National Aeronautics and
Space Administration

21st Century Community Learning Center
NASA Engineering Design Challenge

Packing Up for the Moon

STEM Facilitation Guide

NASA: Why We Explore

Humanity's interest in the heavens has been universal and enduring. Humans are driven to explore the unknown, discover new worlds, push the boundaries of our scientific and technical limits, and then push further.

Human space exploration helps address fundamental questions about our place in the universe and the history of our solar system. Through addressing the challenges related to human space exploration, we expand technology, create new industries, and help foster peaceful connections with other nations. Curiosity and exploration are vital to the human spirit. Accepting the challenge of going deeper into space will invite the citizens of the world today and the generations of tomorrow to join NASA on this exciting journey.

The United States is a world leader in the pursuit of new frontiers, discoveries, and knowledge. The National Aeronautics and Space Administration, more commonly known as NASA, performs a unique role in America's leadership in space. NASA has landed people on the Moon, sent spacecraft to the Sun and every planet in the solar system, and launched robotic explorers to travel beyond the solar system. NASA's vision is to discover and expand knowledge for the benefit of humanity.

NASA was formed in 1958 and has amassed a rich history of unique scientific and technological achievements in human space flight. From John Glenn's 1962 orbit around the Earth in Mercury Friendship 7, through the Apollo missions and the space shuttle years, to today's orbiting International Space Station (ISS), NASA is on the forefront of manned space flight.

Figure 1. Illustration of the Orion spacecraft, a multi-purpose crew vehicle designed to carry astronauts into deep space. (NASA)

NASA is leading the next steps into deep space near the Moon, where astronauts will build and begin testing the systems needed for challenging missions to deep space destinations, including Mars. This area of space near the Moon offers a true deep space environment to gain experience for human missions that push farther into the solar system, yet astronauts will be close enough to access the lunar surface for robotic missions and, if needed, return to Earth in days rather than weeks or months.

NASA's future success and global leadership will be determined largely by the investments and innovations we make today in scientific research, technology, and our workforce. NASA's focus has always been, and always will be, to discover, invent, and demonstrate new technologies, tools, and techniques that will allow our Nation to explore space while improving life on Earth.

Career Connection

What is an engineer? An **engineer** is a person who works on a team to solve a problem that humans want to solve or make better. Engineers are at the heart of every engineering challenge. Engineers design and build things we use every day. The NASA for Kids video "Intro to Engineering" explains the role of an engineer and can be shared with your students: http://youtu.be/wE-z_TJyzil. After viewing the video, have students discuss what they learned about what an engineer does.

Figure 2. Aerospace Engineer Chris Randall tests rocket parts and life support systems to ensure they work as planned. (NASA)

Some examples of NASA-engineered products include the following:

- Portable x-ray machines: NASA engineers worked to create a small, low-radiation x-ray machine so medical professionals can examine people's injuries at accident scenes.
- Infrared ear thermometers: NASA engineers developed infrared temperature sensors for space missions, and these sensors were adapted to create a faster and easier way to take someone's body temperature.
- Food processing control: NASA engineers worked with food production companies to create a process to identify the critical points where food could be contaminated.
- Airplanes: NASA engineers work with private companies to design and develop aircraft that are safer, quieter, lighter, more fuel efficient, and more reliable.

Figure 3. Simulation System Engineer Debbie Martinez works on developing general aviation flight simulation software. (NASA)

Engineers help to improve society. Women and men of all races, ethnicities, and walks of life can become engineers. Encourage students to explore NASA engineer career profiles at https://www.nasa.gov/audience/forstudents/careers/profiles/index.html.

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Introduction to the Engineering Design Challenge

Figure 4. Artist's rendering of the Space Launch System. (NASA)

Facilitator's Overview

NASA has created an **engineering design challenge (EDC)** that involves students in using the **engineering design process (EDP)** to develop solutions to authentic NASA mission-centered challenges.

The EDC serves as an authentic, standards-driven investigation that allows students to engage in the process of answering questions and solving problems like today's scientists and engineers do. This EDC provides students with opportunities to gain tangible skills that are essential in science, technology, engineering, and mathematics (STEM) careers. This guide is organized into three sections:

1. **Introductory Materials** establish a basic level of understanding about the EDP and the EDC and provide tools to support students through the challenge.
2. **Facilitator Instructions** provide instructions for facilitators to use throughout the design challenge and include tools to assess student understanding throughout each step.
3. **Student Team Challenge Journal** contains prompts and tools to guide students through the cycle of steps in the EDP while documenting their work for each step. It is suggested that each student have a copy of this journal.

What is the Engineering Design Process?

The EDP is a systematic practice for solving problems. Engineers work through the process to solve problems and create new technologies and systems that enhance our lives. All EDP models begin by identifying a need or problem, but there is no defined or fixed path toward the end goal. The EDP model allows problem solvers the flexibility to move between steps as appropriate for the challenge faced.

What is an Engineering Design Challenge?

The EDC is a learner-centered instructional approach that organizes learning around a shared goal or challenge. Students are presented with a challenge or problem and, using the EDP, work in teams to complete activities and experiments to develop solutions toward solving that problem. These challenges facilitate teamwork and engage students in problem-solving practices used by real-world engineers.

Engineering Design Process

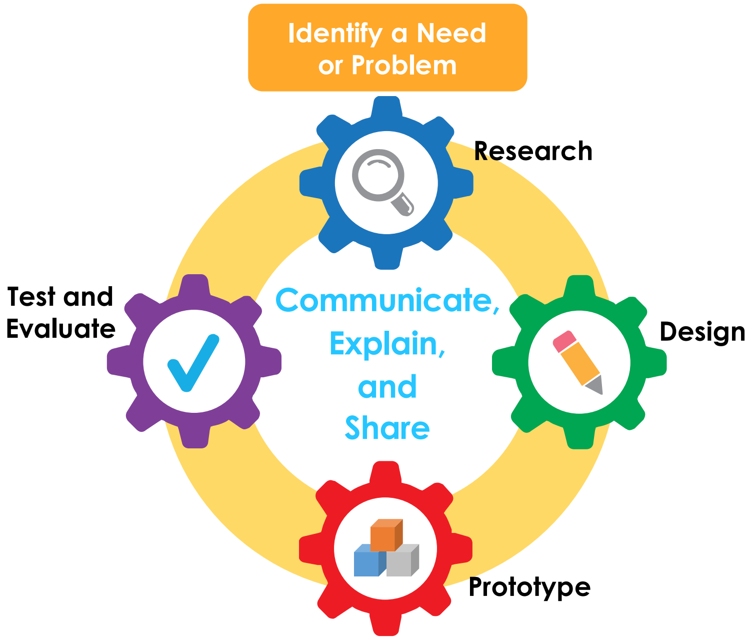


Figure 5. Engineering design process model. Model and accompanying text adapted from 2016 Massachusetts Science and Technology/Engineering Curriculum Framework, Massachusetts Department of Elementary and Secondary Education, http://www.doe.mass.edu/frameworks/scitech/2016-04.pdf.

Identify a Need or Problem. Identify a need or problem to be solved, improved, or fixed. Identify the criteria and constraints that will need to be met to solve the problem.

Research. Use resources from the internet, the library, or discussions with NASA scientists and engineers to learn more about the need or problem and possible solutions. Investigate how this problem is currently being solved or what efforts scientists and engineers are making to find a solution.

Design. Use all information gathered to create the design(s). Design includes modeling possible solutions, refining models, and choosing the model(s) that best meets the original need or problem.

Prototype. Construct a prototype, or physical model, based on the design model(s). Prototypes are used to test proposed solutions.

Test and Evaluate. Test prototype to determine how effectively it solves the need or problem. Collect data to use as evidence of success or need for improvement. Redesign and refine prototypes to continue looking for possible solutions.

Communicate, Explain, and Share. Communicating, explaining, and sharing the solution and design is essential to tell others how it works, how it solves (or does not solve) the identified need or problem, and how it meets (or fails to meet) the criteria and constraints. Determining how to communicate and act on constructive criticism is critical.

Engineering Design Challenge: Packing Up for the Moon

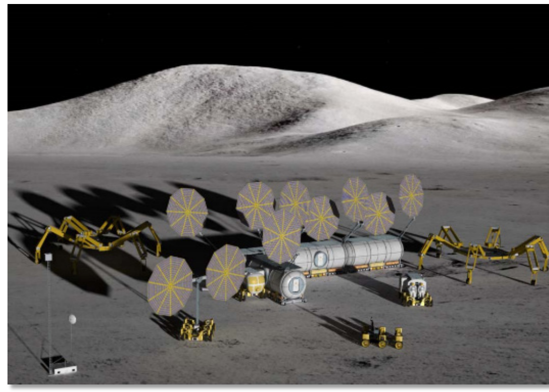


Figure 6. Artist's conception of a potential lunar outpost. (NASA)

Future astronaut crews on long-duration missions will need to learn how to grow safe, edible, and nutritious plants while living and working in space, on the Moon, and on other planets.

The lunar environment is so extreme that astronauts and plants are not able to live on the lunar surface without a protective habitat. Because of the extreme environment, the lunar habitat must provide the plants with light, water, and atmosphere. All the essential supplies and materials needed to survive on the Moon will be stowed on a rocket, shipped to the Moon, and deployed on the surface. There is a limited amount of space available on the rocket for the large amount of lunar cargo needed. The mass and the volume of the stowed cargo must be closely monitored for fuel efficiency and storage limitations.

The Challenge

Student teams will design and build a tabletop model of a plant growth chamber that can be folded, stowed, and shipped on a rocket destined for the Moon. When the shipment arrives, the future lunar astronauts will then be able to expand the plant growth chamber and deploy it on the lunar surface. Because this project is in the development stage, the team will only need to design, build, and present a tabletop model of the plant growth chamber rather than a full-size lunar structure designed to grow enough food for the entire lunar crew.

Criteria and Constraints

The plant growth chamber must meet the following criteria and constraints:

1. On the rocket, the plant growth chamber model must not exceed a mass of 50 g and a stowed volume of 1,000 cm^3.
2. The deployed plant growth chamber can be any shape; however, the volume cannot exceed 1,000,000 cm^3.
3. The deployed plant growth chamber may or may not be connected to the lunar habitat, but it must provide a way for astronauts to have access to the chamber.
4. The model plant growth chamber must use a system of expansion from its stowed shipment package on the rocket to its final deployed structure on the Moon.

Pacing Guide

The Pacing Guide offers a suggested timeline for each phase of the engineering design process (EDP). Facilitators may condense or expand the schedule to accommodate the needs and explorations of their student teams. This challenge may be completed in an estimated 20 sessions, with each session approximately 1 hour. At the completion of each EDP phase, students will communicate, explain, and share their discoveries, successes, and understandings.

Activity	Sessions
Introduction • Complete the Team Building activities • Explore NASA Mission Background and careers • Complete the STEM Investigations • Investigate each phase of the EDP	2 sessions
Identify a Need or Problem • Explore the challenge scenario and watch the introductory video • Identify the criteria and the constraints of the challenge	2 sessions
Research • Brainstorm research questions related to the challenge scenario • Complete a KWL chart • Connect with a NASA scientist or engineer	3 sessions
Design • Complete an individual drawing of the prototype based on the challenge scenario, criteria, and constraints • Evaluate each of the individual drawings for strength and unique ideas • Combine all of the individual drawings and ideas into a team drawing	3 sessions
Prototype • Construct a prototype using the team drawing • Evaluate the prototype against the criteria and constraints • Create a budget worksheet that will record and calculate the material costs • Demonstrate the ability to work effectively and respectfully with a team	3 sessions
Test and Evaluate • Complete the tests on the prototype according to the criteria and constraints of the challenge • Collect and analyze data from each of the tests • Determine how to best improve the prototype	3 sessions
Student Team Presentation • Collect photos and videos that will illustrate the process the team followed to complete the challenge • Represent all phases of the EDP in the student team presentation • Summarize each of the team's successes and challenges in the presentation	4 sessions

Learning Outcomes

Education Standards

The engineering standards addressed here are tailored for 6th–8th grade students based on Next Generation Science Standards. Even if your state has not adopted these standards, similar core ideas are likely found in other terms in your state's standards.

Standards Addressed

Next Generation Science Standards
Engineering Design • **MS–ETS1–1** Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions. • **MS–ETS1–2** Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem. • **MS–ETS1–3** Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success. • **MS–ETS1–4** Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

Connected Concepts

Common Core State Standards	
Mathematics	***English Language Arts***
• **MP.2** Reason abstractly and quantitatively. • **MP.4** Model with mathematics. • **6.RP.1** Understand the concept of a ratio and use ratio language to describe a ratio relationship between two quantities. • **6.RP.3** Use ratio and rate reasoning to solve real-world and mathematical problems. • **7.RP.2** Recognize and represent proportional relationships between quantities. • **7.EE.3** Solve multi-step real-life and mathematical problems posed with positive and negative rational numbers in any form (whole numbers, fractions, and decimals), using tools strategically. Apply properties of operations to calculate with numbers in any form; convert between forms as appropriate; and assess the reasonableness of answers using mental computation and estimation strategies.	• **RST.6–8.2** Determine the central ideas or conclusions of a text; provide an accurate summary of the text distinct from prior knowledge or opinions. • **RST.6–8.7** Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table). • **WHST.6–8.7** Conduct short research projects to answer a question (including a self-generated question), drawing on several sources and generating additional related, focused questions that allow for multiple avenues of exploration. • **WHST.6–8.8** Gather relevant information from multiple print and digital sources, using search terms effectively; assess the credibility and accuracy of each source; and quote or paraphrase the data and conclusions of others while avoiding plagiarism and following a standard format for citation. • **WHST.6–8.9** Draw evidence from informational texts to support analysis, reflection, and research. • **SL.6–8.5** Integrate multimedia and visual displays into presentations to clarify information, strengthen claims and evidence, and add interest.

Evidence of Learning

This guide uses a number of tools to indicate student progress, including the following:

- Accessing of existing knowledge and assessment of level of understanding
- Supporting Science Investigations, Data Collection Sheets, and post-investigation discussions
- Sample guiding questions to assist in facilitating discussions
- A final assessment, including creation of a video or slide presentation explaining the iterative design process, challenges encountered, and how decisions were made based upon the concepts learned

Student Team Challenge Journal

The engineering design process (EDP) that each team uses will vary from team to team. Prior to starting the engineering design challenge, print and assemble enough copies of the Student Team Challenge Journal into three-ring or loose-leaf binders so that each student receives a complete journal. Included in the journal are the EDP practices students will use to record their progress. Print extra copies of these EDP sheets and make them available for students. Students will select the appropriate sheets as they move through the process. Instruct students to work page-by-page through their journals, documenting the challenges they faced and the steps they took. This documentation will help students prepare their final presentations.

Solution Presentation Criteria

Student teams should use the Student Presentation Rubric to guide them as they work through the challenge. The Student Presentation Organizer and the Team Progress Chart are tools students can use to help them create a final product that clearly communicates the team progress through the engineering design challenge.

Once the video or slide presentation is complete, submit according to the guidelines on the Y4Y (You for Youth) website.

Team Presentation Rubric

Student name _________________________ **Team name** ___________________________

The Team Presentation Rubric will be used to evaluate the student team presentations (video, student presentation, and/or slide presentation).

1. In the introduction, the team name, the challenge name, and the title of the presentation were all included. Personal or identifying information was NOT given in the introduction.

0	1	2	3	4	5
Not included	Needs improvement	Below average	Average	Above average	Excellent

2. The team explained the challenge, including the criteria and the constraints.

0	1	2	3	4	5
Not included	Needs improvement	Below average	Average	Above average	Excellent

3. The team described the results of their research, including the STEM career they explored and the information they collected from the virtual connection with the NASA scientist or engineer.

0	1	2	3	4	5
Not included	Needs improvement	Below average	Average	Above average	Excellent

4. The team explained how they used the engineering design process to design and construct their final prototype or model.

0	1	2	3	4	5
Not included	Needs improvement	Below average	Average	Above average	Excellent

5. As a conclusion, the team described the challenges and successes they experienced as they built, tested, and improved their prototype or model.

0	1	2	3	4	5
Not included	Needs improvement	Below average	Average	Above average	Excellent

Comments and Encouragement

Facilitator Instructions

Recommended Materials

The following materials are required to complete this challenge. The quantity will depend on the number of students participating. Alternatives and additional materials can be used if desired, but be mindful of safety when allowing students to bring in or handle materials that could potentially be dangerous.

Each team will require the following items:

- Digital scale or balance
- Measuring tape
- Rulers
- Grid paper

Figure 7. Household supplies that could be used as construction materials for the challenge.

Examples of additional materials that may be used:

- Aluminum foil
- Balloons
- Binder clips
- Bubble wrap
- Cardboard or cardstock
- Clothespins
- Cloth
- Coffee filters
- Cotton balls
- Craft sticks or tongue depressors
- Glue sticks
- Mini foil pie plates
- Modeling clay
- Paper bags
- Paper clips
- Paper towel or toilet paper tubes (empty)
- Pennies
- Plastic eggs
- Plastic wrap
- Rubber bands
- Skewers or stirrers
- Staplers and staples
- Straws
- String
- Tape (masking, electrical, transparent, and duct)

Safety

Safety, an important issue for all curricular areas of education, is of special concern for STEM-based activities and courses. Many national and state academic standards address the need for schools and subject areas to promote development of student knowledge and abilities in a safe learning environment.

School administrators, teachers, and facilitators are responsible for providing a learning environment that is safe, suitable, and supportive. Facilitators are also responsible for their students' welfare in the classroom and laboratory.

Facilitators should

- Approve all drawings before students start building their designs.
- Look for flimsy structure designs and potentially hazardous combinations of materials.
- Ensure that resources are clean and dry, with no sharp edges exposed.
- Make sure all materials are undamaged and in good repair.
- Prohibit students from bringing in or using additional materials for their designs without prior approval.

Students should

- Make safety a priority during all activities.
- Wear safety goggles when conducting all investigations and the challenge.
- Demonstrate courtesy and respect for ideas expressed by others in the group.
- Use tools and equipment in a safe manner.
- Assume responsibility for their own safety and the safety of others.

Team Building

Begin by dividing students into teams of no more than four to give all students an opportunity to contribute. By working as members of a team, students develop skills such as trust, cooperation, and decision making. Working as a team member, however, can be challenging for some students. The following exercises are recommended to help teams begin to work together effectively.

Figure 8. This Apollo 11 patch depicts an eagle landing on the Moon with a view of the Earth in the background. (NASA)

Establish a team name. Many NASA teams are named based on the work they do.

Design a mission patch. Teams that work on NASA missions and spacecraft are unified under a mission patch designed with symbols and artwork to identify the group's mission.

Create a vision statement. This is a short inspirational sentence or phrase that describes the core goal of the team's work. NASA's current vision statement is "*To discover and expand knowledge for the benefit of humanity.*"

As students begin to work together, their individual strengths will become apparent. Students can volunteer or be assigned tasks or responsibilities that are vital to completing the challenge. Team jobs can also be rotated throughout the team members to give all students an opportunity to improve their team skills. The following list includes examples of jobs that student teams will need to complete. Feel free to come up with others, and remember that all team members should serve as builders and engineers for the team.

Design engineer. Sketches, outlines, patterns, or plans the ideas the team generates

Technical engineer. Assembles, maintains, repairs, and modifies the structural components of the design

Operations engineer. Sets up and operates the prototype to complete a test

Technical writer/videographer. Records and organizes data and prepares documentation (text, pictures, and/or video) to be reported and published

NASA Mission Background

Why is growing plants important to future deep space astronaut crews?

As NASA sets its sights on returning to the Moon and preparing for Mars, scientists are studying how plants grow in space and how to produce food for astronauts during extended missions. Astronauts on longer missions will require life-support capabilities and food production systems beyond what is now available.

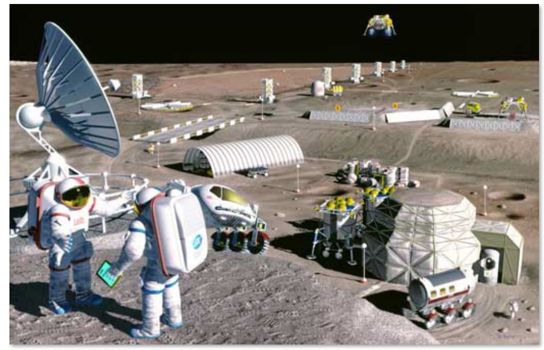


Figure 9. Artist's conception of a potential Martian outpost. (NASA)

Plants grown off Earth will require clean water, nutrients in the soil, and an Earth-like atmosphere to produce food for astronauts. During photosynthesis, these plants will remove carbon dioxide (CO_2) from the air while they produce oxygen (O_2) and food for the off-Earth crew. At very high light intensities, plants such as wheat would supply food and oxygen for one person in a small amount of space. At moderate light intensities, a diverse mixture of crops would supply a more complete diet and sufficient oxygen for one person. Plants are also important for water regeneration on the spacecraft or habitat. Plant systems will be used to purify wastewater as water vapor is condensed to produce clean drinking water.

Figure 10. Artist's conception of a potential Martian outpost. (NASA)

The Martian Environment

Future astronaut crews on long-term missions to Mars will be living and working in an environment that is dramatically different from Earth's. Mars is very cold and has an average temperature of –62 °C, far below the freezing point of water. Its rocky and dusty red surface is covered with canyons, inactive volcanoes, and craters. Although the Martian atmosphere is considerably different than Earth's, Mars does have clouds, wind, and dust.

Growing Plants Off Earth

Plant species that are used to produce food to feed Earth's population cannot grow in the extreme environment of Mars. However, NASA scientists are currently developing plant growth chambers that will allow astronauts to grow plants on Mars in the simulated environment of Earth. To accomplish this goal, the extreme Martian environment must be adapted in order for plants to survive. The lack of atmosphere does not provide the necessary protection from the dangerous solar radiation or the temperature excesses found on the planet's surface. The Martian day and night cycle is so extreme that it will not allow the plants to properly engage in photosynthesis. The limited amount of fresh water and necessary nutrients found in the Martian soil will also prohibit the growth of plants. All of these environmental problems must be addressed in growth chambers before plants can be grown on Mars.

How are plants affected by the low-gravity environment of Mars?

Astronauts on long missions will need to grow their own food. One plant experiment on the International Space Station (ISS) has successfully grown a mustard plant from seed in 2 months. The low-gravity environment of Mars affects virtually every aspect of plant growth. Understanding how gravity affects plant processes in the Martian environment can help answer important questions about the basics of plant growth and development.

Figure 11. NASA astronaut Peggy Whitson harvests Tokyo Bekana cabbage grown inside "Veggie," the vegetable production system on the International Space Station (ISS). ISS astronauts are studying how plants respond to microgravity. (NASA)

As biologists learn more about how plants function in extreme environments, this knowledge can be applied to new research that will enhance life on Earth. Plant research results contribute to NASA's goals of furthering human exploration of space and improving the quality of life on Earth through applications in medicine, agriculture, biotechnology, and environmental management.

Figure 12. NASA astronaut Doug Hurley organizes supplies and equipment in the Leonardo Permanent Multipurpose Module, a component that joined the International Space Station complex after being flown into space aboard the Space Shuttle Discovery. (NASA)

How do you pack cargo onto the SLS?

America's Space Launch System (SLS) is a new heavy-lift rocket that will be the largest launch vehicle ever built. The SLS will carry the Orion spacecraft as well as important cargo, equipment, and science experiments into deep space. Cargo is packed on the rocket with specially designed cases. The 130-metric-ton (143-ton) rocket will lift more than 286,000 lb of payload, and it will provide 20 percent more thrust than the Saturn V rocket. The SLS will stand 284 ft tall and weigh nearly 6 million pounds.

Engagement: Accessing Existing Knowledge

Prior to starting the engineering design challenge, it will be useful to identify students' existing knowledge and level of understanding using a series of guided questions related to this specific challenge. This discussion will allow facilitators to tailor the challenge and the Supporting Science Investigations to the group, maximizing the educational benefit.

The following questions provide a starting point from which additional topics may be discussed.

- How is Mars different from Earth?
- Could we live on Mars today? Why or why not?
- What would we need on Mars in order to live?
- What is a plant growth chamber?
- Why would we need a plant growth chamber on Mars?
- Do we have similar objects on Earth?
- How can we make something expand and contract easily?

STEM Vocabulary

Engineering design challenges and the engineering design process (EDP) are concepts that may be unfamiliar to your students. Younger students in particular may not have heard words like "criteria" or "constraints," which are commonly associated with engineering design.

A list of related STEM vocabulary words is included in this guide. If practical or appropriate, a vocabulary wall can be created to assist in familiarizing students with these words.

Student Team Challenge Journal

Before moving on to the Supporting Science Investigations, provide students with the Student Team Challenge Journal. Additional sheets should be made available as students work through the challenge. Where possible, engage students by relating the information to their everyday lives.

Exploration: Supporting Science Investigations

The following pages contain two Supporting Science Investigations to help with students' understanding of the background material. Ideally, both Supporting Science Investigations will be performed, but facilitators should ensure that at least one of these investigations is completed prior to commencing the engineering design challenge. These investigations will explore the primary concepts used during the challenge.

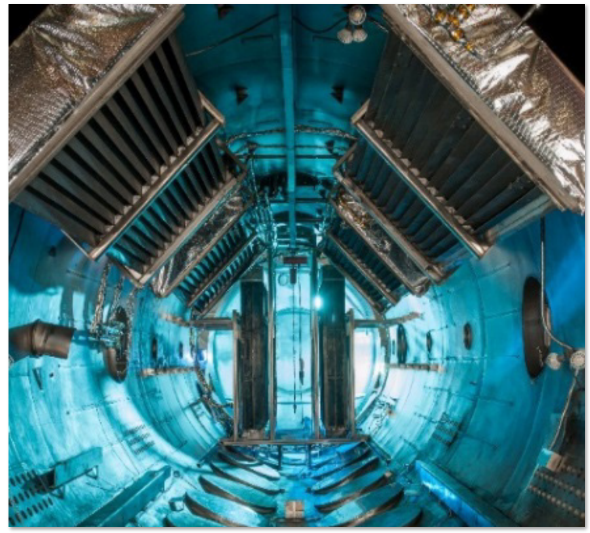


Figure 13. Vacuum Chamber 5 (VF–5) at NASA's Glenn Research Center provides an environment that simulates space-like conditions. VF–5 has been used to test electric propulsion systems and power systems for in situ resource utilization.

This section includes the following Supporting Science Investigations and their respective concepts.

- Investigation 1: Jackson Cubes
  - Thin materials can be folded to create large-volume spaces.
  - Folded objects can be expanded, contracted, and resized easily.
  - Large objects can be made from smaller, pre-made units.

- Investigation 2: Stability
  - The shape of a material can affect the strength of a system in which it is used.
  - The properties of a material may be modified.
  - There are multiple ways to modify a material.

Supporting Science Investigation 1: Jackson Cubes

Concept

In this activity, students will discover how paper can be folded to create solid structures. Students will use multicolored sheets of paper to create a cube that can be quickly built and dismantled. A cube is a symmetrical three-dimensional shape, either solid or hollow, contained by six equal squares.

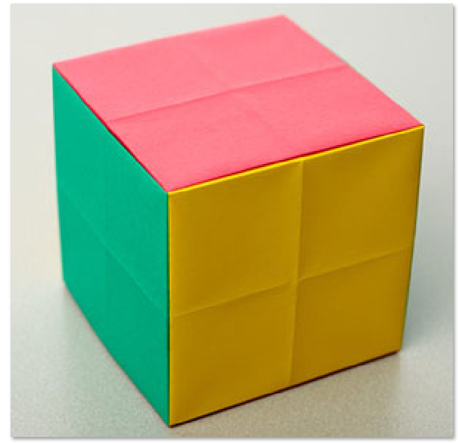


Figure 14. Students will create a sturdy cube by folding squares of paper.

Materials

For each student:
- 3–6 different-colored paper squares
- Ruler

Notes

- Make the paper squares in advance from colored sheets of 8.5 x 11 in. paper. Fold the short edge of the paper to create a triangle, then cut off the rest of the paper. Unfold the triangle to produce a square measuring 8.5 x 8.5 in. (approx. 22 cm).
- Make a Jackson Cube prior to working with students. This will help you guide students who are less spatially-oriented to complete the cube on their own.
- Print the instructions for this investigation in color if possible, as the color photos will help clarify the procedure for students.
- Prior to performing this activity, visit this NASA site to find connected information for educators and students: https://www.nasa.gov/mission_pages/station/research/news/origaBEAMi.
- View the instructional video prior to having students make their own cubes. This can be done as a class.

Procedure

1. Gather materials.
2. Fold a square of paper in half, then unfold it.
3. Rotate the paper 90 degrees. Fold it in half, then unfold it.

At this point, students should have a square of paper with two folds that create a + sign in the middle of the paper.

4. Fold the nearest edge of paper to one of the center folds.
5. Rotate the paper 180 degrees and fold that edge of the paper to the same center fold.
6. Rotate the paper 90 degrees and fold that edge to the other center fold.
7. Rotate the paper 180 degrees and fold that edge of the paper to the same center fold.
8. Partly unfold the final two folds so the ends of the paper are pointing upright.

At this point, students should have a folded piece of paper in the shape of the letter U (Fig. 15).

Figure 15. Students will create the six walls of the cube one side at a time.

9. Repeat steps 2 through 8 five more times. This will provide all six sides of the cube.
10. Start building the cube by placing three of the folded walls together, as shown in Figure 16:

Figure 16. Place the first three walls together.

11. Add the next two sides, as shown here in green (Fig. 17):

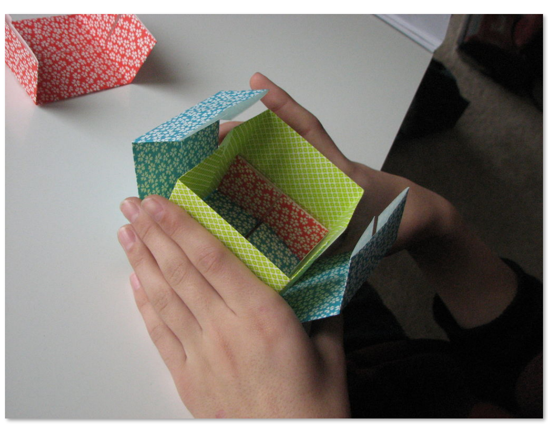


Figure 17. Add the next two sides of the cube.

12. Slot in the final section, ensuring that it locks in between the two side walls (Fig. 18). The cube is now complete.

Figure 18. Slot in the final section.

13. If desired, allow students to modify their cubes, trying different sizes of paper.
14. Have students complete the questions on their Data Collection Sheets.

Options for Differentiating Instruction

The following suggestions may be used when modifying this investigation for students outside of the designated age range or ability levels.

Modification

- Consider pre-folding the sections and focus on simply building the cube.

Enrichment

- Invite students to build the Origami Expanding Box. Instructions can be found here: https://www.youtube.com/watch?v=I4wYks2mbrQ.

Supporting Science Investigation 2: Stability

Concept

NASA began construction of the International Space Station (ISS) in November 1998 and completed it in 2011. The ISS is larger than a six-bedroom house and has a mass of almost a million pounds. The station's integrated truss structure is 357 ft long and is the longest man-made object to fly in space.

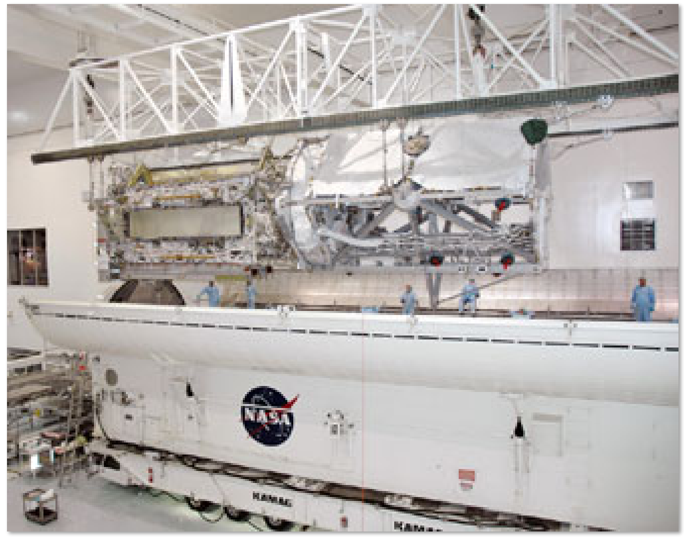


Figure 19. Inside the Kennedy Space Center's Space Station Processing Facility, the International Space Station's P3/P4 integrated truss segment is lowered into the cargo hold for transport and installation in the orbiter Atlantis. (NASA/Troy Cryder)

The ISS was constructed from many pieces that had to be packed onto a spacecraft, launched from Earth, taken into space, and assembled as the station orbited Earth. More than 115 space flights were conducted on five different types of launch vehicles over the course of the station's construction. The structural pieces fit inside the launch vehicle and were then able to be assembled and used on the ISS.

In this activity, students will discover how different shapes can be used to enhance the stability of a structure. Students will create a truss-like model that can support itself and additional weight.

Materials

For each group of 4 students:

- Box of drinking straws (approx. 100)
- Roll of masking tape
- Heavy objects of a known weight (e.g., a classroom set of paperback books, each one weighing the same, or a gram weight set)
- Scissors
- Meter stick
- Scale

Procedure

1. Discuss the ISS photos with students. Point out the truss segment being placed into the cargo hold for transport (Fig. 19) and what truss segments look like during and after assembly on the ISS (Figs. 20 and 21).
2. Divide students into teams of four. (Smaller teams also will work, depending on the time allotted for this investigation.)

Figure 20. Astronauts Michael Lopez-Alegria and John Herrington work on the newly installed International Space Station's P1 truss during shuttle mission STS–113 in 2002. (NASA)

Figure 21. During Space Shuttle Discovery's 2009 mission to the International Space Station, the STS–119 crew delivered and installed the S6 integrated truss segment. This image was taken from Discovery as STS–119 performed a fly-around after undocking. (NASA)

3. Instruct teams to build model trusses using only straws and masking tape. Direct half of the teams to build a model truss using a square shape for the structure, and direct the remaining teams to use a triangle shape. Instruct all teams that their three-dimensional model must have four flat sides. The size of the squares and triangles can be a choice students make during the process.
4. Each team will build a model truss that spans two chairs at a distance of 50 cm.
5. Teams will test the strength of their designs by adding a weight to the flat surface on top of the structure. They will continue to add weight until the structure fails. Instruct students to observe what is happening to the structure as it is being weighed down.
6. Have students record their design, number of straws used, and weight supported on the Data Collection Sheet.

7. Once student designs have been tested, encourage each team to think about and discuss how they might transport their team's truss off Earth.

Options for Differentiating Instruction

The following suggestions may be used when modifying this investigation for students outside of the designated age range or ability levels.

Modification

- Have students build the triangle truss only.

Enrichment

- Give teams a heavier object and challenge them to build a truss to hold the increased weight.

Explanation: Supporting Science Investigations Discussion

The following investigation discussions are designed to reinforce students' understanding of the specific concepts learned during the Supporting Science Investigations.

Each discussion is based on the standard Think–Pair–Share strategy, which encourages individual participation, collaborative learning, and higher-level thinking. This strategy consists of three parts:

- **Think**: Students think independently about the question that has been posed.
- **Pair**: Students are paired to discuss their thoughts.
- **Share**: Students share their ideas with the whole class.

Focus on one question at a time. When students are done sharing their thoughts and ideas on the first question, move to the second question and repeat the process.

Procedure

1. Discussion Questions for each Supporting Science Investigation are included in this guide.
2. Ask one of the Discussion Questions to begin the Think–Pair–Share process.
3. Provide approximately 5 minutes for students to think independently.
4. Next, provide approximately 5 minutes for the students to share in pairs.
5. Finally, have students share their ideas in a class discussion.

Investigation Discussion 1: Jackson Cubes

Concepts Learned

The following scientific concepts should have been realized by performing this investigation:

- Thin materials can be folded to create large-volume spaces.
- Folded objects can be expanded, contracted, and resized easily.
- Large objects can be made from smaller, pre-made units.

Discussion Questions

The Jackson Cubes activity showed us that it is possible to make objects with a large volume using materials that by themselves contain very little volume.

1. Imagine you had to construct a large building using this method. How practical would it be? Are buildings built this way today?
2. Now, imagine you had to construct a building on Mars using this method. Would it have to be built differently?
3. How will you apply what you learned in this investigation to your design?

Investigation Discussion 2: Stability

Concepts Learned

The following scientific concepts should have been realized by performing this investigation:

- The shape of a material can affect the strength of system in which it is used.
- The properties of a material may be modified.
- There are multiple ways to modify a material.

Discussion Questions

The Stability activity demonstrated how a material can be modified into different shapes to enhance its stability when used as part of a design system. The stability of each section of a system can affect the strength of the whole system, helping it withstand weight and maintain its structure.

1. Can you think of any other materials that have multiple properties?
2. How could a material with multiple properties be used by astronauts in space?
3. How will you apply what you learned in this investigation to your design?

Elaboration: The Engineering Design Challenge

Using the Engineering Design Process

Discuss the engineering design process (EDP) with students and explain how students will use this process to work through the engineering design challenge. The following pages explain how each step of the EDP relates to the challenge and how to facilitate the process. Regardless of the step being undertaken by each team, it is important that they work in a scientific manner. Explain the EDP sheets and how to use the appropriate pages for recording group ideas. It is important for students to understand that they may choose any path through the EDP, but they should be able to communicate why they selected a particular path.

Discuss with your students the information covered within the engineering design challenge. Using the background information, talk about current NASA missions and how those relate to this challenge. As a class, discuss the individual components of this challenge. Explain the specific criteria and check with students for understanding. Discuss with students what the constraints mean, how and why they are important, and how they relate to their everyday experiences.

Consider using a budget sheet with students as an optional real-world component. Suggestions include the following:

- Provide students with a price sheet that lists the cost of the items they have used to complete the challenge.
- Have teams use the Budget Reporting Data Sheet included here to determine the cost of their solution as tested.
- For enrichment, advise students that NASA plans to mass-produce their design for use as a delivery vehicle for monthly supply trips to Mars, but due to financial constraints, the annual budget has been reduced. Students will be required to redesign their prototype to reduce costs, but without reducing performance.

Engineering Design Process

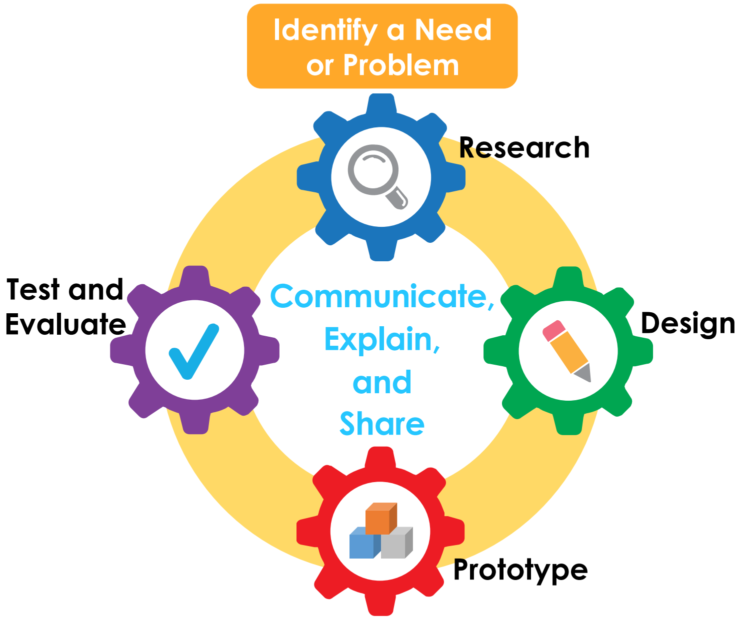


Figure 22. Engineering Design Process model. Model and accompanying text adapted from 2016 Massachusetts Science and Technology/Engineering Curriculum Framework, Massachusetts Department of Elementary and Secondary Education, http://www.doe.mass.edu/frameworks/scitech/2016-04.pdf.

Identify a Need or Problem. Identify a need or problem to be solved, improved, or fixed. Identify the criteria and constraints that will need to be met to solve the problem.

Research. Use resources from the internet, the library, or discussions with NASA scientists and engineers to learn more about the need or problem and possible solutions. Investigate how this problem is currently being solved or what efforts scientists and engineers are making to find a solution.

Design. Use all information gathered to create the design(s). Design includes modeling possible solutions, refining models, and choosing the model(s) that best meets the original need or problem.

Prototype. Construct a prototype, or physical model, based on the design model(s). Prototypes are used to test proposed solutions.

Test and Evaluate. Test prototype to determine how effectively it solves the need or problem. Collect data to use as evidence of success or need for improvement. Redesign and refine prototypes to continue looking for possible solutions.

Communicate, Explain, and Share. Communicating, explaining, and sharing the solution and design is essential to tell others how it works, how it solves (or does not solve) the identified need or problem, and how it meets (or fails to meet) the criteria and constraints. Determining how to communicate and act on constructive criticism is critical.

The Engineering Design Challenge

The Challenge

Student teams will design and build a tabletop model of a plant growth chamber that can be folded, stowed, and shipped on a rocket destined for the Moon. When the shipment arrives, the future lunar astronauts will then be able to expand the plant growth chamber and deploy it on the lunar surface. Because this project is in the development stage, the team will only need to design, build, and present a tabletop model of the plant growth chamber rather than a full-size lunar structure designed to grow enough food for the entire lunar crew.

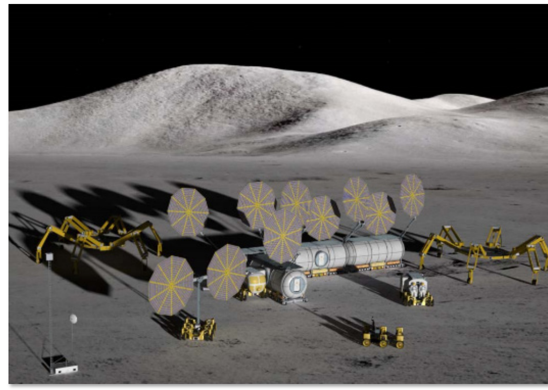


Figure 23. Artist's conception of a potential lunar outpost. (NASA)

Criteria and Constraints

The plant growth chamber must meet the following criteria and constraints:

1. On the rocket, the plant growth chamber model must not exceed a mass of 50 g and a stowed volume of 1,000 cm^3.
2. The deployed plant growth chamber can be any shape; however, the volume cannot exceed 1,000,000 cm^3.
3. The deployed plant growth chamber may or may not be connected to the lunar habitat, but it must provide a way for astronauts to have access to the chamber.
4. The model plant growth chamber must use a system of expansion from its stowed shipment package on the rocket to its final deployed structure on the Moon.

Options for Differentiating Instruction

The following suggestions may be used when modifying this engineering design challenge for students outside of the designated age range or ability levels.

Modification

- Consider removing the requirement for a method of access into and out of the chamber.

Enrichment

- Consider requiring an access port of a specific size for the astronauts to use.

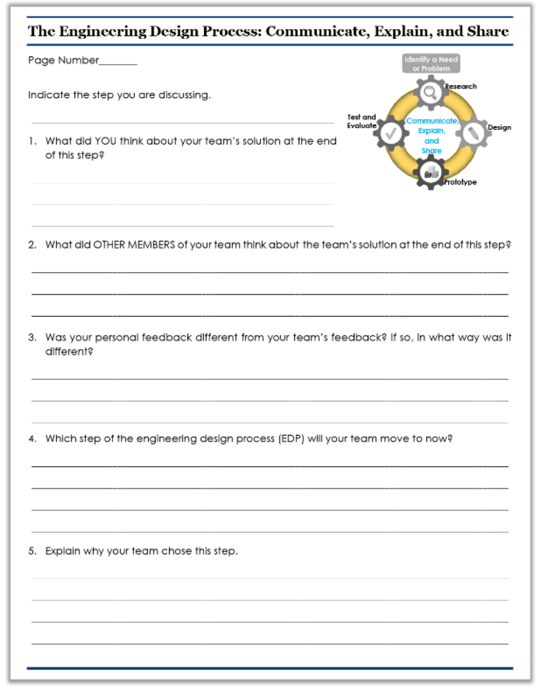
Student Team Challenge Journals

Students will be creating their Student Team Challenge Journals as they move through the engineering design process (EDP) to solve the challenge. Take time prior to starting the challenge to explain the best way for students to document their work and what the goals are for completing the challenge. The pages should document how student teams moved through the EDP. Students should be instructed to use as many sheets as needed to document each step of the process.

1. Always fill in the page number. This will help keep the pages in order.
2. Direct students to collaborate within their teams and use the five questions on the Communicate, Explain, and Share page to think about where they are in the process before they move on to the next step. Allow for extra copies of this section if needed. Here is an example: "We are moving back to the design phase because the prototype failed to meet the criteria. It was 50 g over the limit."
3. When documenting the prototype stage, remind students to make note of any challenges they faced in building the design and how those challenges were resolved.

As students proceed through the process, they should record steps accomplished on the Team Progress Chart, found at the back of the Student Team Challenge Journal. Think of this chart as a Table of Contents for the journals that are being created as students move through the process.

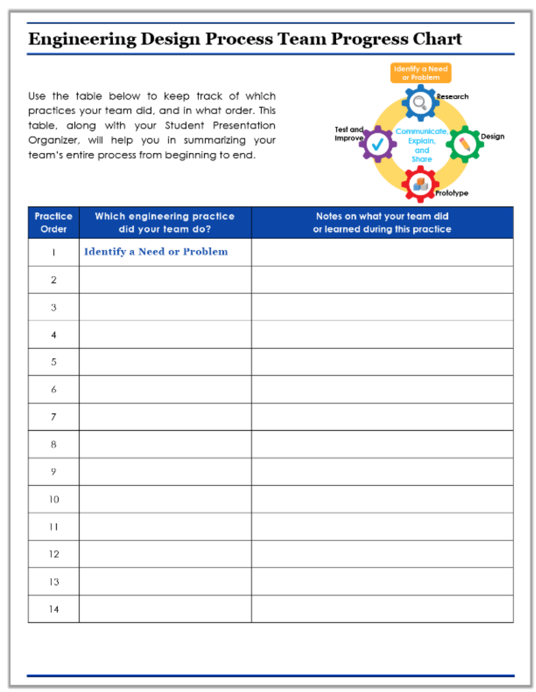
In order to successfully complete the engineering design challenge, teams must use the EDP. As they work the steps of the EDP, students will be engaging in authentic engineering practices.


The Engineering Design Process: Communicate, Explain, and Share

Page Number______

Indicate the step you are discussing.

1. What did YOU think about your team's solution at the end of this step?
2. What did OTHER MEMBERS of your team think about the team's solution at the end of this step?
3. Was your personal feedback different from your team's feedback? If so, in what way was it different?
4. Which step of the engineering design process (EDP) will your team move to now?
5. Explain why your team chose this step.


Engineering Design Process Team Progress Chart

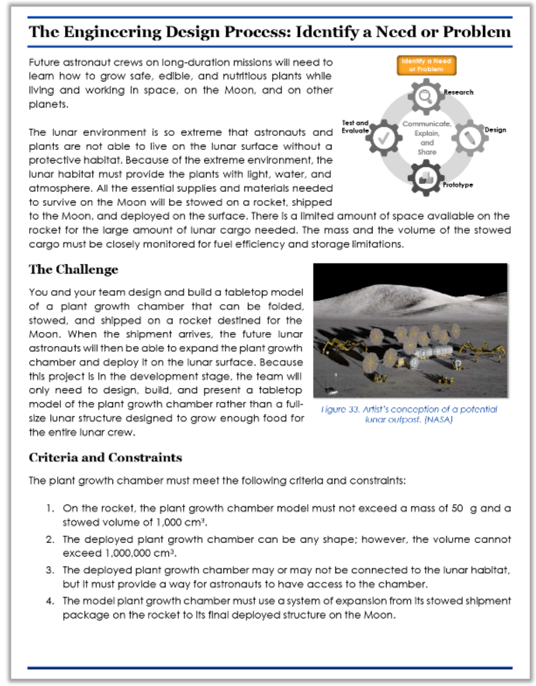
Use the table below to keep track of which practices your team did, and in what order. This table, along with your Student Presentation Organizer, will help you in summarizing your team's entire process from beginning to end.

Practice Order	Which engineering practice did your team do?	Notes on what your team did or learned during this practice
1	Identify a Need or Problem	
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		

Identify a Need or Problem

Students complete the Identify a Need or Problem page from the Student Team Challenge Journal.

Engineering design begins by identifying a need or problem that an attempt can be made to solve, improve, and/or fix. This typically includes articulation of criteria and constraints that will define a successful solution.



The Engineering Design Process: Identify a Need or Problem

Future astronaut crews on long-duration missions will need to learn how to grow safe, edible, and nutritious plants while living and working in space, on the Moon, and on other planets.

The lunar environment is so extreme that astronauts and plants are not able to live on the lunar surface without a protective habitat. Because of the extreme environment, the lunar habitat must provide the plants with light, water, and atmosphere. All the essential supplies and materials needed to survive on the Moon will be stowed on a rocket, shipped to the Moon, and deployed on the surface. There is a limited amount of space available on the rocket for the large amount of lunar cargo needed. The mass and the volume of the stowed cargo must be closely monitored for fuel efficiency and storage limitations.

The Challenge

You and your team design and build a tabletop model of a plant growth chamber that can be folded, stowed, and shipped on a rocket destined for the Moon. When the shipment arrives, the future lunar astronauts will then be able to expand the plant growth chamber and deploy it on the lunar surface. Because this project is in the development stage, the team will only need to design, build, and present a tabletop model of the plant growth chamber rather than a full-size lunar structure designed to grow enough food for the entire lunar crew.

Figure 33. Artist's conception of a potential lunar outpost. (NASA)

Criteria and Constraints

The plant growth chamber must meet the following criteria and constraints:

1. On the rocket, the plant growth chamber model must not exceed a mass of 50 g and a stowed volume of 1,000 cm^3.
2. The deployed plant growth chamber can be any shape; however, the volume cannot exceed 1,000,000 cm^3.
3. The deployed plant growth chamber may or may not be connected to the lunar habitat, but it must provide a way for astronauts to have access to the chamber.
4. The model plant growth chamber must use a system of expansion from its stowed shipment package on the rocket to its final deployed structure on the Moon.

Guiding Questions

Use the following guiding questions as discussion prompts to focus student understanding.

- How can our team design a _____ that will _____?
- What needs to be solved or improved?
- What are we trying to accomplish?

Instructional Procedure

1. Review the engineering design process with students.
2. Show the NASA Beginning Engineering Science and Technology (BEST) video titled "Repeatability," found at https://www.youtube.com/watch?v=-2Az1KDn-YM.
3. Ask students to identify the specific criteria and constraints of the design challenge.
4. Have students fill out the Identify a Need or Problem page in the Student Team Challenge Journal.

Differentiation Suggestions

Modifications

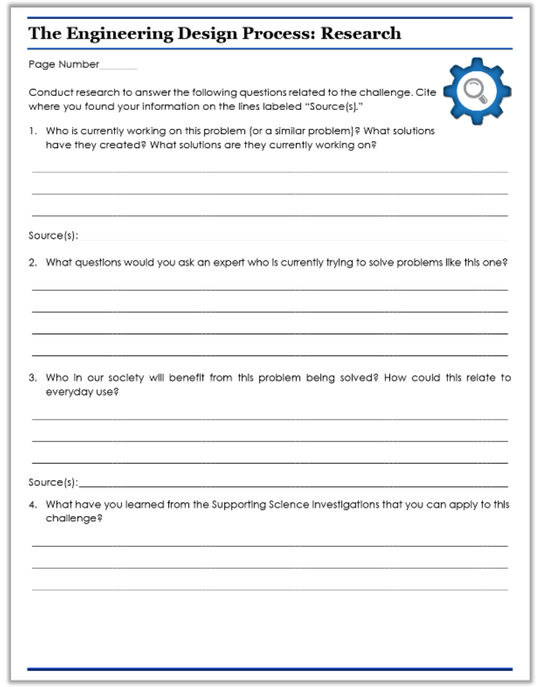
- Allow students extra time to discuss the challenge itself, the problem that needs to be solved, and how the problem could be solved.
- Introduce criteria and constraints one at a time. Allow student designs to meet one challenge requirement successfully before introducing additional requirements.

Enrichment

- Require students to write a letter or an email to a friend as if they were explaining their first job as a newly hired NASA engineer.

Research

Students complete the Research page from the Student Team Challenge Journal.


The Engineering Design Process: Research

Page Number______

Conduct research to answer the following questions related to the challenge. Cite where you found your information on the lines labeled "Source(s)."

1. Who is currently working on this problem (or a similar problem)? What solutions have they created? What solutions are they currently working on?

Source(s):

2. What questions would you ask an expert who is currently trying to solve problems like this one?

3. Who in our society will benefit from this problem being solved? How could this relate to everyday use?

Source(s):

4. What have you learned from the Supporting Science Investigations that you can apply to this challenge?

Research is done to learn more about the identified need or problem and potential solution strategies. Students can use resources from the internet, the library, or discussion with experts to examine how this problem or similar problems are currently being solved.

Guiding Questions

Use the following guiding questions as discussion prompts to focus student understanding.

- Where can you find more information about the topic?
- What questions would you ask an expert or an engineer who is currently working on this problem?
- Who in our society will benefit from this problem being solved?

Instructional Procedure

1. Help students answer any questions they have about the challenge. Use the internet or a school library to research answers.
2. Write down any unanswered questions and save them to ask the NASA subject matter expert (SME) during live connections.
3. Have team members fill out the Research page in the Student Team Challenge Journal.

Differentiation Suggestions

Modifications

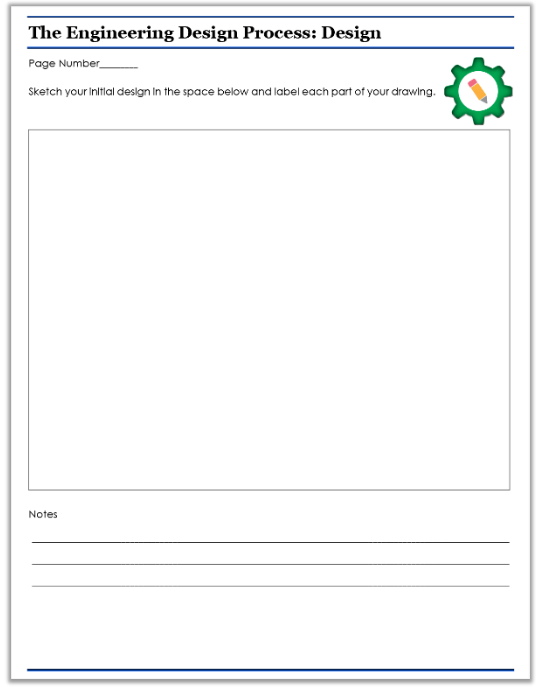
- Provide a list of reputable online resources students can use.
- Arrange a visit to a library.
- Pair up students to complete their research together.

Enrichment

- Have students provide a properly formatted citation for one or more resources.

Design

Students complete the Design pages from the Student Team Challenge Journal.


The Engineering Design Process: Design

Page Number______

Sketch your initial design in the space below and label each part of your drawing.

Notes

The design stage includes modeling possible solutions, refining the models, and choosing the model that best meets the original need or problem.

Guiding Questions

Use the following guiding questions as discussion prompts to focus student understanding.

- What are all the different ways each member of the team can imagine to solve the problem?
- What do we need to add to the design?
- What could go wrong if we add to the design?
- Do the drawings address all the criteria and constraints?

Instructional Procedure

1. Ask each team member to brainstorm individually and make sketches representing ideas for a solution. Students must clearly label and identify each part of their drawing.
2. Each team member should make sure that designs meet all constraints and criteria.
3. Have students sketch their ideas on the Design page in the Student Team Challenge Journal.
4. Ask team members to discuss their ideas and drawings with the rest of the team.
5. Have students record the strengths of each of the designs.
6. Have students fill out the Best Possible Solution page in the Student Team Challenge Journal.

Differentiation Suggestions

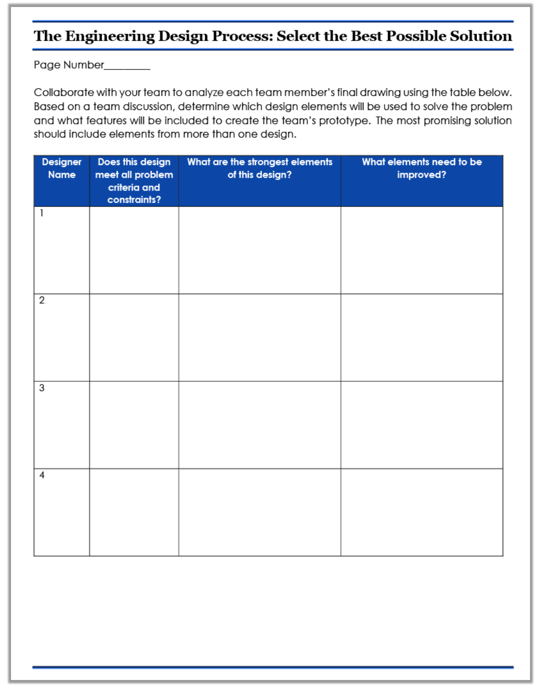
Modifications

- Encourage students to create a series of storyboards rather than a single complete drawing.
- Show students the building materials to help them visualize their sketch prior to beginning the drawing.

Enrichment

- Require students to specify measurements.

Analyzing the Designs



The Engineering Design Process: Select the Best Possible Solution

Page Number________

Collaborate with your team to analyze each team member's final drawing using the table below. Based on a team discussion, determine which design elements will be used to solve the problem and what features will be included to create the team's prototype. The most promising solution should include elements from more than one design.

Designer Name	Does this design meet all problem criteria and constraints?	What are the strongest elements of this design?	What elements need to be improved?
1			
2			
3			
4			

Team members analyze each member's final drawing using the table provided in the Student Team Challenge Journal.

Based on a team discussion, team members will determine which design elements will be used to solve the problem and what features will be included to create the team's prototype. The most promising solution should include elements from more than one design.

Guiding Questions

Use the following guiding questions as discussion prompts to focus student understanding.

- What is one strength of each student's individual design?
- How can that be incorporated into a group design?
- Are the strengths in each design related to the criteria and constraints of the challenge?
- Are elements from each team member's design represented in the final design?

Differentiation Suggestions

Modification

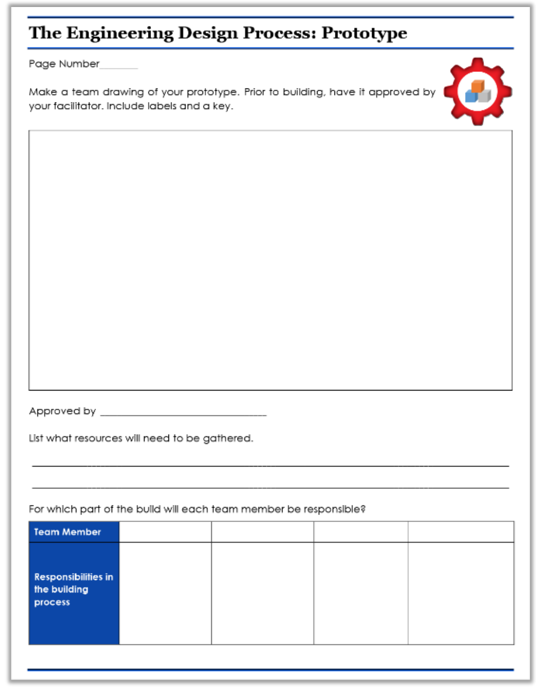
- Have students pick one aspect or characteristic at a time from each team member's drawing to discuss in the group.

Enrichment

- Require students to draw one or more parts of the design to scale.

Prototype

Students complete the Prototype page from the Student Team Challenge Journal.



The Engineering Design Process: Prototype

Page Number______

Make a team drawing of your prototype. Prior to building, have it approved by your facilitator. Include labels and a key.

Approved by ____________________

List what resources will need to be gathered.

For which part of the build will each team member be responsible?

Team Member				
Responsibilities in the building process				

A prototype is constructed based on the design model and used to test the proposed solution. A final design should be drawn precisely and labeled with a key. Facilitators should approve final drawings before building begins. Facilitators are expected to assist students as necessary to ensure classroom safety.

Guiding Questions

Use the following guiding questions as discussion prompts to focus student understanding.

- What resources does your team need to gather?
- What is the plan?
- Who is doing what?

Instructional Procedure

1. Ask each team to identify the design that appears to solve the problem.
2. A final diagram of the design should be drawn precisely and labeled with a key.
3. Have each team determine what materials they will need to build their design and assign responsibilities to team members for prototype completion.
4. Be sure to approve the final drawings before building begins.
5. After teams receive their materials to build their prototype, have them complete a budget sheet showing their building material costs.
6. Have teams construct their prototypes using their drawings.
7. Have teams fill out the Prototype page in the Student Team Challenge Journal.

Differentiation Suggestions

Modification

- Give students extra time to explore various materials prior to building the model.

Enrichment

- Limit materials to add complexity (e.g., only 1 m of duct tape).

Test and Evaluate

Students complete the Test and Evaluate pages from the Student Team Challenge Journal.

Student teams should test their prototypes to determine how effectively they addressed the need or problem and collect data to serve as evidence of their success or need for improvement. Remind students that they must test their prototypes a minimum of three times for each iteration to ensure the validity of their results.

Guiding Questions

Use the following guiding questions as discussion prompts to focus student understanding.

- Did the team collect enough data to analyze the design?
- How did the prototype perform when tested?
- Did the design meet or exceed the criteria and constraints?

Instructional Procedure

1. Visit each team and test their designs to ensure they meet all challenge criteria and constraints.
2. Have teams fill out the Test and Evaluate pages in the Student Team Challenge Journal.

Differentiation Suggestions

Modification

- Encourage students to test only one criteria or constraint at a time rather than all of them at once.

Enrichment

- Create a scatter plot of test results.

The Engineering Design Process: Test and Evaluate

Page Number________

1. Does the plant growth chamber function as intended?

   YES NO

2. If not, explain why. Provide details.

3. Does it meet all of the criteria and constraints? (Check the box for each one that is met.)
   - ☐ On the rocket, the plant growth chamber model must not exceed a mass of 50 g and a stowed volume of 1,000 cm^3.
   - ☐ The deployed plant growth chamber can be any shape; however, the volume cannot exceed 1,000,000 cm^3.
   - ☐ The deployed plant growth chamber may or may not be connected to the lunar habitat, but it must have a way for astronauts to have access to the chamber.
   - ☐ The model plant growth chamber must use a system of expansion from its stowed shipment package on the rocket to its final deployed structure on the Moon.

4. If not, explain why. Provide details.

Measure your design and record your results in the table on the next page. Include results from previous iterations as well. Use the following formulas to calculate volume based upon the shape of your design:

Square or rectangle: **Length x Width x Height**

Pyramid: **(Length x Width x Height) / 3**

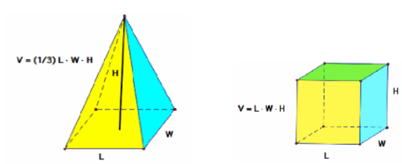
Cylinder: **π x Radius² x Height**

Cone: **π x Radius² x (Height / 3)**

π = the Greek number pi. For the purposes of this challenge, the accepted value of pi is **3.14159.**

To calculate the volume, multiply the length, width, and height for both the stored and deployed model. All of your answers must be labeled as cubic centimeters (cm^3).

Examples for finding volume:



Pyramid Cube

Iteration	Shape	Stored Volume	Deployed Volume	Mass	Observations
1					
2					
3					

5. When your model was deployed, were there any issues with the deployment? If so, what were they?

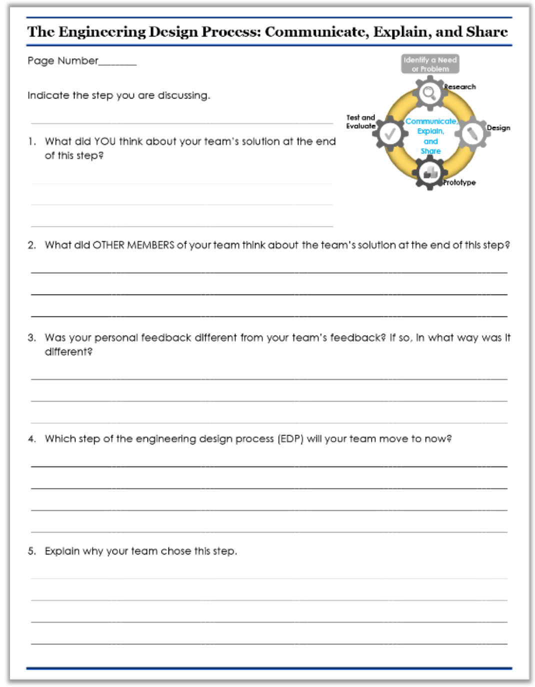
6. How did you expand the plant growth chamber from the stowed configuration to the deployed area on the lunar surface?

Communicate, Explain, and Share

Students complete the Communicate, Explain, and Share pages from the Student Team Challenge Journal.

Throughout the process, students will take time to reflect on their progress and consider what steps should be taken next. For this challenge, students will share with their peers, both one-on-one and as a classroom. Oral and written peer feedback will help students improve their solutions and designs. It is important for students to learn the peer-review process and to be accepting of others' suggestions.

Students will complete the Communicate, Explain, and Share pages after each step to maintain direction and focus during the engineering design process (EDP). Communicating, explaining, and sharing the solution and design is essential to conveying how it works, how it solves the identified need or problem, and how it meets the criteria and constraints. Using the Student Presentation Organizer will help students create the presentation that will be submitted when the challenge has been completed.


The Engineering Design Process: Communicate, Explain, and Share

Page Number______

Indicate the step you are discussing.

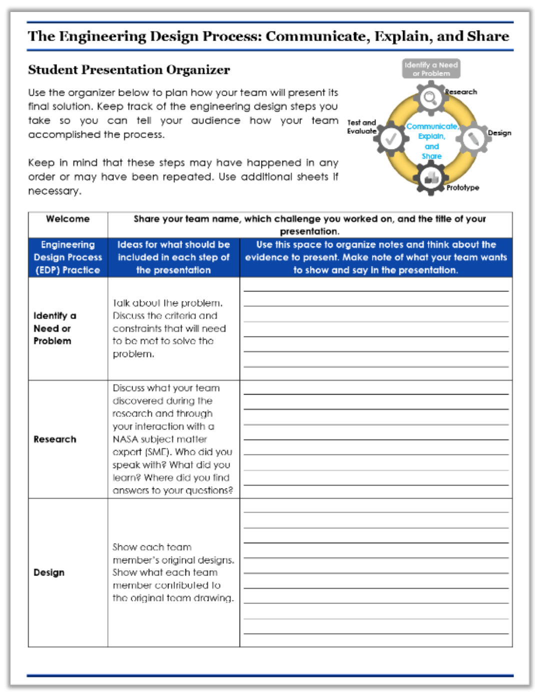
1. What did YOU think about your team's solution at the end of this step?

2. What did OTHER MEMBERS of your team think about the team's solution at the end of this step?

3. Was your personal feedback different from your team's feedback? If so, in what way was it different?

4. Which step of the engineering design process (EDP) will your team move to now?

5. Explain why your team chose this step.


The Engineering Design Process: Communicate, Explain, and Share

Student Presentation Organizer

Use the organizer below to plan how your team will present its final solution. Keep track of the engineering design steps you take so you can tell your audience how your team accomplished the process.

Keep in mind that these steps may have happened in any order or may have been repeated. Use additional sheets if necessary.

Welcome	Share your team name, which challenge you worked on, and the title of your presentation.	
Engineering Design Process (EDP) Practice	Ideas for what should be included in each step of the presentation	Use this space to organize notes and think about the evidence to present. Make note of what your team wants to show and say in the presentation.
Identify a Need or Problem	Talk about the problem. Discuss the criteria and constraints that will need to be met to solve the problem.	
Research	Discuss what your team discovered during the research and through your interaction with a NASA subject matter expert (SME). Who did you speak with? What did you learn? Where did you find answers to your questions?	
Design	Show each team member's original designs. Show what each team member contributed to the original team drawing.	

Guiding Questions

Use the following guiding questions as discussion prompts to focus student understanding.

- What did or did not work in the latest iteration of the design? Why or why not?
- What are the pros and cons of this solution?
- Did each team show that they used all of the processes of the EDP?

Instructional Procedure

1. Ask team members to document and report the results of their designs.
2. Have students identify what changes were made with each iteration of the design and what the team believed caused the design to succeed or fail.

3. Students should complete the corresponding sheets in the Student Team Challenge Journal to help them think about how they completed each step of the EDP.
4. Students should use the Team Progress Chart to document progress as they work on their solutions.
5. Teams should use the Student Presentation Organizer to guide them through the creation of the team video or slide presentation.

Differentiation Suggestions

Modification

- Provide a few basic yes/no questions for students to answer to determine whether their design was successful or not.

Enrichment

- Have student teams use a variety of media to create their presentation.

Evaluation: Student Debriefing Questions

The following questions are designed to help start a discussion with your students. After the design challenge is complete, have teams work together to answer these questions.

1. Why did your team use this approach to solve the problem?
2. How did your research help you decide that this was the best solution?

   Encourage students to talk about their thought processes. How did they make their decisions? Was their approach logical and well reasoned? Do they understand the goals?

3. What changes did you make to your design during your iterations of redesign?
4. How could you further improve on your design?

   Questions 3 and 4 will confirm that students have correctly identified the flaws in their designs and are working to correct them.

5. What were the greatest challenges for your team throughout this process?

   Emphasize to students that even the most successful engineers have setbacks.

6. What strategies did your team use that proved effective in overcoming challenges?

   Have students elaborate on why they chose certain options or strategies. Did collaborative discussion or debate help them generate more or better ideas?

7. How did you use the engineering design process (EDP) to help with your design?

   Make sure students talk about each practice and discuss how the process helped them complete the challenge.

8. What concerns must be considered in constructing a model plant growth chamber for transport on a spacecraft?

   Emphasize safety and meeting the criteria and constraints. Encourage students to utilize proper scientific terminology and the vocabulary embedded in this guide.

9. What specific problems did you have to address in designing the plant growth chamber?

   This could include technical problems as well as interpersonal problems. Emphasize how the students worked to find a solution to each problem. Was test data consistent? Have students describe any unusual results and tell what might have happened to cause them.

10. If you were an astronaut heading to an off-Earth destination, would you trust your team's plant growth chamber to allow you to grow food for your survival off Earth? Why or why not?

    This question can serve two purposes. One allows students to visualize themselves as astronauts as a way to evaluate their solution in a real-world context. The other allows students to consider various career pathways such as electrical or mechanical engineer, repair technician, or payload scientist.

Creating Solution Presentations

For the final stage of the challenge, students will document their progress in a video or slide presentation to share with other groups who have completed this engineering design challenge. The Student Team Challenge Journal was designed to help document each stage of the engineering design process (EDP). Encourage students to use their journals to help build the presentation.

Submission Guidelines

The finished presentation must meet the following guidelines:

- The introduction must say this: "This is team (team name) and we worked on the (name of challenge). The title of our presentation is (presentation title)."

  Do not identify by name any student, teacher, school, group, city, or region in your presentation. Submissions that do not follow these directions will be disqualified.

- The presentation should document every step students took to complete the challenge, including the Supporting Science Investigations.
- Identify any information provided by NASA subject matter experts (SMEs) that helped you in your design or testing.
- Explain which characteristics of the design provided the most reliable results and why.
- The total length of the presentation should be 3 to 5 minutes.

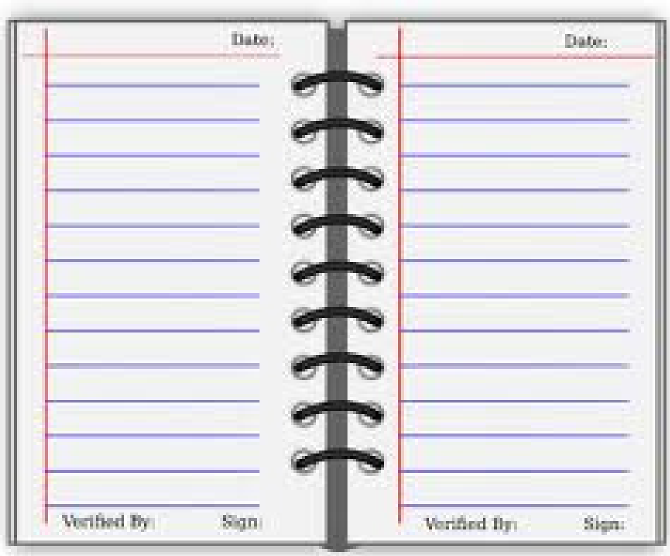
Once the video or slide document is complete, submit the presentations using the process explained on Y4Y (You for Youth) website.

Budget Reporting Worksheet

Directions: As a team, complete the cost sheet below. Be sure to include all materials needed, unit cost, quantity, and the item total needed to complete your design. At the end, total up the entire cost of your solution.

Line Item Number	Material	Unit Cost	Quantity	Item Total
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
			Total Cost:	

Student Team Challenge Journal



Supporting Science Investigation 1: Jackson Cubes

Concept

In this activity, you will discover how paper can be folded to create solid structures. You will use multicolored sheets of paper to create a cube that can be quickly built and dismantled. A cube is a symmetrical three-dimensional shape, either solid or hollow, contained by six equal squares.

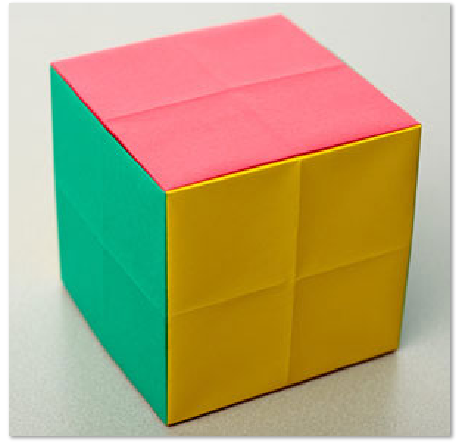


Figure 24. You will create a sturdy cube by folding squares of paper.

Materials

- 3–6 different-colored paper squares
- Ruler

Procedure

1. Gather materials.
2. Fold a square of paper in half, then unfold it.
3. Rotate the paper 90 degrees. Fold it in half, then unfold it.

At this point, you should have a square of paper with two folds that create a + sign in the middle of the paper.

4. Fold the nearest edge of paper to one of the center folds you created.
5. Rotate the paper 180 degrees and fold that edge of the paper to the same center fold.
6. Rotate the paper 90 degrees and fold that edge to the other center fold.
7. Rotate the paper 180 degrees and fold that edge of the paper to the same center fold.
8. Partly unfold the final two folds so the ends of the paper are pointing upright.

At this point, you should have a folded piece of paper in the shape of the letter U (Fig. 25).

9. Repeat steps 2 through 8 five more times. This will provide you with all six sides of the cube.

Figure 25. Students will create the six walls of the cube one side at a time.

10. Start building the cube by placing three of the folded walls together, as shown in Figure 26:

Figure 26. Place the first three walls together.

11. Add the next two sides, as shown here in green (Fig. 27):

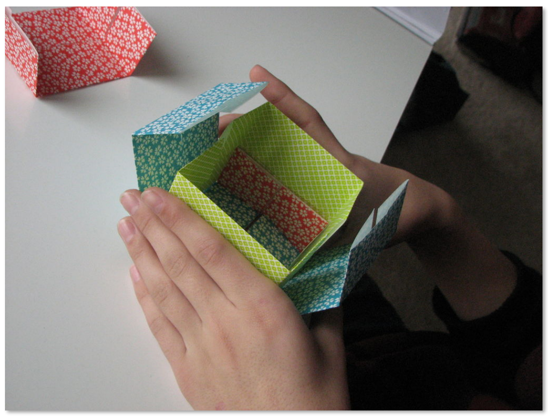


Figure 27. Add the next two sides of the cube.

12. Slot in the final section, ensuring that it locks in between the two side walls (Fig. 28). The cube is now complete.

Figure 28. Slot in the final section.

13. You can modify your cube, trying different sizes of paper.

14. Complete the questions on the Data Collection Sheet.

Data Collection Sheet

Using a ruler, measure the height, width, and length of your cube. From there, use the formula below to calculate the volume of your cube.

Length x Height x Width = Volume

Length, cm	Height, cm	Width, cm	Volume, cm^3	Observations

1. Describe any difficulties building the cube.

____

____

____

____

2. How would you modify the cube's design if you were building a rectangular prism?

____

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____

Discussion Questions

The Jackson Cubes activity showed us that it is possible to make objects with a large volume using materials that by themselves contain very little volume.

1. Imagine you had to construct a large building using this method. Do you think it can be done? Why or why not?

____

____

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____

____

2. Imagine you had to construct a building on Mars using this method. Would it have to be built differently?

____

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3. How will you apply what you learned in this investigation to your design?

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Supporting Science Investigation 2: Stability

Concept

NASA began construction of the International Space Station (ISS) in November 1998 and completed it in 2011. The ISS is larger than a six-bedroom house and has a mass of almost a million pounds. The station's integrated truss structure is 357 ft long and is the longest man-made object to fly in space.

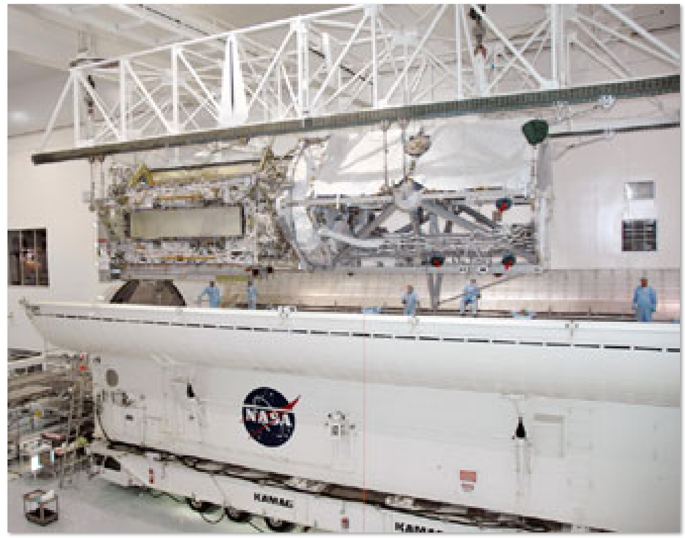


Figure 29. Inside the Kennedy Space Center's Space Station Processing Facility, the International Space Station's P3/P4 integrated truss segment is lowered into the cargo hold for transport and installation in the orbiter Atlantis. (NASA/Troy Cryder)

The ISS was constructed from many pieces that had to be packed onto a spacecraft, launched from Earth, taken into space, and assembled as the station orbited Earth. More than 115 space flights were conducted on five different types of launch vehicles over the course of the station's construction. The structural pieces fit inside the launch vehicle and was then able to be assembled and used on the ISS.

In this activity, you will discover how different shapes can be used to enhance the stability of a structure. You will work in teams to create a truss-like model that can support itself and additional weight.

Materials

For each group of 4 students:

- Box of drinking straws (approx. 100)
- Roll of masking tape
- Heavy objects of a known weight (e.g., a classroom set of paperback books, each one weighing the same, or a gram weight set)
- Scissors
- Meter stick
- Scale

Procedure

1. Discuss the ISS photos. Look at the photo of the truss segment being placed into the cargo hold for transport (Fig. 29) and observe what truss segments look like during and after assembly on the ISS (Figs. 30 and 31).
2. Divide into teams.

Figure 30. Astronauts Michael Lopez-Alegria and John Herrington work on the newly installed International Space Station's P1 truss during shuttle mission STS–113 in 2002. (NASA)

Figure 31. During Space Shuttle Discovery's 2009 mission to the International Space Station, the STS–119 crew delivered and installed the S6 integrated truss segment. This image was taken from Discovery as STS–119 performed a fly-around after undocking. (NASA)

3. Your team will build a model truss using only straws and masking tape. Half of the teams will build their model truss using a square shape for the structure, and half of the teams will use a triangle shape for the structure. Your three-dimensional model must have four flat sides. Your team can decide on the size of the squares or triangles during the design process.
4. Each team will build a model truss that spans two chairs at a distance of 50 cm.
5. Test the strength of your team's designs by adding a weight to the flat surface on top of the structure. Continue adding weight until the structure fails. Observe what is happening to the structure as it is being weighed down.
6. Record your design, number of straws used, and weight supported on the Data Collection Sheet.
7. Once your designs have been tested, think about and discuss how you might transport your team's truss off Earth.

Data Collection Sheet

Complete the table below using the results from your experiments.

Iteration (attempt) number	Shape of truss design structure	Number of straws used	Weight of truss, kg	Weight supported before failure, kg	Observation
1					
2					
3					
4					

1. Explain the results above. At what weight did the truss fail?

____

____

____

2. How was the shape relevant to the failure of the truss? Why do you think this? (Document your findings.)

____

____

____

____

____

Discussion Questions

The Stability investigation demonstrated how the shape of a material can affect the strength of the design when used in a system.

1. Can you think of other shapes that could be used to build a truss system?

2. We saw how trusses are used in the structure of the International Space Station. How else might a truss be used by astronauts in space or on another planet?

3. How will you apply what you learned in this investigation to your design?

The Engineering Design Process

The engineering design process (EDP) consists of a series of steps, each designed to help you develop a solution to a problem. Start with "Identify a Need or Problem" and use the EDP diagram shown here to help solve this challenge.

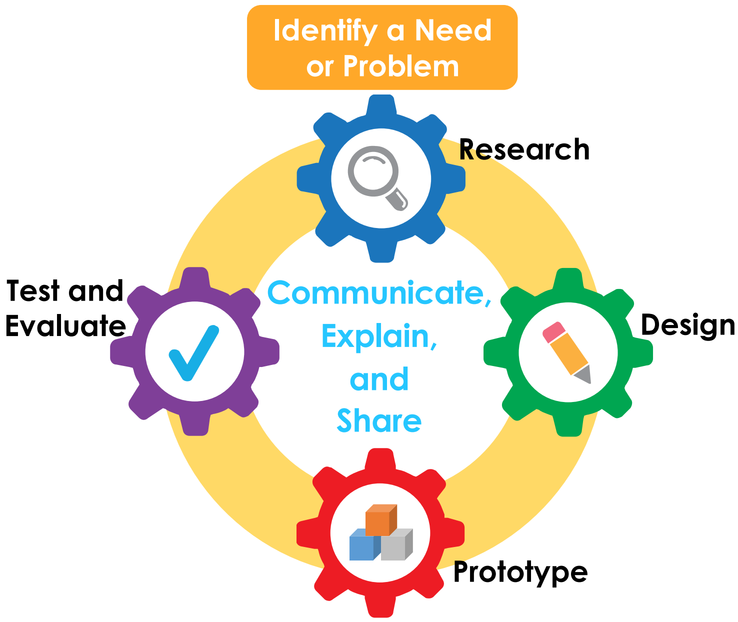


Figure 32. Engineering design process model. Model and accompanying text adapted from 2016 Massachusetts Science and Technology/Engineering Curriculum Framework, Massachusetts Department of Elementary and Secondary Education, http://www.doe.mass.edu/frameworks/scitech/2016-04.pdf.

Identify a Need or Problem. Identify a need or problem to be solved, improved, or fixed. Identify the criteria and constraints that will need to be met to solve the problem.

Research. Use resources from the internet, the library, or discussions with NASA scientists and engineers to learn more about the need or problem and possible solutions. Investigate how this problem is currently being solved or what efforts scientists and engineers are making to find a solution.

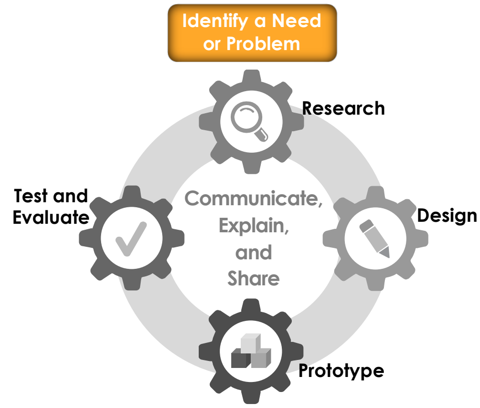
Design. Use all information gathered to create the design(s). Design includes modeling possible solutions, refining models, and choosing the model(s) that best meets the original need or problem.

Prototype. Construct a prototype, or physical model, based on the design model(s). Prototypes are used to test proposed solutions.

Test and Evaluate. Test prototype to determine how effectively it solves the need or problem. Collect data to use as evidence of success or need for improvement. Redesign and refine prototypes to continue looking for possible solutions.

Communicate, Explain, and Share. Communicating, explaining, and sharing the solution and design is essential to tell others how it works, how it solves (or does not solve) the identified need or problem, and how it meets (or fails to meet) the criteria and constraints. Determining how to communicate and act on constructive criticism is critical.

The Engineering Design Process: Identify a Need or Problem



Future astronaut crews on long-duration missions will need to learn how to grow safe, edible, and nutritious plants while living and working in space, on the Moon, and on other planets.

The lunar environment is so extreme that astronauts and plants are not able to live on the lunar surface without a protective habitat. Because of the extreme environment, the lunar habitat must provide the plants with light, water, and atmosphere. All the essential supplies and materials needed to survive on the Moon will be stowed on a rocket, shipped to the Moon, and deployed on the surface. There is a limited amount of space available on the rocket for the large amount of lunar cargo needed. The mass and the volume of the stowed cargo must be closely monitored for fuel efficiency and storage limitations.

The Challenge

You and your team design and build a tabletop model of a plant growth chamber that can be folded, stowed, and shipped on a rocket destined for the Moon. When the shipment arrives, the future lunar astronauts will then be able to expand the plant growth chamber and deploy it on the lunar surface. Because this project is in the development stage, the team will only need to design, build, and present a tabletop model of the plant growth chamber rather than a full-size lunar structure designed to grow enough food for the entire lunar crew.

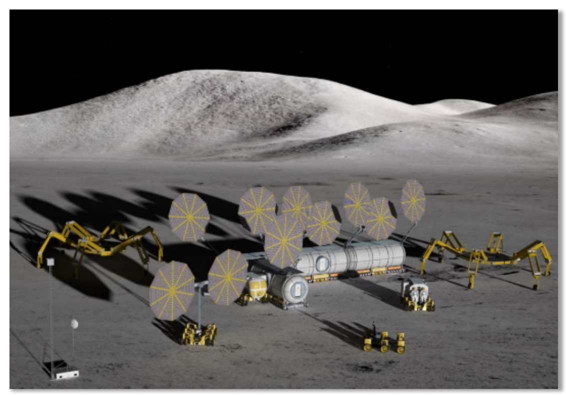


Figure 33. Artist's conception of a potential lunar outpost. (NASA)

Criteria and Constraints

The plant growth chamber must meet the following criteria and constraints:

1. On the rocket, the plant growth chamber model must not exceed a mass of 50 g and a stowed volume of 1,000 cm^3.
2. The deployed plant growth chamber can be any shape; however, the volume cannot exceed 1,000,000 cm^3.
3. The deployed plant growth chamber may or may not be connected to the lunar habitat, but it must provide a way for astronauts to have access to the chamber.
4. The model plant growth chamber must use a system of expansion from its stowed shipment package on the rocket to its final deployed structure on the Moon.

Packing Up for the Moon

Based on this information and the challenge's introductory video, answer the following questions.

1. Using your own words, restate the problem in this form: "How can I design a ________ that will ________?" Be sure to include all expected criteria and constraints.

____

____

____

2. What general scientific concepts do you and your team need to consider before you begin solving this need or problem?

____

____

____

The Engineering Design Process: Research

Page Number_________

Conduct research to answer the following questions related to the challenge. Cite where you found your information on the lines labeled "Source(s)."

1. Who is currently working on this problem (or a similar problem)? What solutions have they created? What solutions are they currently working on?

Source(s): ______________________________

2. What questions would you ask an expert who is currently trying to solve problems like this one?

3. Who in our society will benefit from this problem being solved? How could this relate to everyday use?

Source(s): ______________________________

4. What have you learned from the Supporting Science Investigations that you can apply to this challenge?

The Engineering Design Process: Design

Page Number_________

Sketch your initial design in the space below and label each part of your drawing.

Notes

____

____

____

____

The Engineering Design Process: Select the Best Possible Solution

Page Number_________

Collaborate with your team to analyze each team member's final drawing using the table below. Based on a team discussion, determine which design elements will be used to solve the problem and what features will be included to create the team's prototype. The most promising solution should include elements from more than one design.

Designer Name	Does this design meet all problem criteria and constraints?	What are the strongest elements of this design?	What elements need to be improved?
1			
2			
3			
4			

The Engineering Design Process: Prototype

Page Number_________

Make a team drawing of your prototype. Prior to building, have it approved by your facilitator. Include labels and a key.

Approved by ______________________________

List what resources will need to be gathered.

____

____

For which part of the build will each team member be responsible?

Team Member				
Responsibilities in the building process				

The Engineering Design Process: Test and Evaluate

Page Number_________

1. Does the plant growth chamber function as intended?

   YES NO

2. If not, explain why. Provide details.

3. Does it meet all of the criteria and constraints? (Check the box for each one that is met.)

   - ☐ On the rocket, the plant growth chamber model must not exceed a mass of 50 g and a stowed volume of 1,000 cm^3.
   - ☐ The deployed plant growth chamber can be any shape; however, the volume cannot exceed 1,000,000 cm^3.
   - ☐ The deployed plant growth chamber may or may not be connected to the lunar habitat, but it must have a way for astronauts to have access to the chamber.
   - ☐ The model plant growth chamber must use a system of expansion from its stowed shipment package on the rocket to its final deployed structure on the Moon.

4. If not, explain why. Provide details.

Measure your design and record your results in the table on the next page. Include results from previous iterations as well. Use the following formulas to calculate volume based upon the shape of your design:

Square or rectangle: **Length x Width x Height**

Pyramid: **(Length x Width x Height) / 3**

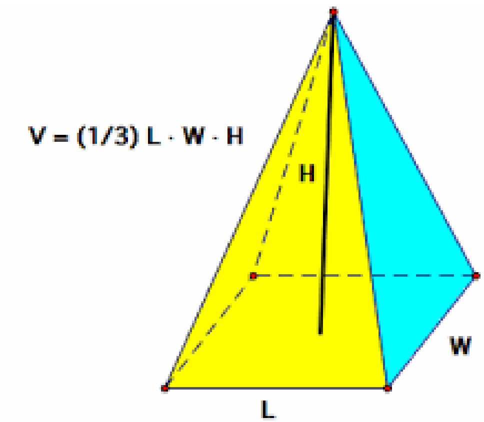
Cylinder: **π x Radius² x Height**

Cone: **π x Radius² x (Height / 3)**

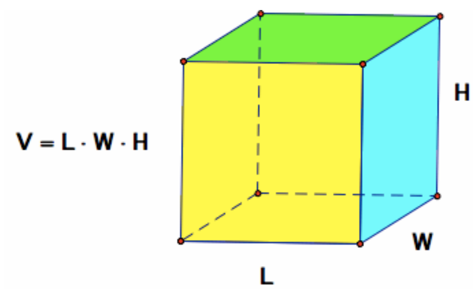
π = the Greek number pi. For the purposes of this challenge, the accepted value of pi is **3.14159**.

To calculate the volume, multiply the length, width, and height for both the stored and deployed model. All of your answers must be labeled as cubic centimeters (cm^3).

Examples for finding volume:



Pyramid



Cube

Iteration	Shape	Stored Volume	Deployed Volume	Mass	Observations
1					
2					
3					

5. When your model was deployed, were there any issues with the deployment? If so, what were they?

____

____

____

6. How did you expand the plant growth chamber from the stowed configuration to the deployed area on the lunar surface?

____

____

____

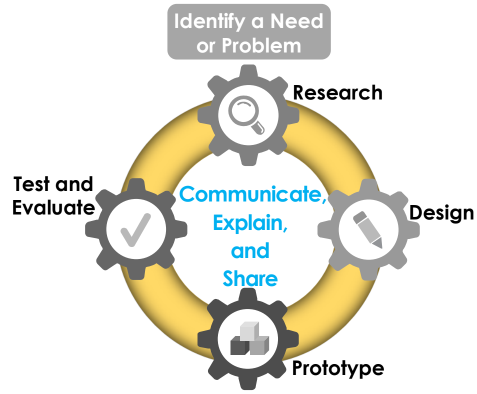
Make a drawing of the expansion system you designed to expand your model from the stowed position on the rocket to the deployed position on the lunar surface. Be sure to label all of the parts. Use a separate sheet of paper if needed.

Packing Up for the Moon

You and your team will need to make a map of the lunar surface to show where you are going to place your plant growth chamber in relation to the lunar habitat. Show how the astronauts will have access to the plant growth chamber. Use a separate sheet of paper if needed.

The Engineering Design Process: Communicate, Explain, and Share

Page Number_______



Indicate the step you are discussing.

____

1. What did YOU think about your team's solution at the end of this step?

____

____

____

2. What did OTHER MEMBERS of your team think about the team's solution at the end of this step?

____

____

____

3. Was your personal feedback different from your team's feedback? If so, in what way was it different?

____

____

____

4. Which step of the engineering design process (EDP) will your team move to now?

____

____

____

____

5. Explain why your team chose this step.

____

____

____

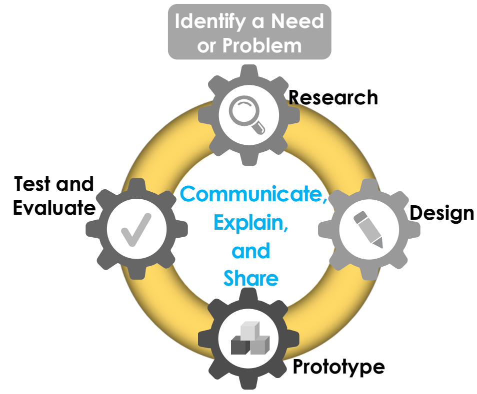
____

The Engineering Design Process: Communicate, Explain, and Share

Student Presentation Organizer

Use the organizer below to plan how your team will present its final solution. Keep track of the engineering design steps you take so you can tell your audience how your team accomplished the process.

Keep in mind that these steps may have happened in any order or may have been repeated. Use additional sheets if necessary.

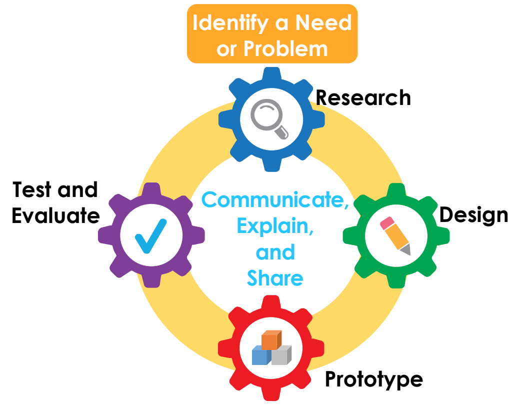


Welcome	Share your team name, which challenge you worked on, and the title of your presentation.	
Engineering Design Process (EDP) Practice	**Ideas for what should be included in each step of the presentation**	**Use this space to organize notes and think about the evidence to present. Make note of what your team wants to show and say in the presentation.**
Identify a Need or Problem	Talk about the problem. Discuss the criteria and constraints that will need to be met to solve the problem.	
Research	Discuss what your team discovered during the research and through your interaction with a NASA subject matter expert (SME). Who did you speak with? What did you learn? Where did you find answers to your questions?	
Design	Show each team member's original designs. Show what each team member contributed to the original team drawing.	

Prototype	Show materials used and how you put the prototype together.	
Test and Evaluate	Talk about how your team tested the design and discuss the results. Using the data, discuss the strengths and weaknesses of your team prototype.	
Communicate, Explain, and Share	Talk about your data. Was your team able to solve the problem or not? What improvements did your team make to reach your final solution? Discuss any further action your team would take to improve this solution. Describe how your team members communicated with each other to improve the solution. Also describe how you discussed options with people outside your group.	

Engineering Design Process Team Progress Chart

Use the table below to keep track of which practices your team did, and in what order. This table, along with your Student Presentation Organizer, will help you in summarizing your team's entire process from beginning to end.



Practice Order	Which engineering practice did your team do?	Notes on what your team did or learned during this practice
1	**Identify a Need or Problem**	
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		

Solution Presentation

The final stage of the challenge is to document your progress for sharing with other groups who have completed this engineering design challenge. Your journey may be documented using video or slide presentations.

The finished presentation must meet the following guidelines:

- The introduction must say this: "This is team (team name), and we worked on the (name of challenge). The title of our presentation is (presentation title)."

  Do not identify by name any student, teacher, school, group, city, or region in your presentation. Submissions that do not follow these directions will be disqualified.

- The presentation must document every step you took to complete the challenge, including the Supporting Science Investigations. Use every page of your Student Team Challenge Journal to help complete this presentation.
- Identify any information provided by NASA subject matter experts (SMEs) that helped you in your design or testing.
- Explain which characteristics of the design provided the most reliable results and why.
- The total length of the presentation should be 3 to 5 minutes.

Team Presentation Rubric

Student name ____________________ **Team name** ______________________

The Team Presentation Rubric will be used to evaluate the student team presentations (video, student presentation, and/or slide presentation).

1. In the introduction, the team name, the challenge name, and the title of the presentation were all included. Personal or identifying information was NOT given in the introduction.

0	1	2	3	4	5
Not included	Needs improvement	Below average	Average	Above average	Excellent

2. The team explained the challenge, including the criteria and the constraints.

0	1	2	3	4	5
Not included	Needs improvement	Below average	Average	Above average	Excellent

3. The team described the results of their research, including the STEM career they explored and the information they collected from the virtual connection with the NASA scientist or engineer.

0	1	2	3	4	5
Not included	Needs improvement	Below average	Average	Above average	Excellent

4. The team explained how they used the engineering design process to design and construct their final prototype or model.

0	1	2	3	4	5
Not included	Needs improvement	Below average	Average	Above average	Excellent

5. As a conclusion, the team described the challenges and successes they experienced as they built, tested, and improved their prototype or model.

0	1	2	3	4	5
Not included	Needs improvement	Below average	Average	Above average	Excellent

Comments and Encouragement

Vocabulary List

Atmosphere. Gaseous mass or envelope surrounding a celestial body

Constraints. Limits placed on a design due to available resources and environment

Criteria. Standards by which something may be judged or decided

Ecosystem. An ecological community and its physical environment

Growth chamber. An enclosed space that encourages something to grow

Iteration. One cycle of a repetitive process

Lunar. Of, involving, caused by, or affecting the Moon

Lunar atmosphere. The thin layer of gases surrounding the Moon's surface

Model. A small object, usually built to scale, that represents another larger object

Orbit. The path of a celestial body or artificial satellite as it revolves around another object

Prediction. The act of attempting to tell beforehand what will happen

Prototype. An original type, form, or instance that is a model on which later stages are based

Vacuum. The nearly total absence of gas molecules

Volume. The quantity of three-dimensional space enclosed by some closed boundary; for example, the space that a substance (solid, liquid, gas, or plasma) or shape occupies or contains

NASA Resources

Online Resources

To read more about orbiting agriculture on the International Space Station (ISS):
http://www.nasa.gov/missions/science/f_lada.html

To watch a video about plant biology on the ISS:
http://www.youtube.com/watch?v=iNangMq5wSQ

For a complex, comprehensive exploration of plant growth off Earth:
http://www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Lunar_Plant_Growth_Chamber.html#.VnLxo_krJhE

For an extensive review of NASA's mission on the ISS and the work being done there:
http://www.nasa.gov/mission_pages/station/research/experiments/185.html

Back cover: Future long-duration space missions will require crewmembers to grow their own food, so understanding how plants respond to microgravity is an important step toward that goal. The International Space Station's Veg-03 experiment uses the "Veggie" plant growth facility to cultivate Tokyo Bekana cabbage, red romaine lettuce, and mizuna. Crewmembers harvest the plants on orbit and return samples to Earth for testing. (NASA)

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NP-2019-04-054-GRC