Communications antennas Low-gain (top) and medium-gain antennas mounted here receive commands and frequency referencesignals "up" from Earth, and provide science data back "down" to Earth via NASA's Deep Space Network.

Horizon sensor provides input for altitude control and guidance.

Sun sensors provide input for attitude control.

The Doppler Gravity Experiment uses the communications system to improve current models of the Moon's gravitational field. It does this by measuring minute variations in the spacecraft's speed. The Moon has more anomalies in its gravitational field than the Earth does; the crust is thicker on the far side of the Moon.

Extendable Booms support the science instruments at a distance from the spacecraft, to provide unobstructed "views," and reduce interference from onboard systems. The booms are made of fiberglass, and were coiled inside cannisters in the spacecraft before launch.

Solar Panel consists of thousands of interconnected photovoltaic cells on a cylindrical shape. They convert sunlight directly into electricity to power the spacecraft's systems. The panel also offers shade for thermal control.

The Gamma Ray Spectometer maps abundances of ten elements on the Moon's surface: thorium, potassium, uranium, iron, oxygen, silicon, aluminum, calcium, magnesium, and titanium. The instrument's mass is 8.6 kilograms; it uses 3 watts of power, and produces data at a rate of 688 bits per second.

Assembled Lunar Prospector Space Craft™ SCIENCE KIT depicted.

Edible Lunar Prospector Spacecraft

Overview

Students work individually to build a Lunar Prospector spacecraft from edible treats. Each student becomes a specialist, researching the function of each part of the Lunar Prospector spacecraft.

Purpose

Through a study of the Lunar Prospector spacecraft, students will:

- Build an edible model of the Lunar Prospector spacecraft.
- Identify the technology used aboard the Lunar Prospector spacecraft.

Preparation

1. Copy the Lunar Prospector fact sheet for each student. Access <http://lunar.arc.nasa.gov/> and <http://nssdc.gsfc.nasa.gov/planetary/lunarprosp.html>.
2. Fill a baggie with edible materials listed below for each student.

Materials

Per student:

- Student Data Sheets (CD Location: Educator Resources/Guides/Student Guide)
- 6 jumbo marshmallows
- 14 toothpicks
- 3 pretzel rods
- 3 gumdrops
- 1 Starburst fruit chew
- 2 JUJYFRUITs
- 1 peppermint stick
- 1 small plastic/paper plate
- 1 small plastic knife
- Paper towels
- Wet wipes
- Construction paper
- Plastic gloves (optional)

Procedure

1. Have a student pass out a copy of the Lunar Prospector fact sheets to each student.
2. Team members will work a jigsaw technique with the parts of the spacecraft where each team member becomes the “expert” for one or more parts of the spacecraft. They are to read about the part on the fact sheet and then share their information with the group.
3. Distribute the bags of materials. Tell the teams that they will now build a model of the Lunar Prospector spacecraft with the materials provided.
4. Students can use a diagram of the spacecraft and some imagination to add instruments and engineering components onto their spacecraft.
5. Once the spacecraft is built, they will need to label the parts using toothpicks and construction paper labels.
6. Make a class presentation about how the spacecraft operates during the mission. Have the teams share their spacecraft models with each group, explaining one part and its function to the class.
7. Direct students to clean up supplies.

Questions

1. What did you learn about the Lunar Prospector spacecraft that you found interesting?
2. What are the major parts of the spacecraft?
3. What does each part do?
4. What was difficult about making your model?
5. What do you like best about your model?
6. Are there more instruments on Lunar Prospector to do the science or to operate the spacecraft? Why is that?

Lunar Reconnaissance Orbiter

NSSDC ID: LUNARRO
Other Names: LRO
Launch Date: October 1, 2008
Launch Vehicle: Delta II or possibly Atlas V or Delta IV
Launch Site: Kennedy Space Center
Launch Mass: Fully fueled—1,000 to 1,200 kg; Dry—500 to 600 kg
Power System: About 400 W by solar arrays and stored in lithium-ion battteries

The Lunar Reconnaissance Orbiter (LRO) is a Moon-orbiting mission scheduled to launch in the fall of 2008. The first mission of NASA's Robotic Lunar Exploration Program, it is designed to map the surface of the Moon and characterize future landing sites in terms of terrain roughness, usable resources and radiation environment with the ultimate goal of facilitating the return of humans to the Moon. The following measurements are listed as having the highest priority:

- Characterization of deep space radiation environment in lunar orbit.
- Geodetic (geodesic-line) global topography.
- High spatial resolution hydrogen mapping.
- Temperature mapping in polar shadowed regions.
- Imaging of the lunar surface in permanently shadowed regions.
- Identification of possible deposits of appreciable near-surface water ice in polar cold traps.
- Assessment of meter-scale and smaller scale features for landing sites.
- Characterization of polar region lighting environment.

A primary goal of the mission is to find landing sites suitable for in situ resource utilization.

Preliminary plans call for the LRO to be launched from Kennedy Space Center in October 2008 on a Delta II (2925-10), but this could be upgraded to a 2925H-10, an Atlas V or a Delta IV. It will take 4 days to reach the Moon and enter an initial orbit with a periselene altitude of 100 km, which will then be lowered. The mission is expected to last for 1 year in a 30-km to 50-km altitude lunar polar orbit. An extended mission of up to 5 years in a higher altitude low-maintenance orbit may follow. The satellite is expected to have a launch mass of about 1,000 kg to 1,200 kg, with 500 kg to 600 kg of this being propellant. The platform will be three-axis stabilized and power of about 400 W will be provided by solar arrays and stored in lithium-ion batteries. Communications will be via S-band for uplink and low-rate downlink and Ka-band for high-rate downlink (100 Mbps to 300 Mbps).

Source: LRO at <http://nssdc.gsfc.nasa.gov/database/MasterCatalog?sc=LUNARRO>.

The spacecraft will have the capability of carrying about 100 kg of scientific payload that will be composed of the following:

- A high-resolution (1-meter-or-better) camera to acquire images of small scale landing site hazards and document lighting conditions at the lunar poles.
- A laser altimeter to measure landing site slopes and search for polar ices.
- A neutron detector to search for water ice and characterize the space radiation environment.
- A radiometer to map the temperature of the lunar surface to identify cold traps and possible lunar ice deposits.
- A Lyman-alpha mapper to observe the lunar surface in UV, looking for surface ices and frosts and imaging permanently shadowed regions.
- A cosmic ray telescope to investigate background space radiation.

NASA has also signed an agreement with the U.S. National Reconnaissance Office to cooperate on the development of a miniature synthetic aperture radar sensor to map the Moon's surface. Total payload power requirement is estimated at 100 W. The total estimated cost for the mission is roughly $460 million.

Robots Versus Humans

Overview

When spacecraft are sent into space to study far off places, the spacecraft, its systems and instruments are an extension of the engineers and scientists back on Earth. Many functions and senses of the human body are emulated in spacecraft.

Purpose

Through a study of the LRO spacecraft, students will:

- Understand functions of spacecraft systems and instruments.
- Identify spacecraft technology with human functions.

Preparation

1. Reproduce Student Data Sheets from the Lunar Nautics CD:
2. Reproduce Student and Educator Guide as transparencies:
3. Obtain an overhead projector for use.

Materials

Per student:

- Student Data Sheets (CD Location: Educator Resources/Guides/Student Guide)
- Transparencies of LRO Fact Sheet and the Definition of a Robot (CD Location: Educator Resources/Guides/Educator Guide) and Component Functions Table (CD Location: Educator Resources/Guides/Student Guide)
- Overhead projector
- Erasable transparency markers
- Chart paper
- Magic markers
- Scissors

Procedure

Part I: What is a Robotic Spacecraft?

1. Group students into teams.
2. Have a student pass out a copy of the LRO fact sheets, Component Functions Table and Robot Versus Humans Student Sheets to each group or individual.
3. Ask students to record a group definition of a robot on a piece of paper. One person in the group should record the definition and another should report the definition to the whole class.
4. Have each group post and report their definition of a robot. Record the key words from the definitions on chart paper or a blackboard.
5. Inform students that a robot designed to explore space is called a spacecraft.
6. Ask students what capabilities or features they would recommend for a robot that would be sent into space to explore another planet. List their responses for later comparison. If needed, guide students by suggesting an analogy with human capabilities, such as movement, senses, communication, thinking, etc.
7. Have students work in groups to discuss and predict the humanlike function of each of the parts.
8. Instruct students to design a spacecraft with components, as seen or of their own design, in a logical configuration on a sheet of paper.
9. Instruct students to label each of the spacecraft components with its name as well as the predicted humanlike function. Have the students give their robot a name.
10. Have the students in each group display their design to the whole class.

11. Quickly review the various student designs. Ask students if they would like to share the rationale for their designs.
12. Ask students what they would like to know about spacecraft. List their questions on chart paper or blackboard.

Part II: Making the Connections to the Lunar Reconnaissance Orbiter

1. Display a transparency of the LRO Component Functions Table.
2. Explain that the students will use their LRO Component Functions Table to predict the function of each component. Members of each group should take turns drawing symbols on the LRO, and move clockwise around the spacecraft.
3. After student groups have completed the LRO diagram with their symbols, display a transparency of the teacher's completed diagram. Using the diagram transparency and the Definition of a Robot transparency, review the form and function of each major part of the LRO robot.
4. Discuss the students' discoveries about the LRO spacecraft in light of what they wanted to know about a robotic spacecraft. Guide students to reflect on what the LRO spacecraft is designed to do, and on how the key components of LRO's technological design will enable it to carry out that mission. Discuss whether or why each component is essential to the success of the mission.

Questions

1. What are the five human senses? (Sight, Taste, Smell, Sound and Touch)
2. What are some of the main systems of the body? (Skeletal, Muscular, Digestive, Circulatory, Respiratory, Urinary, Reproductive, Nervous, Endocrine and Sensory)
3. How is a spacecraft a robot?
4. Does the robot that you designed have humanlike capabilities?
5. What would you hope to discover with your robot?
6. What questions would your robot help scientists answer?

Answer Key/What is Happening?

N/A

The Definition of a Robot

When asked what a robot is, students often come up with images of fictional devices like C3PO, which walks with a human gait and talks with a British accent in the Star Wars movies. Another robot candidate is the one in the movie *Artificial Intelligence*. Such Hollywood-generated robots are shaped more or less like humans and they communicate like humans. Students tend not to think of washing machines or spacecraft like Voyager or LRO as robots; but these are classic examples of what is meant by a robot.

Definition of a robot: A programmable and/or remotely controlled machine, capable of performing or extending humanly performed tasks, often in environments that are too hazardous for humans or in situations that are too repetitious or tedious for humans.

Robots like Voyager, Pathfinder and LRO are extensions of human senses, not only in terms of operating in a remote, hostile environment like outer space, but also in terms of sensing in ways that humans cannot (e.g., detecting magnetic fields or seeing in the IR or UV portions of the electromagnetic spectrum).

Lunar Reconnaissance Orbiter Component Functions

Spacecraft (body/torso/skeleton)
The bus is the core structure (or framework) to which bus spacecraft components are attached. This is made out of aluminum, the same metal used in soft-drink cans.

Computers (brain)
Computers manage a variety of intelligent functions such as navigation and propulsion, storing information from scientific instruments and sending information to Earth.

Spacecraft cameras (eyes)
Lunar Reconnaissance Orbiter Camera (LROC) will collect very detailed pictures of possible future landing sites and places for habitats. The camera's pictures will help scientists learn about different lunar soils.

High-gain/low-gain antennas (ears and mouth)
Receivers and transmitters are used for communication between the spacecraft and Earth-based controllers. The antennae hear and speak for the spacecraft.

Thermal Control (sweat glands)
Mechanism that dissipates heat generated from the spacecraft out into space.

Solar Arrays (food and drink)
These are the source of energy for instruments and transmitters. The solar power is then stored in the onboard battery.

Orientation thrusters (dancing feet or legs)
These are small rocket thrusters that are used for delicate maneuvers that rotate the spacecraft. This is useful for aiming instruments and pointing the antennae toward Earth.

Instruments (e.g., hands, tongue, nose, etc.)

Cosmic Ray Telescope for the Effects of Radiation: Cosmic Ray Telescope for the Effects of Radiation (CRaTER) measures radiation. It will test special shielding that could be used to protect bases and spacecraft from radiation. Radiation can be very harmful to people; we have to know the amount of radiation in different places on the Moon so that we can live and work there safely and for a long time.

Lyman Alpha Mapping Project: Lyman Alpha Mapping Project (LAMP) will use UV light that is reflected off the Moon's surface from starlight. Using this tiny bit of light, scientists can look into places that regular cameras cannot see into — places like very deep craters that are always in the shadows. These places are protected from the Sun's heat and radiation — which means they are very cold — and they may have hidden ice.

Magnetometer Boom (Extended Arm): This is an 11-meter-long arm extending from the spacecraft. There are instruments in the middle and on the end of it that are used to detect and measure magnetic fields.

Lunar Orbiter Laser Altimeter: Lunar Orbiter Laser Altimeter (LOLA) will send harmless laser beams to the Moon's surface. The beams will bounce back to LOLA and can be used to make a map of the entire surface — a map that shows scientists features as small as 0.48 m across. LOLA will help scientists figure out how smooth or rough the surface is and if ice is there — because different surfaces cause laser beams to scatter in different ways.

Source: based on NASA's Saturn Educators Guide

Edible Lunar Reconnaissance Orbiter Spacecraft

Overview

Students work individually to build a LRO spacecraft from edible treats. Each student becomes a specialist, researching the function of each part of the spacecraft.

Purpose

Through a study of the LRO spacecraft, students will:
- Build an edible model of the LRO spacecraft.
- Identify the technology used aboard the LRO spacecraft.

Preparation

1. The day before this activity, have students complete a one-page research summary on the LRO as homework. Access <http://directory.eoportal.org/pres_LROLunarReconnaissanceOrbiterLCROSS.html>.
2. Copy the LRO photo sheets (see link above) for each student.
3. Fill a baggie with the materials listed below for each student.

Materials

Per student:
- Student Data Sheets (CD Location: Educator Resources/Guides/Student Guide)
- 5 Crème Wafers
- 1 individual graham cracker (one-half of a sheet)
- 2 Starburst fruit chews
- 2 pieces of candy corn
- 2 individual skittles (a pack can be divided among students)
- 1 Tootsie roll
- 1 jumbo marshmallow
- 3 pretzel sticks
- Marshmallow crème or icing (small containers or shared jar)
- 1 small paper/plastic plate
- 1 plastic knife
- Paper towels
- Wet wipes

Procedure

1. Distribute the LRO research summaries to each student.
2. Distribute the materials. Tell the teams that they will now build a model of the LRO spacecraft with the materials provided.
3. Students can use a diagram of the spacecraft and some imagination to add instruments and engineering components onto their spacecraft.
4. Direct students to clean up supplies.

Questions

1. What did you learn about the LRO spacecraft that you found interesting?
2. What are the major parts of the spacecraft?
3. What does each part do?
4. What was difficult about making your model?
5. What do you like best about your model?

Answers/What is Happening

N/A

Design Concepts and Challenges

This section provides concept and design activities to enhance the core skill of the Lunar Nautics mission.

Design and Engineering — Defines design and engineering design team process and technology design process.

Rocket Staging: Balloon Staging — Examines the staging of rockets.

Pop Bottle Rocket — Investigates designing, building and testing a model rocket.

Lunar Landing: Swinging Tray — Explores how gravity affects orbiting and landing spacecraft.

Lunar Base Supply Egg Drop — Examines teamwork in designing, building and testing a vehicle for lunar supply drops.

Robots and Rovers: Rover Relay — Investigates communications in space.

Rover Race—Explores teamwork in designing, building and testing a lunar rover/miner.

Spacesuits: Potato Astronaut — Investigates how the layers of a spacesuit protect an astronaut.

Bending Under Pressure — Examines how pressure affects astronauts in their spacesuits and how joints are made moveable.

Spacesuit Designer — Investigates the designing, building and testing of a spacesuit arm to provide astronauts with maximum range of motion.

Solar Power: Solar Energy — Examines how photovoltaics work and are influenced by external factors.

Solar Oven — Explores solar power in the designing, building and testing of a solar powered oven.

Microgravity/Come-Back Bottle — Investigates how toys act on Earth and in free fall.

Microgravity Sled — Examines teamwork, organization, communication and problem solving in building a lunar prospecting sled in a microgravity simulation.

Design and Engineering

Research indicates that cooperative learning methods—having students work in small groups—can help them learn concepts and skills. Using official engineering job titles will enhance the experience. Teams of three or four students will work best. If you have three students per team, one will have the combined role of facilities engineer and developmental engineer.

Tips for forming and implementing design teams:

- It takes time and practice for students to function well in teams. An activity to introduce them to team roles is suggested as a way to enhance team success.
- Students should know and understand the roles of everyone on the team.

Project Engineer (PE):

- Checks the team's work.
- Asks the instructor questions.
- Leads team discussions.
- Is in charge of safety.

Developmental Engineer (DE):

- Is in charge of getting the design completed.
- Leads construction.
- Makes the supply list.
- Approves the design after construction.

Facilities Engineer (FE):

- Collects the supplies and equipment.
- Directs cleanup.
- Returns supplies and equipment.
- Makes sure to use only what is needed.

Test Engineer (TE):

- Records all information.
- Makes sure written reports are completed.
- Fills out forms of any kind for the team.
- Makes team reports to the rest of the group.

General Responsibilities:

- Students should accept their roles and know their responsibilities.
- Students should be willing to accept direction from other team members.
- Students need to understand that they can share responsibilities with other team members. For example, the facilities engineer may ask other team members to help him/her collect or return supplies. The facilities engineer is ultimately responsible for all supplies, but is not the only team member who can obtain or return them.
- Keep teams together for the entire length of the Lunar Nautics project.
- Try to mix ability and gender groups as much as possible.
- Rotate the engineering roles within a team on a fair and equitable basis.
- Ensure that all group members are using the building materials and activities are hands-on. Do not let any student opt out of science and technology activities.

The Technological Design Process

There are five steps in the technological design process. They are as follows:

1. **Identify appropriate problems**: Students should develop their abilities by identifying a specified need, considering its various aspects and talking to potential users or beneficiaries.

2. **Design a solution or product**: Students should make and compare different proposals in light of selected criteria. They should consider constraints such as costs, time, trade-offs and materials needed, and communicate ideas using drawings and simple models.

3. **Implement a proposed design**: Students should organize materials and other resources, plan their work, collaborate when appropriate, choose suitable tools and techniques, and use appropriate measurement methods to ensure accuracy.

4. **Evaluate completed designs or products**: Students should use relevant criteria, consider various factors that might affect acceptability/suitability for intended users or beneficiaries and develop related quality measures. They also should suggest improvements and, for their own products, try proposed modifications.

5. **Communicate the technological design process**: Students should review and describe any completed piece of work and identify the stages of problem identification, solution design, implementation and evaluation.

Source: Forming and Implementing Design Teams. A World in Motion, The Engineering Society for Advancing Mobility Land Sea Air and Space (SAE International) Abilities of Technological Design. National Science Education Standards, National Research Council, 1996, National Academy Press.

Rocket Staging: Balloon Staging

Overview

Traveling into outer space takes enormous amounts of energy. This activity is a simple demonstration of rocket staging that Johann Schmidlap first proposed in the 16th century.

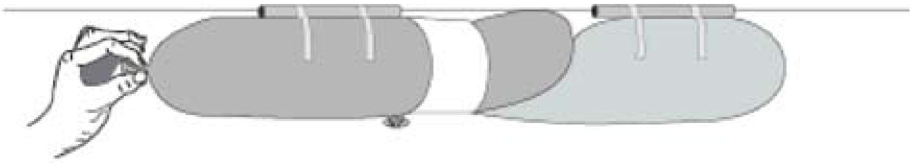
Purpose

Through participation in this demonstration, students will:

- Learn how rockets can achieve greater distances by using the technology of staging.

Preparation

- Gather all materials.



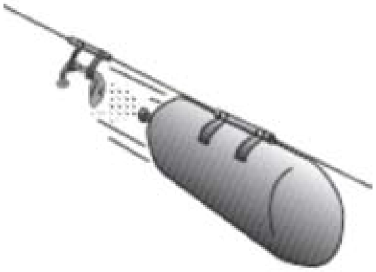
Materials

Per class:

- Student Data Sheets
  (CD Location: Educator Resources/Guides/Student Guide)
- 2 long, party balloons
- Nylon monofilament fishing line (any weight)
- 2 plastic straws (milkshake size)
- Styrofoam coffee cup
- Masking tape
- Scissors
- 2 spring clothespins

Procedure

1. Thread the fishing line through the two straws. Stretch the fishing line snugly across a room and secure its ends. Make sure the line is just high enough for people to pass safely underneath.
2. Cut the coffee cup in half so that the lip of the cup forms a continuous ring.
3. Stretch the balloons by preinflating them. Inflate the first balloon about three-fourths full of air and squeeze its nozzle tight. Pull the nozzle through the ring. Twist the nozzle and hold it shut with a spring clothespin. Inflate the second balloon. While doing so, make sure the front end of the second balloon extends through the ring a short distance. As the second balloon inflates, it will press against the nozzle of the first balloon and take over the clip's job of holding it shut. It may take a bit of practice to achieve this. Clip the nozzle of the second balloon shut also.
4. Take the balloons to one end of the fishing line and tape each balloon to a straw with masking tape. The balloons should point parallel to the fishing line.
5. Remove the clip from the first balloon and untwist the nozzle. Remove the nozzle from the second balloon as well, but continue holding it shut with your fingers.
6. If you wish, conduct a rocket countdown as you release the balloon you are holding. The escaping gas will propel both balloons along the fishing line. When the first balloon released runs out of air, it will release the other balloon to continue the trip.
7. Distribute design sheets and ask students to design and describe their own multistage rocket.
8. Collect and display student designs for multistage rockets. Ask each student to explain his/her rocket to the class.



Questions

1. Can a two-stage balloon fly without the fishing line as a guide? How might the balloons be modified to make this possible?
2. How might other launch arrangements such as side-by-side balloons and three stages work?

Answer Key/What is happening?

When a lower stage has exhausted its load of propellants, the entire stage drops away, making the upper stages more efficient in reaching higher altitudes. In the typical rocket, the stages are mounted one on top of the other. The lowest stage is the largest and heaviest. In the Space Shuttle, the stages attach side by side. The solid rocket boosters attach to the side of the external tank. Also attached to the external tank is the Shuttle orbiter. When exhausted, the solid rocket boosters jettison. Later, the orbiter discards the external tank as well.

Source: Rockets: An Educator's Guide with Activities in Science, Mathematics, and Technology EG-2003-01-108-HQ.

Soda Bottle Rocket

Objective

To construct and launch a simple soda bottle rocket.

Purpose

Working in teams, students will:

- Construct a simple bottle rocket from 2-liter soft drink bottles and other materials.
- Understand how air pressure works with action/reaction.
- Develop skills in teamwork, communication and problem solving.

Preparation

1 Begin saving 2-liter bottles several weeks in advance to have a sufficient supply for your class.
2. Order rocket launching materials including at least one bottle rocket launcher, launch pad base, predrilled 2-liter bottles, and a bike pump. Obtain one from a science or technology education supply catalog. See Resources section of Lunar Nautics CD.
3. Secure a safe launch location. You should clear an area of at least 30.48 m in all directions from the launch pad. The center of an athletic field is a good choice.
4. Secure Internet access.
5. Preassemble the rocket launcher.
6. A test launch is highly recommended before attempting the activity with students.
7. Provide glue guns for each table or set up glue stations in various parts of the room.
8. Collect a variety of decorative materials before beginning this activity so students can customize their rockets. When the rockets are complete, test fly them.
9. In group discussion, have your students create launch safety rules that everybody must follow. Include how far back observers should stand, how many people should prepare the rocket for launch, who should retrieve the rocket, etc.

Materials

Per class:

- Student Data Sheets (CD Location: Educator Resources/Guides/Student Guide)
- 2-liter plastic soft drink bottles
- Low-temperature glue guns
- Poster board
- Duct tape
- Modeling clay
- Scissors
- Safety Glasses
- Decals
- Stickers
- Marker pens
- Launch pad/bottle rocket launcher
- Bicycle pump with pressure gauge

Procedure

1. Wrap and glue or tape a tube of poster board around the bottle.
2. Cut out several fins of any shape and glue them to the tube.
3. Form a nose cone and hold it together with tape or glue.
4. Press a wad of modeling clay into the top of the nose cone.
5. Glue or tape nose cone to upper end of bottle.
6. Decorate your rocket.
7. When all rockets are complete, it is time to launch.
8. Have students fill their rockets with their chosen amount of water. Note: Some water may be lost when the rocket is placed on the launch pad. Bring extra water in case of spillage or for multiple launches.
9. Head to the launch site.
10. Print and Design staff: See <http://quest.nasa.gov/space/teachers/rockets/act11ws1.html>.
11. Quality of construction
    (Score the quality of construction on a scale from 1 (poor quality) to 5 (top quality):

Quality Elements	Score
a. Alignment of fins	_____
b. Attachment of fins to bottle	_____
c. Straightness of nose cone	_____
d. Neatness of construction	_____
e. Overall construction	_____
f. Total	_____

12. Evaluate the performance of each rocket. Scoring will be as follows (Longest Flight = Highest Flight):
    - a. First Place = 5 points
    - b. Second Place = 4 points
    - c. Third Place = 3 points
    - d. Fourth Place = 2 points
    - e. Fifth Place = 1 point
13. Compare the altitude the rockets reach with their design and quality of the construction.

Questions

1. What is the purpose of the nose cone?
2. What is the purpose of fins?
3. Describe the effect that more/less water has on the upward movement and distance of the rocket?

Answer Key/What is Happening?

The nose cone is an extension of the bottle. It comes in a variety of shapes and is used to improve the aerodynamics of the rocket.

A finless bottle can be launched as a rocket but will tumble, thereby encountering much more drag than a bottle that can be kept facing nose forward. The use of fins along with the addition of nose mass can produce aerodynamically stable rockets that pass through the air in a straight line.

Newton's Third Law of Motion states, that for every action there is an equal and opposite reaction. In launching a pop-bottle rocket, the action is the water and air pressure escaping downward through the nozzle. This causes the equal and opposite reaction of the upward movement of the rocket.

Extensions

1. Challenge rocket teams to invent a way to attach a parachute to the rocket that will deploy on the rocket's way back down.
2. Parachutes for bottle rockets can be made from a plastic bag and string. The nose cone is merely placed over the rocket and parachute for launch. The cone needs to fit properly for launch or it will slip off. The modeling clay in the cone will cause the cone to fall off, deploying the parachute or paper helicopters, after the rocket tilts over at the top of its flight.
3. Extend the poster board tube above the rounded end of the bottle. This will make a payload compartment for lofting various items with the rocket. Payloads might include streamers or paper helicopters that will spill out when the rocket reaches the top of its flight. Copy and distribute the page on how to make paper helicopters. Ask the students to identify other possible payloads for the rocket. If students suggest launching small animals with their rockets, discuss the purpose of flying animals and the possible dangers if they are actually flown.
4. Conduct flight experiments by varying the amount of air pressure and water to the rocket before launch. Have the students develop experimental test procedures and control for variables.

Lunar Landing: Swinging Tray

Overview

Knowing that gravity is responsible for keeping satellites in orbit leads us to the question, why do astronauts appear to float in space? The answer is simple; the Space Shuttle orbiter falls in a circular path about Earth and so does everything in it. Students will learn that gravity acts as a centripetal force and how spacecraft can orbit the Earth or other planets.

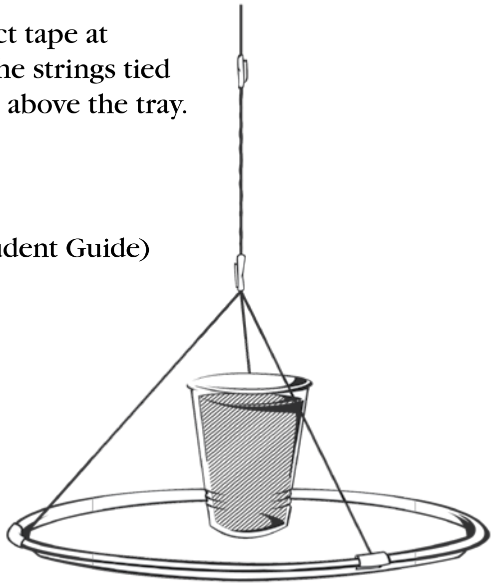
Purpose

Through participation in this demonstration, students will:

- Learn that gravity acts as a centripetal force that keeps satellites in orbit and controls the path of the Moon.

Preparation

1. Gather all materials.
2. Attach strings to the edge of the metal pizza tray securely with duct tape at three triangular points. (Holes can also be drilled in the tray and the strings tied through the holes.) The strings should all come together at a point above the tray.



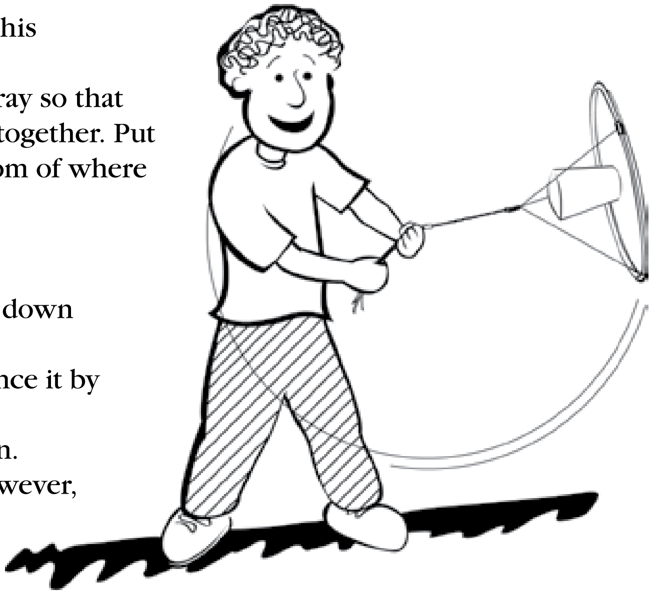
Materials

Per team:

- Student Data Sheets (CD Location: Educator Resources/Guides/Student Guide)
- Metal pizza tray
- String
- Duct tape
- Plastic cup
- Water
- Food coloring
- Hard hat
- Safety glasses

Procedure

1. Conduct this demonstration outdoors and have the students stand far enough back so that they are a safe distance away from the demonstrator.
2. Wear a hard hat and safety glasses while conducting this demonstration.
3. Hold the pizza tray by the strings and spin the pizza tray so that about 15.24 cm to 20.32 cm of the strings are wound together. Put pieces of tape on the strings to hold the top and bottom of where it is wound. Set aside.
4. Put a few drops of food coloring in the water.
5. Fill the plastic cup with water.
6. Ask the students if it is possible to get the cup upside down without spilling the water.
7. Place the water cup in the center of the tray and balance it by holding the strings.
8. Carefully, begin swinging the tray in a circular fashion. The water should stay in the cup as it is swinging; however, when the swinging motion is stopped, the water will spill out.



Questions

1. What do we call the path that the tray moves in? (We call the path an orbit.)
2. If the strings are held at a shorter distance to the tray, shortening the tray's orbit, what happens to the speed of the tray? (The speed increases when the tray's orbit is shorter.)
3. Pulling on the string is acting as a force called? (Centripetal.)
4. What would happen if the centripetal force in this experiment were removed by cutting the string? (The tray would fly out of its orbit in a direction tangent to the orbital path.)

Answer Key/What is happening?

When you spin the tray in a circle, the tray is held in its orbit by the string. You must constantly pull on the string to keep the tray from flying off in a straight line. The force you apply to the tray through the string is the centripetal force.

Similarly, for a satellite that is in orbit around the Earth, it is the Earth's gravity that exerts a centripetal force on the satellite that prevents it from flying off into space. The Earth's gravity pulls on the satellite like you pull on the string to keep the tray traveling in circular motion.

The Moon is a satellite orbiting the Earth, and the Earth is a satellite circling the Sun. The Earth's gravity also keeps the Moon in orbit, and the Sun's gravity keeps the planets orbiting around it.

Source: Toys in Space II and various other sources.

Lunar Base Supply Egg Drop

Overview

Although attempts will be made to make any future lunar base as self-sufficient as possible, it will likely need periodic resupply from Earth. This can be achieved more cheaply and efficiently with a passive style landing of a supply payload. The lack of atmosphere on the Moon will prevent the use of devices such as parachutes or aerobrakes to slow the descent of the payload. Even in the reduced gravity of the Moon (about one-sixth that of Earth), the design of the payload package is critical to the successful resupply of the base in that it must ensure that much needed supplies arrive intact.

Purpose

The purpose of this activity is for team members to demonstrate their abilities of technological design. This activity is intended as an introduction to:

- Cooperative learning teams and the roles team members will play.
- Steps of the design process that are used to meet a challenge.

Preparation

1. Gather all materials and make copies of the Lunar Base Supply Egg Drop Student Sheets.
2. Research indicates that cooperative learning methods—having students work in small groups—can help them learn concepts and skills. Using official engineering job titles will enhance the experience. Teams of three or four will work best. If you have three students per team, one will have the combined role of facilities engineer and developmental engineer (see role cards).

Materials

Per team:

- Student Data Sheets (CD Location: Educator Resources/Guides/Student Guide)
- Eggs
- Scissors
- Cups
- Straws
- Paper towels
- Cotton balls
- Plastic bags
- Bubble wrap
- 17.78-cm round balloons (limit three per team)
- String
- Drop cloth
- Role Cards
- Masking tape (about 60.96 cm per team)

Note: Specific construction materials can vary as long as all teams have equal access to materials.

Procedure

1. Set the scene properly before you bring up the topic of the egg drop. The discussion should center around the problems of a passive landing on the Moon without the ability to use aerobrakes or parachutes to slow the vehicle.
2. Introduce the challenge. This is an exercise using one's ingenuity to package a delicate object (the egg represents the payload) to withstand impact. Their task is to design and construct a package for the raw egg payload that will allow the raw egg payload to be recovered unharmed (both the shell and yolk should be intact) when dropped from a second story (height of at lest 9.144 m).
3. The package can measure no larger than 20.32 × 20.32 × 20.32 cm.
4. Divide the class into teams.
5. Distribute role badges and explain the responsibilities of each team.
6. Distribute Student Sheets and discuss the steps of the design process.
7. Students should use the Student Sheets to guide the design process.
8. Each team must sketch its container. Because there is no atmosphere on the Moon, no drag devices can be part of the package. The instructor must eliminate any such devices from the design before approval is given.
9. After design and construction is complete, drop the package from the given altitude.
10. Recover packages and bring them to a central location for opening and evaluation.
11. Examine the contents of the packages to determine the various levels of success.
12. Scoring will be as follows:
    a. Shell intact: complete success = 5 points
    b. Shell broken, yolk intact: partial success = 3 points
    c. Shell broken, yolk broken: mission failure = 1 point
13. Discuss the results as a class.

Questions

1. How many teams had complete success with their payload drop? Partial success?
2. What structures worked well?
3. What structures did not work well?
4. How would you redesign your package based on the lesson you have learned?

Answer Key/What is Happening?

The materials used to surround the egg payload act like airbags and cushion the payload. Materials can also be used to create a suspension that protects the payload. Much like crumple zones in a car protect the occupants, some of the external wrapping materials can absorb impact to protect the payload.

Robots and Rovers: Rover Relay

Overview

Scientists want to search for signs of water and other useful resources on the Moon for a permanent lunar base. Often a robot or rover vehicle is sent in that can move on the surface of the Moon, study the area, locate rocks, and collect samples for analysis.

In order for a rover to navigate on the Moon, it must understand commands given to it from Earth. Commands will take from 2 seconds to 10 seconds to reach the rover once the command is sent. It will take another 2 seconds to 10 seconds for confirmation to reach Earth from the rover. The Rover Relay will attempt to let the students experience the difficulty involved in communicating commands to a rover, waiting for the rover to perform the commands and receiving confirmation.

Purpose

Through participation in this demonstration, students will:

- Play the game.
- Experience and appreciate the difficulty involved in a time delay.
- Problem solve ways to deal with the communication problems.

Preparation

1. Gather all materials.
2. This game should be played outdoors on a large field so the teams have room to spread out and operate their robots. The class will be divided evenly into relay teams and each team will stand in a straight line. There should be ample distance between teams. The teacher will lay out objects for each team (one object for each team member) in a random pattern. Each team should have the same objects and the objects should have similar placement for each teams.

Materials

Per team:

- Objects to retrieve (e.g., cloth, jump rope, ball, traffic cones, yardstick, etc.)

Procedure

1. The first person in line is the robot.
2. The last person in line is mission control.
3. The other people in line represent the time delay.
4. All teams begin at the same time.
5. When the teacher says Begin, mission control decides on an object to have the robot retrieve. Mission control needs to decide what commands need to be given to the robot, one command at a time, in order to have the object retrieved.
6. Mission Control whispers one command to the person next to them, that person repeats whispering the message to the person in front of them, and so forth until the command reaches the robot.
7. The robot performs the command and tells the person behind him or her that he or she has done so. That person informs the person behind him or her, and so on, until the message reaches mission control.
8. Mission control sends another command in the same manner.
9. When the robot has retrieved the object, he or she goes to the end of the line and becomes mission control. The person at the head of the line now becomes a new robot.
10. Repeat until all objects have been retrieved.

Questions

1. When the game is over, return to the classroom and discuss what happened. How could your team improve its directions to the robot? What are the implications for a rover on the Moon? What are the similarities and differences?
2. Discuss what things worked for communicating effectively and efficiently with your robot. What are things that scientists and engineers need to consider in order to communicate with a rover on the Moon?

Answer Key/What is Happening?

Great distance presents a time delay communication problem.

Adapted from NASA IITA Program and Washington University's Sojourner "Rover Relay"

Rover Race

Overview

Lunar rocks and minerals are very important to the construction and long-term viability of a lunar base. Vehicles will be specifically designed to mine, collect and transport useful materials. These vehicles must be tested for their feasibility, versatility and reliability.

Purpose

Through the building and testing of a lunar rover/miner, students will:

- Understand the importance of design and testing.
- Develop skills in teamwork, communication and problem solving.

Preparation

1. Gather all materials.
2. Copy the Rover Race Student Sheets.
3. Set up a lunar terrain obstacle course approximately 1.83 m by 0.91 m using books, rocks, blocks, boxes, pencils, etc. Mark boundaries of the course with masking tape.
4. At the end of the course, put a pile of mixed rocks and a nearby collection area marked off with masking tape.

Materials

- Student Data Sheets (CD Location: Educator Resources/Guides/Student Guide)
- LEGO, ROBOTIX, K'NEX or other robotic systems to create a moving lunar rover/miner
- Materials for lunar terrain obstacle course (i.e., books, rocks, blocks, etc.)
- Masking tape to mark boundaries of obstacle course
- Two types of rocks that are visually distinct from each other

Procedure

1. Review the robotic materials available and their use.
2. Hand out Rover Race Student Sheets.
3. Ask students to create a rover/miner that is able to traverse lunar terrain and sort rocks. (You may choose to allow students to see the course prior to rover/miner construction. Students should not be allowed to make changes to their rover/miner while waiting their turn on the obstacle course.)
4. Designate one type of rock the "target rock," perhaps the mineral ilmenite, iron titanium oxide, which could provide construction materials and oxygen.
5. Establish appropriate time penalties for driving out of bounds, physically moving the rover with remote connection cords or hands, and for getting the wrong type of rocks in the collection area. Inform students of said penalties.
6. Teams must traverse the obstacle course and sort three samples of the target rock into the collection area. One student drives (the test engineer), and others may give instructions.
7. Time each team's obstacle course run. You may want to put a time limit on each run.
8. Criteria:
    a. Rover/miner must travel over the surface of the Moon.
    b. Rover/miner must sort three samples of a designated material (target rock) and transfer them to a specified collection area.
9. Scoring will be as follows (robot is timed):
    a. Robot meets all criteria and has fastest time = 5 points.
    b. Robot meets all criteria with second fastest time = 4 points.
    c. Robot meets all criteria with third fastest time = 3 points.
    d. Robot meets at least two criteria = 2 points.
    e. Robot meets at least one criterion = 1 point.

Questions

1. Did you take into account the lunar terrain when designing your vehicle?
2. How would your vehicle fare in the lunar regolith?
3. How will your rover/miner sort and move the rocks? Pick up? Scoop? Push?

Answer Key/What is Happening?

Testing under all conceivable conditions of terrain, environmental factors and system failures is crucial for the success of any design.

Spacesuits: Potato Astronaut

Overview

Astronauts on spacewalks need spacesuits for impact protection; that is because they are likely to encounter fast-moving particles called meteoroids. A meteoroid is usually a fragment of an asteroid consisting of rock and/or metal. It can be very large with a mass of several hundred metric tons, or it can be very small — a micrometeoroid, which is a particle smaller than a grain of sand. Micrometeoroids are usually fragments from comets. Every day, Earth's atmosphere is struck by millions of meteoroids and micrometeoroids. Most never reach the surface because they are vaporized by the intense heat generated by the friction of passing through the atmosphere. It is rare for a meteoroid to be large enough to survive the descent through the atmosphere and reach solid Earth. If it does, it is called a meteorite.

In space, there is no blanket of atmosphere to protect spacecraft from the full force of meteoroids. It was once believed that meteoroids traveling at velocities up to 80 kilometers per second would prove a great hazard to spacecraft. However, scientific satellites with meteoroid detection devices proved that the hazard was minimal. It was learned that the majority of meteoroids are too small to penetrate the hull of spacecraft. Their impacts primarily cause pitting and sandblasting of the covering surface.

Spacecraft debris has become of great concern to spacecraft engineers. Thousands of space launches have left many fragments of launch vehicles, paint chips and other space trash in orbit. Most particles are small, but they travel at speeds of nearly 8,000 meters per second. These space-age particles have become a significant hazard to spacecraft and to astronauts on extra vehicular activities (EVAs).

Engineers have protected spacecraft from micrometeoroids and space trash in a number of ways, including thick-wall construction and multilayer shields consisting of foil and hydrocarbon materials. A micrometeoroid striking a multilayer shield disintegrates into harmless gas that disperses on inner walls. Spacesuits provide impact protection through various fabric-layer combinations and strategically placed rigid materials.

Although effective for particles of small mass, these protective strategies do little if the particle is large. It is especially important for spacewalking astronauts to be careful when they repair satellites or do assembly jobs on the International Space Station. A lost bolt or nut could damage a future space mission through an accidental collision. (Note: A low orbit tends to be clearer of particles than higher orbits because low-orbit particles tend to decay and burn up in the atmosphere.)

Purpose

Through participation in this demonstration, students will:

- Investigate the relationship between velocity and penetration depth.
- Explore how layered materials protect astronauts.

Preparation

- Gather all materials.

Materials

Per class:

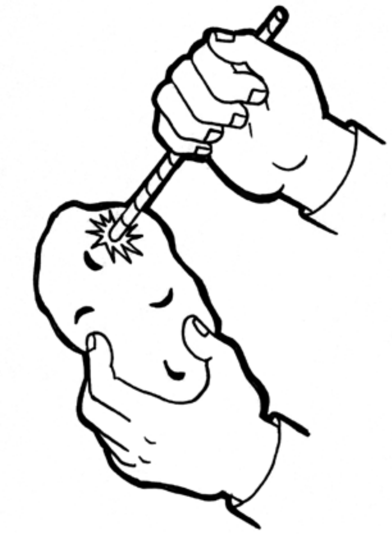
- Chair
- PVC pipe (≈2.44 m in length, ≈1.27 cm in diameter)
- Large nail
- Latex glove
- 1 sheet of Mylar
- 1 sheet of Kevlar
- 2 rubber bands
- Clip

Per team:

- Student Data Sheets (CD Location: Educator Resources/Guides/Student Guide)
- Plastic (milkshake-size) straw
- Potato
- Various materials to layer (e.g., tissue paper, notebook paper, handkerchiefs, rubber bands, napkins, aluminum foil, wax paper, plastic wrap, etc.)

Procedure

1. Lay potato on the ground.
2. Show PVC pipe. Stand on chair, rest pipe on potato and drop nail down pipe.
3. Lift pipe and show nail in potato.
4. Put potato into latex glove, blow up the glove and secure it with the clip.
5. Wrap potato in Mylar.
6. Wrap potato in Kevlar and finish with a rubber band to keep layers together.
7. Lay potato on the floor. Stand on chair with pipe and nail in hand. Rest pipe on potato and drop nail down pipe.
8. Unwrap potato and show to students.
9. Have students hold a raw potato in one hand (see illustration). While grasping the straw with the other hand, stab the potato with a slow motion. Observe how deeply the straw penetrates the potato.
10. Repeat the experiment, but this time stab the potato with a fast motion. Observe how deeply the straw penetrates the potato. Compare observations with the results of step 9.
11. Challenge the students to think of ways to protect the potato from damage caused by impacts using just the materials available in the classroom, adding one layer at a time.
12. Test the new method for protecting a potato. Conduct a discussion to evaluate technologies developed. Refine the constraints for a protection system (e.g., the thickness of the materials used).
13. Have students redesign their system based on the refined constraints. Conduct additional impact tests with the straw.



Safety Precautions

The audience should remain at a safe distance just in case the nail deflects from the Kevlar. Do not leave props unsupervised.

Be careful to hold the potato as illustrated so that the straw does not hit your hand. Work gloves will provide additional protection.

Questions

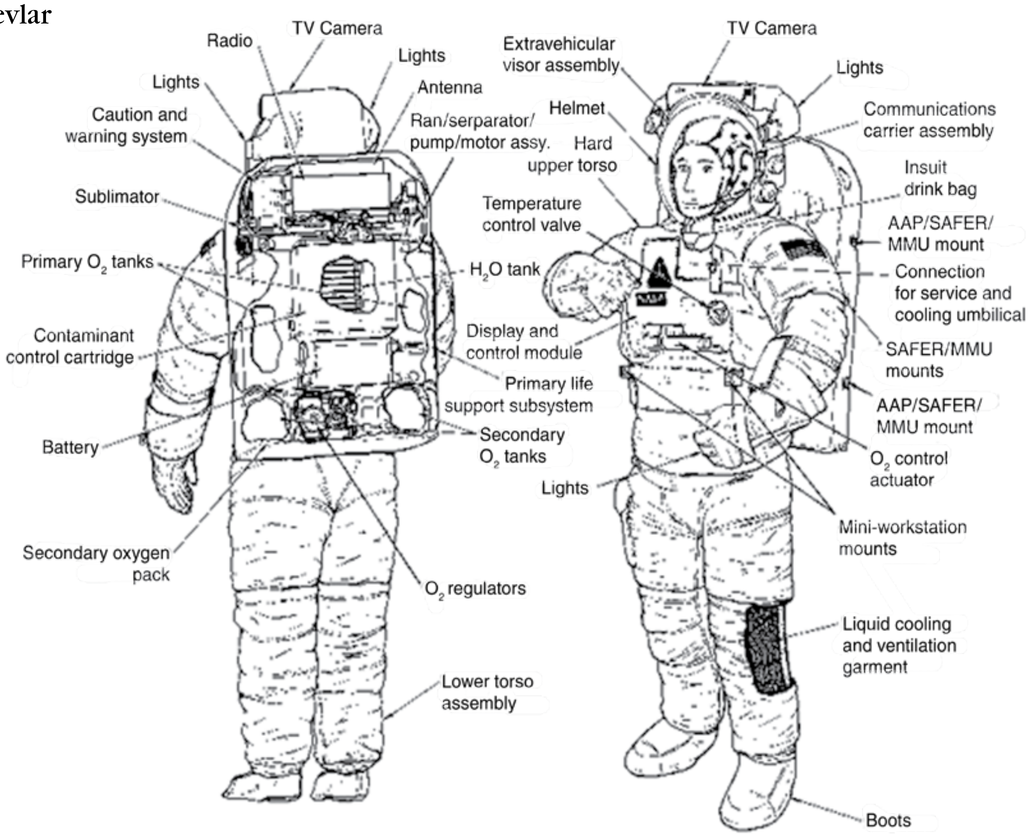
1. How do technologies for protecting astronauts from micrometeoroid and space debris impacts compare to other protective technologies? Can you name other protective garments or devices (e.g., bullet-proof vests, suits of armor, shields on power tools and windshields on vehicles)?
2. How does the function determine the form (e.g., motorcycle helmet—provides protection during crash, reduces aerodynamic drag, comfortable to wear, protects face from bug and rock impacts, etc.)?

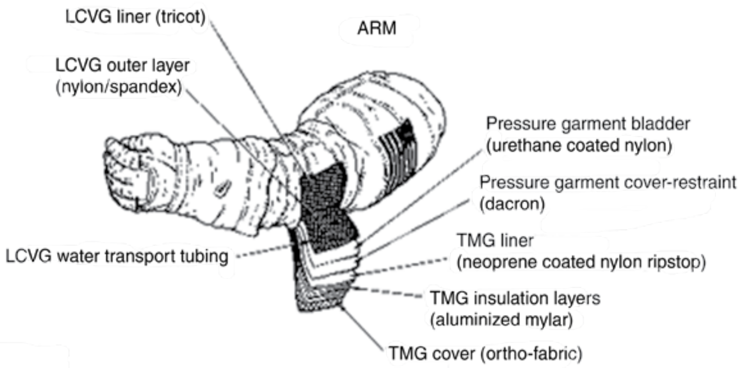
Answer Key/ What is Happening?

The effects of high-speed micrometeoroid impacts on an astronaut are simulated with a potato (astronaut) and the nail and straw (micrometeoroid).

The Shuttle Extravehicular Mobility Unit (EMU) has 14 layers to protect astronauts on EVAs. The inner layers comprise the liquid-cooling-and-ventilation garment. First comes a liner of nylon tricot over which is a layer of spandex fabric, laced with plastic tubing. Next comes the pressure bladder layer of urethane-coated nylon and fabric layer of pressure restraining Dacron®. Above the bladder and restraint layer is a liner of neoprene coated nylon ripstop. This is followed by a seven-layer thermal micrometeoroid garment of aluminized Mylar, laminated with Dacron scrim. The outer layer of the suit is made of Orth-Fabric, which consists of a blend of Gortex®, Kevlar and Nomex® materials.

Source: NASA Quest





Bending Under Pressure

Overview

Maintaining proper pressure inside a spacesuit is essential to astronaut survival during a spacewalk. A lack of pressure will cause body fluids to turn to gas, resulting in death in a few seconds.

While making spacewalks possible, pressure produces its own problems. An inflated spacesuit can be very difficult to bend. In essence, a spacesuit is a balloon with an astronaut inside. The rubber of the balloon keeps in oxygen that is delivered to the suit from pressurized oxygen tanks in the backpack. But, as pressure inside the balloon builds up, the balloon's walls become stiff, making normal bending motions impossible. Lack of flexibility defeats the purposes of the spacewalk : mobility and the ability to do work in space.

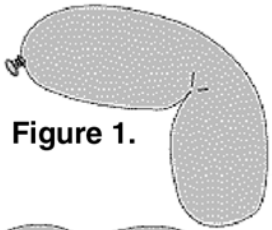


Figure 1.

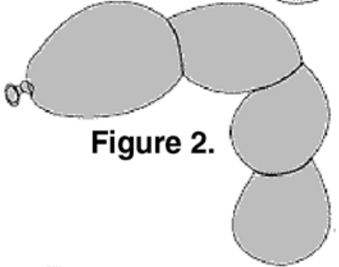


Figure 2.

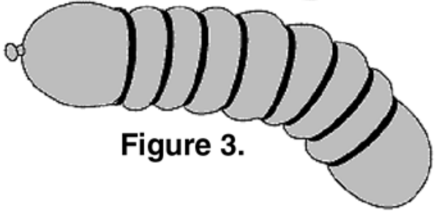


Figure 3.

Purpose

Through participation in this demonstration, students will:

- Observe how an external joint in a spacesuit arm segment increases bendability of the segment.

Preparation

- Gather all materials.

Materials

Per team:

- Student Data Sheets (CD Location: Educator Resources/Guides/Student Guide)
- 2 long balloons
- Three heavy-duty rubber bands
- Slinky

Procedure

1. Inflate a long balloon and tie it off. The balloon represents the pressure bladder of a spacesuit arm. Let students try to bend the balloon in the middle (see fig. 1).
2. Inflate a second long balloon. As you are inflating the balloon, slip heavy-duty rubber bands over the balloon at intervals so that, as inflation continues, the balloon is pinched by the rubber bands. It is easier to accomplish this by preinflating the balloon. It may be necessary to double the rubber band to pinch the balloon enough for the demonstration (see fig. 2).
3. Have students compare the force required for bending this balloon with the force needed for the first balloon.
4. Use a Slinky as an alternative to the rubber bands. Place the Slinky on a desktop and pick up one end. Slip in the balloon and inflate it. As the balloon inflates, it will be pinched in a spiral pattern by the Slinky. The pattern will achieve the same result as the rubber bands (see fig. 3).

Questions

1. What other items are inflated (e.g., air mattresses, inner tubes, beach balls, etc.)?
2. How do you think that these other inflatables might compare to the balloon as you try to bend them?

Answer Key/What is Happening?

Spacesuit designers have learned that strategically placed breaking points at appropriate locations outside the pressure bladder (the balloon-like layer inside a spacesuit) makes the suit become more bendable. The breaking points help form joints that bend more easily than unjointed materials. Other techniques for promoting bending include stitching folds that spread apart and contract with bending into the restraint layer and building joints into the restraint layer like ribs on vacuum cleaner hoses.

Source: NASA Quest

Spacesuit Designer

Overview

In spite of many decades of experience in developing and evaluating spacesuits, they are still fatiguing to wear. The internal pressure of the suit creates resistance to movements of the arms, hands and legs. The exhaustion factor of spacesuits can be mitigated somewhat by ensuring that the suit fits properly. It is essential that the suit's joints precisely match the position of the astronaut's joints. During the extended exploration of the Moon that will take place from a lunar base, spacesuit fit will be more important than ever.

To avoid the expensive and time-consuming process of creating custom-made suits for astronauts, as NASA did during the Apollo missions, suits with interchangeable parts are used. Different size upper and lower torsos are available, but arm and leg lengths are still difficult to match. NASA has solved this problem by creating sizing inserts that are added or removed from the restraint layer in the arms and legs to achieve the right fit. Selecting the right combination of rings provides the best fit possible.

Purpose

Through construction of a spacesuit arm, students will:
- Understand the importance of proper fit for spacesuits.
- Develop skills in teamwork and problem solving.

Preparation

1. Gather all materials.
2. Cut 10.16-cm diameter PVC into segments measuring 25-mm, 50-mm, 75-mm and 100-mm long (see materials list for number of segments per team).
3. Divide students into teams of three or four.
4. Make copies of Spacesuit Designer Student Sheets.

Materials

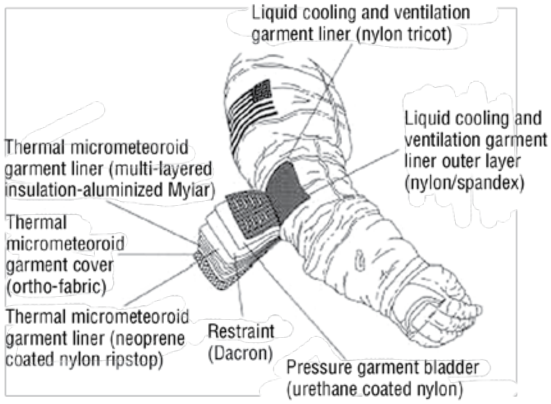
Per team.
- Student Data Sheets (CD Location: Educator Resources/Guides/Student Guide)
- 10.16-cm diameter PVC cut into segments of the following lengths:
  - 25 mm: four
  - 50 mm: four
  - 75 mm: four
  - 100 mm: four
- Vinyl clothes-dryer hose (25 cm)
- Duct tape
- Measuring tape
- Scissors
- Thick rubber gloves
- Wire cutters
- Role cards

Procedure

1. Distribute role cards and student sheets.
2. Explain importance of well-fitting spacesuits. (See overview.)
3. Tell the students to select one member of their team to serve as the astronaut. It should be someone with good range of motion.
4. Their objective is to fit a suit arm that provides maximum range of motion, excellent fit and maximum comfort to that astronaut.
5. Distribute the PVC rings, dryer hose, gloves, measuring tape, duct tape and scissors to each group. Wire cutters may be necessary if teams decide to use less than the 25 cm of dryer hose that is provided.
6. The students should begin by measuring the arm and mapping the range of motion of the arm without the suit.
7. How many instructions you give for the actual construction of the spacesuit arm is up to you. Useful tips are:
    a. Use two of the 50-mm segments with the clothes dryer hose to create the elbow; fitting the hose ends over one end of each of the segments.
    b. Slip the cuff of one of the gloves over a 50-mm pipe segment. The fit may be tight, but try to slide the ring in so that it just reaches the position of the wrist. Trim off the excess of the cuff so that the glove can be affixed to the ring with duct tape.
    c. PVC rings are joined with duct tape.
8. After completing the arm, the group should test it by placing the astronaut's arm into the suit arm. They will then evaluate the arm by repeating the range of motion tests.
9. Final adjustments and changes can be made to improve comfort and range of motion before evaluation by the instructor.
10. Evaluate each group on range of motion, fit, workmanship and overall quality of design.

Questions

1. What other measurements were useful for creating a good fit?
2. How many measurements do you think would be required to design an entire spacesuit?
3. How would the lower gravity condition of the Moon affect the fit of the spacesuit?



Answer Key/What is Happening?

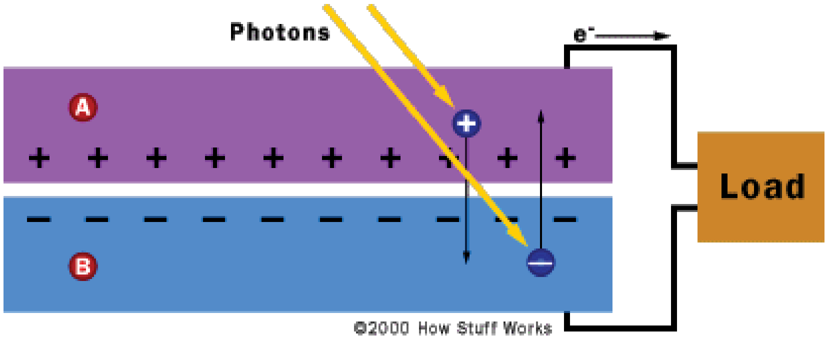
NASA takes over 100 measurements to ensure a good fit for each astronaut's spacesuit.
Most astronauts are 2-cm to 3-cm taller in space, because of the lack of compression of the spine.
Thigh circumference will decrease due to fluid shift to the upper torso.

Adapted from Getting the Right Fit. Source: NASA Quest

Solar Power: Solar Energy

Overview

Photovoltaics is the direct conversion of light into electricity at the atomic level. Some materials exhibit a property known as the photoelectric effect that causes them to absorb photons of light and release electrons. When these free electrons are captured, an electric current results that can be used as electricity. Photovoltaic or solar cells are made of silicon (sand). Solar cells are used to power calculators, watches, lights, refrigerators, and even cars. Solar electricity is quiet, clean and nonpolluting.



©2000 How Stuff Works

Figure 1

Solar cells are made of the same kinds of semiconductor materials used in the microelectronics industry. For solar cells, a thin semiconductor wafer is specially treated to form an electric field, positive on one side and negative on the other (fig. 1). When light energy strikes the solar cell, electrons are knocked loose from the atoms in the semiconductor material. If electrical conductors are attached to the positive and negative sides, forming an electrical circuit, the electrons can be captured in the form of an electric current (i.e., electricity. This electricity can then be used to power a load, such as a light or a tool.

A number of solar cells electrically connected to each other and mounted in a support structure or frame is called a photovoltaic module (fig. 2). Modules are designed to supply electricity at a certain voltage, such as a common 12-V system. The current produced is directly dependent on how much light strikes the module.

Multiple modules can be wired together to form an array (fig. 3). In general, more electricity will be produced from a module or array having a larger area. Photovoltaic modules and arrays produce direct-current (DC) electricity. They can be connected in both series and parallel electrical arrangements to produce any required voltage and current combination.

Figure 2

Purpose

Through participation in this demonstration, students will:

- Learn how a photovoltaic cell generates electricity.
- Discover how the intensity of light sources can alter current and voltage, and therefore light output.
- Explore how different light filters affect current and voltage, and therefore light output.
- Explore how the angle at which a solar cell is positioned in relation to the Sun affects its power output.

Preparation

- Assemble materials.
- The solar cells can be connected by the students or be connected ahead of time.

Figure 3

Materials

Per team:

- Student Data Sheets (CD Location: Educator Resources/ Guides/Student Guide)
- 4 0.55-V solar cells with leads
- Short lengths of 22-gauge wire
- 8 to 10 small alligator clips
- 1 red light emitting diode (LED)
- 1 multimeter capable of measuring voltages below 5 volts and current below 1 amp
- 1 reflector light socket (lamp)
- 5 light bulbs (i.e., 15 W, 40 W, 60 W, 75 W and 100 W)
- 1 20-ohm, 0.5-W resistor
- Several pieces of cellophane of various colors
- Screens of different mesh sizes and materials
- Translucent material such as wax paper
- Clear material such as a plate of glass or plastic

Procedure

- To connect the solar cells in series, connect them as as follows:
  - Connect the negative (black) lead from cell # 2 to the positive (red) lead of cell # 1.
  - Connect the negative (black) lead from cell # 3 to the positive (red) lead of cell #2.
  - Connect the negative (black) lead from cell # 4 to the positive (red) lead of cell #3.
  - Connect the positive (red) lead of cell # 4 to one end of the 20-ohm resistor.
- To measure voltage across the LED, connect the multimeter, LED and solar cells as follows:
  - Connect the negative (black) lead from the LED to the negative (black) lead of the multimeter. Connect the positive (red) lead from the LED to the positive (red) lead of the multimeter. Connect the negative (black) lead of cell # 1 to the negative (black) leads of the LED/multimeter combination.
  - Set the control switch of the multimeter to VDC and a range of at least 5 volts.
  - Connect the unconnected lead of the 20-ohm resistor to the positive (red) leads of the LED/multimeter combination.
  - Place a light bulb in the reflector lamp and shine it on the solar cells. Be sure to keep the reflector at a constant distance from the solar cells.
  - Observe and record the voltage indicated on the multimeter.
  - Repeat the above experiment using different wattage light bulbs. Different wattage light bulbs produce a different number of lumens of light.
- To measure current through the LED, connect the multimeter, LED and solar cells as follows:
  - Connect the negative (black) lead from the LED to the negative (black) lead of the multimeter.
  - Connect the positive (red) lead from the LED to the unconnected lead of the 20 ohm resistor.
  - Set the control switch of the multimeter to OHMs and a range of 1 amp.
  - Connect the negative (black) lead of cell # 1 to the positive (red) lead of the multimeter.
  - Place a light bulb in the reflector lamp and shine it on the solar cells. Be sure to keep the reflector at a constant distance from the solar cells.
  - Observe and record the current indicated on the multimeter.
  - Repeat the above experiment using different wattage ight bulbs. Different wattage light bulbs produce a different number of lumens of light.

- Perform the following variations to the voltage and current experiments:
  - Measure the voltage and current. What is the relationship of lumens to the current output of the solar cell?
  - Experiment with angles of the light to the solar cells.
  - Experiment with the distance of the light to the solar cells.
  - Experiment by using different watt bulbs.
  - Place each cover material (i.e., colored cellophane, screening, wax paper, glass or clear plastic) over the solar cells. Observe and record results.

Questions

1. What happens when the light source is turned away from the photovoltaic cells?
2. What do you think will happen with the light source at different angles from the photovoltaic cells?
3. What happens when the light source is at different distances from the photovoltaic cells?
4. What happens when different watt bulbs are used to shine on the photovoltaic cells?
5. What do you think will happen when different materials cover the photovoltaic cells?
6. List the materials used and what happened to the voltmeter/LED when each was used.

Answer Key/What is Happening?

Students might observe, for example, that the angles of the lamp affect the solar cell output and apply this to the angles of the Sun during the day and in different seasons. Students also might observe, for example, that darker colors reduce available Sunlight reaching the solar cells and thus reduce output. Screening with larger mesh allows more Sunlight to pass through to the solar cells than smaller mesh. How might this concept be applied to the effect of clouds or shading on photovoltaic system output?

Series connected: A method of connection in which the positive terminal of one device is connected to the negative terminal of another. The voltages add and the current is limited by the source voltage and amount of resistance in the string.

Parallel connected: A method of connection in which positive terminals are connected together and negative terminals are connected together. Current output adds when more batteries are added but the voltage remains the same (only if all batteries have the same voltage).

Note: Solar cells, resistors and LEDs can be obtained from an electronics store.

Solar Oven

Overview

One of the biggest challenges in establishing a lunar base is to supply it with adequate power. Although various power sources have been proposed and are under consideration, there is no question that solar power will play a significant role.

Purpose

Through the construction and testing of a solar oven, students will:

- Understand the importance of solar energy to the establishment of a lunar base.
- Develop methods to maximize solar power efficiency.
- Develop skills in teamwork, communication and problem solving.

Preparation

1. Gather all materials and make copies of the Solar Oven Challenge Student Sheets
2. Research indicates that cooperative learning methods—having students work in small groups — can help them learn concepts and skills. Using official engineering job titles will enhance the experience. Teams of three or four will work best. If you have three students per team, one will have the combined role of facilities engineer and developmental engineer (see role cards).

Materials

Per team:

- Student Data Sheets (CD Location: Educator Resources/Guides/Student Guide)
- 1 3.79-liter plastic milk container
- Scissors and/or razor knives
- Aluminum foil
- Wire coat hanger (untwisted)
- Plastic wrap
- Hot dog
- Cotton balls
- Cotton batting
- Construction paper (assorted colors with plenty of black available)
- Cardboard
- Wire cutters
- Masking tape
- Books or other objects that can be used to prop up the oven at the proper angle
- Role cards
- Watch or clock with second hand

Note: With the exception of the milk container, aluminum foil, wire coat hanger, plastic wrap and hot dog, specific construction materials can vary as long as all teams have equal access to materials.

Procedure

1. Introduce the challenge. The object is to use the available materials to build the most efficient solar oven, able to cook a hot dog in the least amount of time.
2. Divide the class into teams.
3. Distribute role badges and explain the responsibilities of each team.
4. Distribute Student Sheets and discuss the steps of the design process.
5. Students should use the Student Sheets to guide the design process.
6. Provide students with directions to build a basic solar oven and encourage them to modify and expand upon the basic plan as they see fit (these directions are included in the Student Sheets).

Basic Solar Oven Instructions

1. Using scissors and leaving the mouth of the container intact, cut away the side of the milk container with the handle.
2. Line the inside of the milk container with aluminum foil. Try to keep the foil as smooth as possible and avoid wrinkles.
3. Untwist the coat hanger and cut a section approximately 30.48 cm in length.
4. Push one end of the wire through the bottom of the milk container using the scissors to cut a hole if necessary.
5. Skewer the hot dog with the wire and pass the wire through the mouth of the container.
6. Cover the open part of the oven with plastic wrap.
7. Remind students that these are only the directions to build a basic solar oven and they are free to alter and expand upon these plans to make the most efficient solar oven possible.
8. Allow teams a predetermined amount of time to construct their ovens (approximately 30 minutes should be sufficient).
9. After construction is complete, have all teams bring their oven to a designated area in the Sun. Teams should use books and other objects to prop the ovens at an angle that allows them to receive direct Sunlight.
10. Teams may adjust their ovens during cooking.
11. The instructor will determine when the hot dogs are completely cooked. The team whose oven completely cooks the hot dog in the shortest time wins. Depending on the weather, where you live and the time of year, cooking times may range from 10 minutes to 30 minutes. Obviously, this activity works better on hot, Sunny days.
12. Points will be awarded as follows:
    a. Hot dog cooked in shortest time = 5 points.
    b. Hot dog cooked in next shortest time = 4 points.
    c. Hot dog cooked in next shortest time = 3 points.
    d. Hot dog cooked in next shortest time = 2 points.
    e. Hot dog cooked in next shortest time = 1 point.
13. Discuss the results as a class.

Questions

1. What role did the aluminum foil play in the solar oven?
2. What modifications from the basic design increased the efficiency of the oven?
3. What modifications did not prove effective?
4. How would you redesign your oven based on the lessons you have learned?

Answer Key/What is Happening?

As the rays of the Sun hit the reflective surfaces inside the oven, they will be concentrated on the hot dog.

The plastic wrap traps some of the heat inside the oven.

Additional insulation around the outside of the oven, but not blocking the Sun, can increase the efficiency of the oven.

Microgravity: Come-Back Bottle

Overview

The ability to store and reuse energy has been very important to the development of technology for civilization. This experiment will really get you rolling as you observe the interplay of kinetic and potential energy.

Purpose

Through participation in this demonstration, students will:

- Compare how toys act in free fall and on Earth.
- Observe Newton's First, Second and Third Laws.
- Observe kinetic and potential energy.

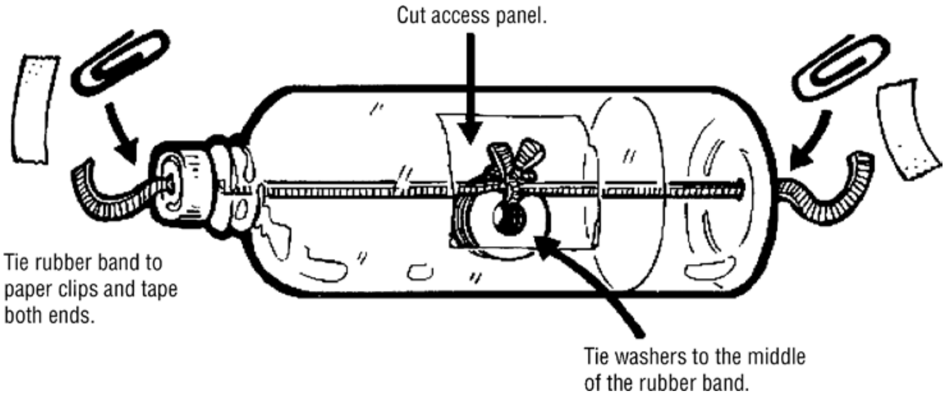
Preparation

- Gather all materials.

Materials

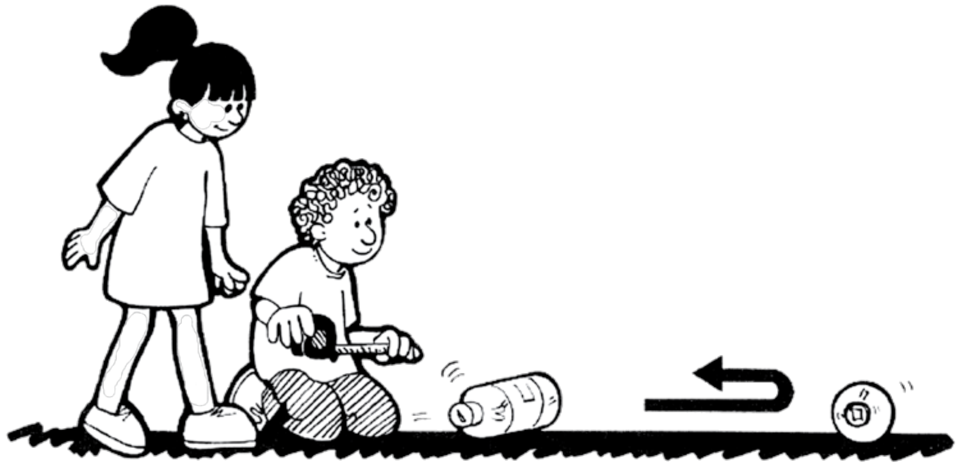
Per team:

- Student Data Sheets (CD Location: Educator Resources/Guides/Student Guide)
- Plastic soda bottle, any size
- 5 large washers
- 1 large paper clip
- 2 small paper clips
- Nail or drill
- Scissors or hobby knife
- Duct tape
- Assorted thick rubber bands
- Meter stick



Procedure

1. Punch or drill a hole in the cap of the soda bottle.
2. Punch or drill a hole in the bottom of the soda bottle.
   Be sure both these holes are large enough to pass your rubber band through them.
3. Cut an access panel into the side of the soda bottle. This panel should be large enough to allow your fingers to work inside the bottle.
4. Cut a heavy rubber band in half, and feed one end of the rubber band through the hole that you made in the cap. It should be fed from the inside of the cap. Tie the free end of the rubber band to a small paper clip, and tape the small paper clip to the top of the cap. You may decide to try different types of rubber bands or try using more than one rubber band to see if this changes the way your come-back bottle works.
5. Drop the free end of the rubber band through the neck of the soda pop bottle, and screw the cap back onto the bottle.
6. Pull the free end of the rubber band through the access panel that you cut. Unbend the large paper clip and form a tiny hook at one end that will fit through the hole in the bottom of the soda bottle. Pass the hook through the hole you made in the bottom of the bottle. Hold the rubber band by the free end, and catch a piece of the rubber band with the tiny hook. Pull the hook back out through the hole and attach (tie) the rubber band to the other small paper clip. Tape the paper clip to the bottom of the bottle.



7. Through the access panel cut into the bottle, use a second rubber band to tie the washers to the middle of the rubber band that stretches between the ends of the bottle. You can vary the number of washers that you use to see if that makes a difference on how your come-back bottle works.
8. Test your come-back bottle (experiment/modify):
   a. Roll your bottle gently across the floor, and observe its motion.
   b. Try out different rolling techniques.
   c. Make modifications to your come-back bottle to get it to roll farther.
9. Come-Back Bottle Race:
   a. Roll your bottle along the floor to wind it up. Give it a push.
   b. Ask your partner to place a foot on the floor to mark the place where your bottle stops moving forward.
   c. Measure the distance that your bottle rolls backward.
   d. The bottle that rolls the farthest is the winner.

Questions

- What causes the come-back bottle to roll back and forth?
- Can the astronauts make a come-back bottle work in space?
- Will the rubber band wind up in space? Will the bottle roll along the floor?
- Can you think of some creative ways to make the come-back bottle work in space?

Answer Key/ What is Happening?

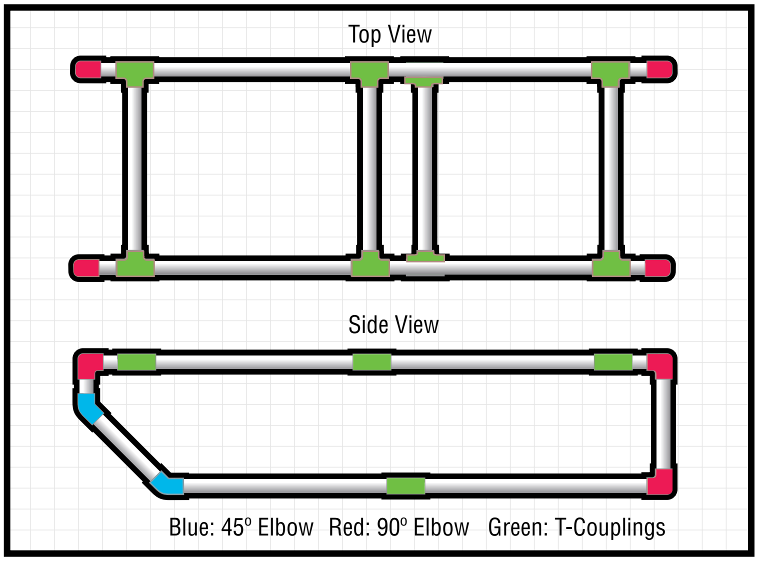
The kinetic energy of the turning bottle is turned into the potential energy of the wound-up rubber band. When the bottle stops, the rubber band starts to unwind, and the potential energy is converted back into kinetic energy as the bottle rolls backward.

Source: Iowa State University E-Set Toys in Space

Microgravity Sled

Overview

One of the most difficult things for astronauts to prepare for prior to their missions is the lower gravity condition that they will face. The best way to study and prepare for the effects of lower gravity conditions is through the use of NASA's Weightless Environment Training Facility (WETF) at the Neutral Buoyancy Lab (NBL) in Houston.

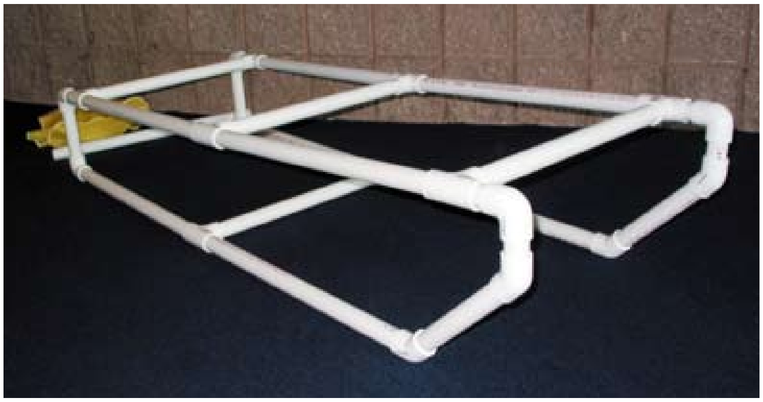


This challenge activity will provide students with a chance to experience what this training is like through the building of the frame for a lunar geologic sample collection sled in a simulated microgravity environment.

Purpose

Through participation in a simulated microgravity training exercise, students will:

- Understand the concept of microgravity.
- Develop skills in teamwork, communications and problem solving.



Preparation

1. Laminate copies of the structure diagram to allow them to be used poolside.
2. Obtain PVC pipe and couplings and cut to appropriate sizes. All PVC has a 2.54-cm diameter. All Couplings are slip couplings. See materials list for number and sizes of PVC sections and couplings needed per team.
3. Make copies of Microgravity Sled Student Sheets.

Materials

Per team:

- Student Data Sheets (CD Location: Educator Resources/Guides/Student Guide)
- PVC parts:
  - 8 58.42-m sections
  - 4 46.99-cm sections
  - 2 22.86-cm sections
  - 2 15.24-cm sections
  - 6 5.08-cm sections (spacers)
  - 1 60.96-cm section with all lengths marked off (used as a measuring stick)
  - 6 90-degree elbow couplings
  - 4 45-degree elbow couplings
  - 8 T-couplings
- 1 mesh dive bag per team to hold PVC and couplings
- Access to a swimming pool (approximately 1.2-m deep)

- Stopwatches
- Laminated copies of the structure diagram (two per team)
- Mask and snorkel or swim goggles (one per student, optional)
- "Reaching for the Stars" Microgravity Training Video, or Internet access to view video/pictures of astronauts training in pool
- Swimsuit (one per person)

Procedure

1. Watch videotape or use Internet to view astronauts using the pool to train for microgravity.
2. Teams will practice building the structure on dry land. Teams can use the diagrams while building. Have teams practice with verbal communication and without. Each practice session can be timed to check for improvement.
3. Depending on the size of the teams, you may want to limit the teams to two team members per team in the water at a time with the other on the side assisting with parts. Make sure the teams switch at least once to allow all team members a chance at assembly in the pool.
4. Discuss the question, "How will building the structure in the simulated microgravity environment—the pool—be different than on dry land?"
5. Allow time for teams to make their final plans and for discussion.

At the Pool:

1. Locate teams a minimum of 1.83 m away from each other along the side of the pool.
2. Teams may organize their parts at poolside as long as they do not lay them out in the shape of the structure.
3. Start the stopwatch.
4. Each team builds their structure on the bottom of the pool. Students must swim down to the bottom carrying the parts and put them together there, returning to the surface when they need more parts or air, whichever comes first.
5. Record times of completion.
6. Remove structures from pool. Build the structure on dry land to ensure that all parts have been removed from the pool. Replace parts in dive bags.

Questions

1. What plan did your team have for construction? Did you need to change your plan in any way?
2. How was the activity in the water different than on dry land?
3. What would it be like to build this structure in the microgravity of space? On the Moon?

Answer Key/What is Happening?

One way to study the effects of microgravity is to be submerged in a large tank of water such as NASA's WETF at the NBL. A water environment is very similar to a space environment and is a great place to train astronauts and test designs for space.

NASA's C-9B aircraft also simulates microgravity but for much shorter periods of time. It is affectionately known as the "weightless wonder." The plane flies up to 10,668 m then descends to 7,315.2 m and continues a series of climbs and drops. When the plane drops, people inside the C-9B experience about 20 to 30 seconds of microgavity.

Appendix

This section provides useful information for the Lunar Nautics program.

CD Informational Contents

Glossary

A list of useful terms and definitions can be found on the Lunar Nautics CD.

Resources

A list of Internet sites and NASA Teacher Resource sites for more information can be found on the Lunar Nautics CD.

Educator Resources

Guides: Educator's Guide, Student Guide

PowerPoint Presentations: To the Moon and Mars, LN Base Components, LN Science, LNSS (Lunar Nautics Space Systems, Inc.)

Printouts: LN Team Badges/Master Role Cards, Lunar Nautics Employee Posters, The Never-Ending Quest Puzzle, Moon Match Cards, Employee Advancement Checklist, LN Certificate of Completion

Extras: LN Budget Spread Sheet, Lunar Map, Lunar Surface Image (for 3-D Base construction) Lunar Lander Game, Lunar Lander Template

Trivia Game: LN Trivia Challenge

National Aeronautics and Space Administration

George C. Marshall Space Flight Center
Huntsville, AL 35812
www.nasa.gov/marshall

www.nasa.gov

Pub 8–387248