National Aeronautics and
Space Administration

**21st Century Community Learning Center**
**NASA Engineering Design Challenge**

# Why Pressure Suits

## 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.

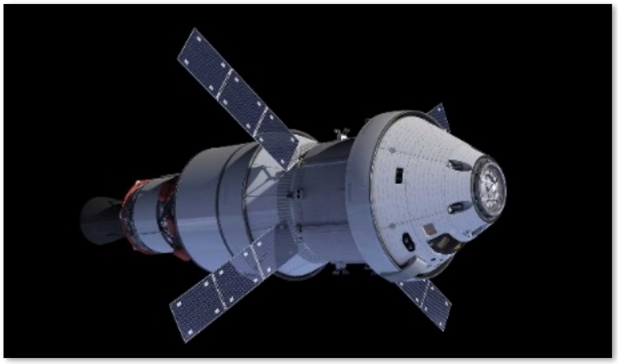


*Figure 1. Illustration of the Orion Spacecraft, a multi-purpose crew vehicle designed to carry astronauts into deep space. (NASA)*

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](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:

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

- 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.

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](https://www.nasa.gov/audience/forstudents/careers/profiles/index.html)

# Table of Contents

# 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

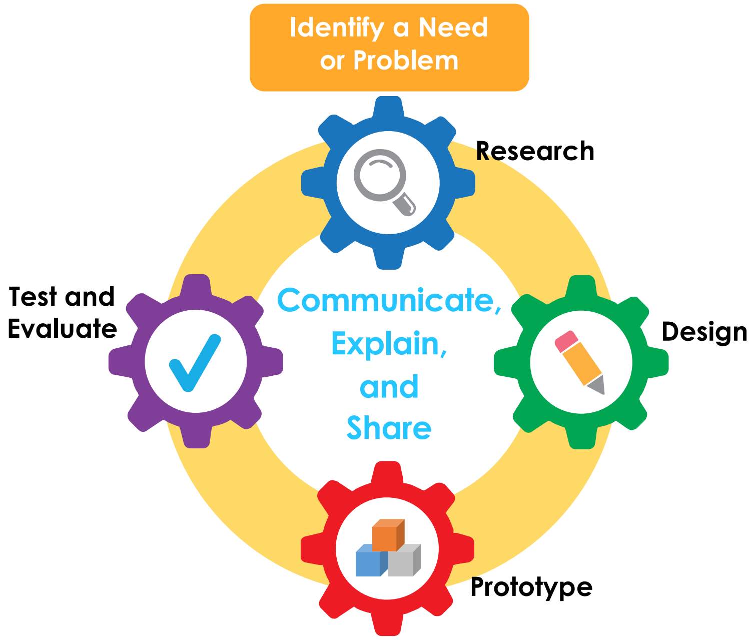



*Figure 5. Engineering design process model. Model and accompanying text adapted from 2016 Massachusetts Science and Technology/Engineering Curriculum Framework, Massachusetts Department of Elementary and Secondary Education, http://www.doe.mass.edu/frameworks/scitech/2016-04.pdf.*

**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: Why Pressure Suits

*Figure 6. A current NASA pressure suit. (NASA)*

NASA works tirelessly to ensure the safety of its pilots and astronauts. As research continues, the pressure suits that provide many layers of protection against the harsh environments of the upper atmosphere and space continue to improve. Pressure suits are necessary for space exploration. Because pilots and astronauts must complete their work in a near-vacuum or absolute-vacuum environment, the protective suits must exert pressure on the body to simulate Earth's environment to keep the pilots and astronauts safe at all times.

## The Challenge

Students will work in teams to design and build a pressure suit that will protect pilots and astronauts from the dangers of low-pressure environments. All materials used for the spacesuit must be tested in a vacuum to make sure they are safe in low-pressure environments. Student teams can use a marshmallow or a balloon to represent the pilot or astronaut.

## Criteria and Constraints

1. The protective suit must be constructed of materials that are not affected by near-vacuum or absolute-vacuum environments.
2. The pressure suit must completely surround the marshmallow or balloon astronaut.
3. The astronaut must fit completely within the vacuum chamber and have a total mass of less than 50 g.
4. The pressure suit must prevent the astronaut from expanding and constricting while in the vacuum chamber.

# 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**<br>• Complete the Team Building activities<br>• Explore NASA Mission Background and careers<br>• Complete the STEM Investigations<br>• Investigate each phase of the EDP | 2 sessions |
| **Identify a Need or Problem**<br>• Explore the challenge scenario and watch the introductory video<br>• Identify the criteria and the constraints of the challenge | 2 sessions |
| **Research**<br>• Brainstorm research questions related to the challenge scenario<br>• Complete a KWL chart<br>• Connect with a NASA scientist or engineer | 3 sessions |
| **Design**<br>• Complete an individual drawing of the prototype based on the challenge scenario, criteria, and constraints<br>• Evaluate each of the individual drawings for strength and unique ideas<br>• Combine all of the individual drawings and ideas into a team drawing | 3 sessions |
| **Prototype**<br>• Construct a prototype using the team drawing<br>• Evaluate the prototype against the criteria and constraints<br>• Create a budget worksheet that will record and calculate the material costs<br>• Demonstrate the ability to work effectively and respectfully with a team | 3 sessions |
| **Test and Evaluate**<br>• Complete the tests on the prototype according to the criteria and constraints of the challenge<br>• Collect and analyze data from each of the tests<br>• Determine how to best improve the prototype | 3 sessions |
| **Student Team Presentation**<br>• Collect photos and videos that will illustrate the process the team followed to complete the challenge<br>• Represent all phases of the EDP in the student team presentation<br>• 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***<br>• **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.<br>• **MS–ETS1–2** Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.<br>• **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.<br>• **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.<br>• **MP.4** Model with mathematics.<br>• **6.RP.1** Understand the concept of a ratio and use ratio language to describe a ratio relationship between two quantities.<br>• **6.RP.3** Use ratio and rate reasoning to solve real-world and mathematical problems.<br>• **7.RP.2** Recognize and represent proportional relationships between quantities.<br>• **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.<br>• **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).<br>• **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.<br>• **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.<br>• **WHST.6–8.9** Draw evidence from informational texts to support analysis, reflection, and research.<br>• **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:

- Vacuum pump
- Marshmallows or balloons (may or may not be filled with water)
- 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
- Cloth
- Clothespins
- Coffee filters
- Cotton balls
- Craft sticks or tongue depressors
- Glue sticks
- Mini aluminum foil pie pans
- 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

For many years, NASA scientists and engineers have been studying how the human body reacts to the vacuum of space. NASA studies have led to continuous improvements in protective suits that pilots and astronauts wear in low-Earth orbit and beyond.

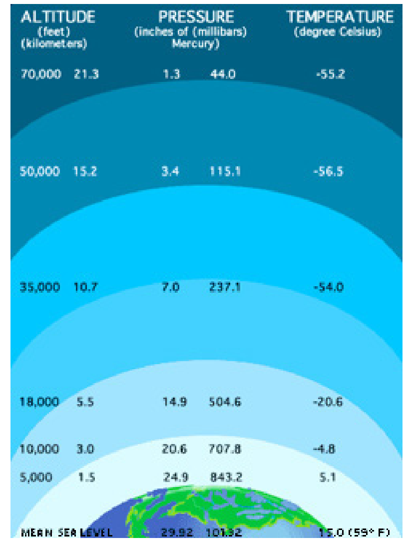



*Figure 9. The standard atmosphere, a generally accepted average of the Earth's conditions for all latitudes, altitudes, and seasons.*

## How does the human body react to the vacuum of space?

Traveling from the surface of the Earth to the upper atmosphere and beyond affects the human body in several different and drastic ways. Air pressure decreases as altitude increases. Space is a near-vacuum or low-vacuum environment because of the lack of air molecules.

While there is no visible delineation between the Earth's atmosphere and space, it is generally agreed that space begins about 100 km (62 miles) above the Earth's surface. The effects of high-altitude exposure on humans, however, begin well below this height.

At approximately 16 km (10 miles) above Earth, there is not enough air to breathe and normal body functions are affected. Cells and tissues start to lose oxygen. Astronauts or pilots will find it difficult to concentrate and will experience shortness of breath, nausea, and fatigue. This physical state is called hypoxia. When sudden decompression occurs, humans have only 5 to 10 seconds to correct the situation. During the first 9 to 11 seconds, they could begin to experience some loss of consciousness. After 13 seconds, their brains could be highly impaired.

Astronauts and high-altitude pilots are trained to react quickly to help themselves and others in these situations. The Federal Aviation Administration requires that an oxygen supply must be available if the plane's cabin pressure suddenly decreases. As pilots and astronauts travel higher into the atmosphere, the loss of pressure will cause water in their noses and mouths to boil. Water vapor will rush out of their bodies and rapidly cool their mouths and nose tissues to near-freezing temperatures.

*Figure 10. U–2 pilots like Air Force Col. Merryl Tengesdal must wear a full-pressure suit to fly the aircraft at high altitudes. Col. Tengesdal is the first black female U–2 pilot. (U.S. Air Force photo/Senior Airman Bobby Cummings)*

Within a short time, the liquid water in the soft tissues that line their lungs will also boil and make their bodies swell. Because skin is strong and porous, air will gradually leak out through their skin rather than bursting through their bodies. As long as blood keeps circulating through their bodies, the pressure of the heart pumping blood in their circulatory systems will keep the water in their blood below its boiling point.

Within 1 minute of vacuum exposure, however, the heart will stop pumping, causing blood to stop circulating and eventually boil. Although the reaction of the human body occurs within a minute, humans will not instantly freeze solid as some movies have shown.

*Figure 11. Astronauts Stan Love and Stephen Bowen wear spacesuits to practice tasks in the Neutral Buoyancy Laboratory at Johnson Space Center. Photo Credit: Bill Brassard (NASA)*

## Why does the human body need a pressure suit?

Because the human body is so vulnerable in low-pressure environments, NASA has spent many years researching how humans can survive and function in low-pressure environments. In 1966, Jim LeBlanc, a technician at NASA's Manned Spacecraft Center (now Johnson Space Center), was inadvertently exposed to a near-vacuum environment while testing a spacesuit prototype. A hose that supplied oxygen disconnected from the suit and caused it to depressurize. LeBlanc remained conscious for about 14 seconds before passing out. Once the chamber was safely repressurized, he regained consciousness. LeBlanc reported later that as he was losing consciousness, he heard air leaking from his body and felt the water on his tongue begin to boil.

Pressure suits must provide everything NASA astronauts need to survive in low-pressure environments and in space. Pressure suits for astronauts and high-altitude pilots must be protective as well as functional, allowing the user to operate machine controls and other equipment. Pressure suits are pressurized with a mixture of air to reduce the dangers associated with the flammability of pure oxygen. Pressure suits are self-contained environments that have systems to provide air, water, air pressure, and temperature regulation incorporated into them. Extra layers protect astronauts from micrometeoroids (small particles of rock flying at intense speeds) outside of the spacecraft.

*Figure 12. NASA's Z–2 spacesuit prototype. (NASA)*

The Z–2 suit, NASA's newest prototype for astronauts to live and work on Mars, incorporates many advances over previous models. The most significant advance is a hard composite upper torso, which provides more long-term durability than a planetary extravehicular activity (EVA) suit. The Z–2 suit is pressurized, uses 100 percent oxygen ($O_2$), and works with a carbon dioxide ($CO_2$) removal system that allows for a spacewalk lasting from 6 to 8.5 hours.

# 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.

- What is a pressure suit?
- Why does an astronaut need a pressure suit in space?
- Do we use pressure suits on Earth?
- What does a pressure suit do?
- Can you describe the environment on Mars?
- How does the environment on Mars differ from the environment on Earth?
- What could happen if a pressure suit failed?
- What are some of the things an astronaut might have to consider while working in a pressure suit?

## 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, students will perform both investigations, 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. NASA Glenn Research Center's Plum Brook Station in Sandusky, Ohio, houses the world's largest vacuum chamber. It measures 100 ft in diameter and is a towering 122 ft tall. (NASA)*

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

- Investigation 1: Balloons in Space
  - A vacuum is a lack of atmosphere.
  - Objects within a vacuum behave differently than they would in Earth's atmosphere.
  - The greater the vacuum, the more it affects an object.
  - Even an object that contains very little air will expand when placed in a vacuum.

- Investigation 2: Hands-On Vacuum
  - A vacuum is a lack of atmosphere.
  - Objects within a vacuum behave differently than they would in Earth's atmosphere.
  - The greater the vacuum, the more it affects an object.

# Supporting Science Investigation 1: Balloons in Space

## Concept

Balloons will expand in a vacuum environment. Human skin and lungs, which are somewhat similar to a balloon, can expand and stretch, but only to a certain point. Placing a small balloon inside a vacuum chamber will show students what would happen to their lungs in a vacuum environment such as space.

*Figure 14. Spacesuit training in a vacuum chamber at Johnson Space Center. (NASA)*

## Materials

For each group of 3 students:

- Vacuum pump and bell jar
- 2 small balloons (1 transparent)
- Water (optional)
- Tape measure
- Permanent marker

## Notes

- There are several budget-friendly alternatives to using an electric vacuum pump for this activity. Science supply companies sell hand-operated vacuum pumps and microscale bell jar and vacuum sets. Alternatively, many kitchen vacuum food sealers have an optional jar sealer that can be attached to a canning jar. All of these options create a partial-vacuum environment that would be suitable for this experiment.
- Information about water's boiling point can be found in the background information of this guide, and more activities about the relationship between temperature and pressure can be found in the temperature section of this guide.

## Procedure

1. Have students use the marker to draw a line around the largest part (middle) of the balloon. This will help them identify where to measure the circumference once the balloon is inflated.
2. Students inflate a small balloon. Do not overinflate the balloon. Have students use the tape measure to measure the circumference of the balloon prior to testing and record that information on their Data Collection Sheets.
3. Have students place the balloon inside the bell jar. It will expand to many times its normal size, so leave plenty of room for expansion in the jar.

4. Start the vacuum pump and ask students to observe what is happening to the balloon in the vacuum. Have students record their observations and answer the questions on their Data Collection Sheets. Have them measure the circumference of the balloon after this test.

*Step 5 may be completed by student teams or performed by the facilitator as a demonstration for students.*

5. Place a small transparent balloon filled with water in the chamber and turn on the vacuum pump. Have students record their observations and answer the questions on their Data Collection Sheets. The balloon will expand when the pump is turned on, but not as much as the air-filled balloon did, because water does not expand as a gas does. There is still air in the balloon, which allows the balloon to expand somewhat. The water in the balloon will begin to boil, even though the water's temperature is not increasing.

## 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 performing this as a demonstration-only activity, or with students taking turns turning the pump on and off.

### *Enrichment*

- Perform the experiment with other objects, such as a beach ball or basketball, and observe the effects on them.

# Supporting Science Investigation 2: Hands-On Vacuum

## Concept

Although watching demonstrations about pressure is helpful, allowing students to create a vacuum and manipulate their own miniature vacuum chamber will strengthen their understanding of the effects of air pressure. In this activity, students will take small marshmallows and place them in a large plastic syringe. They will create a miniature pressure chamber that will allow them to change the amount of pressure acting on their marshmallows and note the effects of varying amounts of air pressure on the marshmallows.


*Figure 15. The Altitude/Environmental/Space Testing facilities at Johnson Space Center provide vacuum, thermal, and thermal-vacuum chamber test operations for both manned and unmanned test environments. (NASA)*

## Materials

For each group of 2 students:

- Large plastic syringe with cap, piece of clay, or electrical tape to plug the end of the syringe
- Small marshmallows

## Procedure

To avoid injury, always use the syringe cap, a piece of clay, or electrical tape to cover the syringe tip opening. Emphasize that students should not use their fingers as a cap.

1. Have students place a small marshmallow inside their syringe.
2. Have students put the plunger back into the syringe, making sure the rubber piece is about halfway down the syringe.
3. Once the plunger is in place, have students put the cap, a piece of clay, or electrical tape on the tip of the syringe.
4. Once students have capped the tip of the syringe, ask them to pull back on the plunger, creating a lower-pressure environment. Students should note on their Data Collection Sheets what happens to the marshmallow (it should expand).
5. Have students push the plunger in as far as they can to create a higher-pressure environment, again noting what happens to the marshmallow (it should contract).
6. Let students experiment on their own with the marshmallow. Have students document the effects of changes in air pressure inside the syringe as they do so. Remind students that the effects of pressure on the marshmallow are similar to the effects on human bodies as they go higher into Earth's atmosphere and then into space. As they go higher into space, less pressure is exerted. In contrast, as humans dive deeper into water, more pressure is exerted.

## 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 using larger syringes to help younger students handle them easily.

*Enrichment*

- Consider using a piece of hose to connect two syringes together. Experiment with how the marshmallow reacts when both syringes apply vacuum or pressure simultaneously.

# 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: Balloons in Space

## Concepts Learned

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

- A vacuum in space is a lack of atmosphere.
- Objects within a vacuum behave differently than they would in Earth's atmosphere.
- The greater the vacuum, the more it affects an object.
- Even an object that contains very little air will expand when placed in a vacuum.

## Discussion Questions

The Balloons in Space activity uses a vacuum pump to demonstrate how a balloon reacts when subjected to the vacuum of space. If water was placed into the balloon, students observed that reaction as well.

1. How do you think the water-filled balloon would react if the glass broke and the pressure equalized immediately?
2. How will you apply what you learned in this investigation to your design?

# Investigation Discussion 2: Hands-On Vacuum

## Concepts Learned

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

- A vacuum is a lack of atmosphere.
- Objects within a vacuum behave differently than they would in Earth's atmosphere.
- The greater the vacuum, the more it affects an object.

## Discussion Questions

In this activity, we determined that a vacuum or a high-pressure environment can be created inside a syringe.

1. Imagine the syringe was three times larger. Would it create three times the change in pressure?
2. If this investigation used a small rock inside the syringe instead of a marshmallow, what do you think would happen to the rock? Why?
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

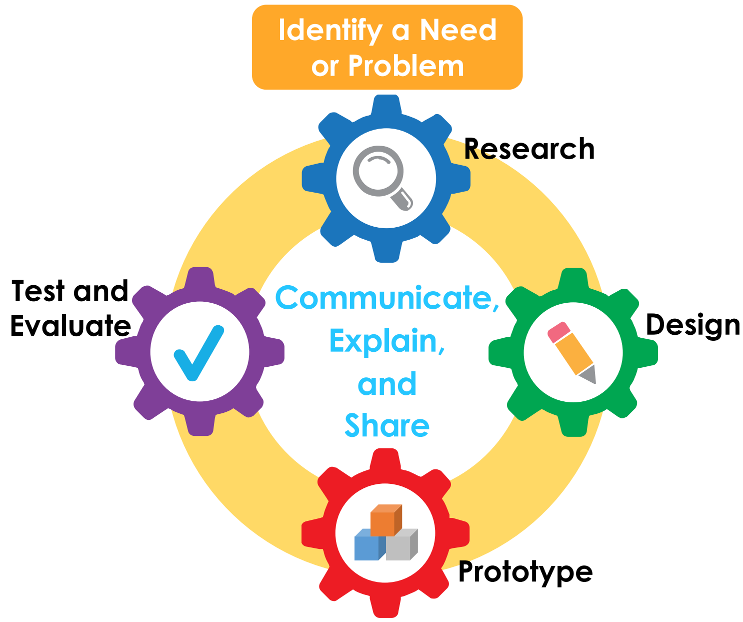



*Figure 16. Engineering Design Process model. Model and accompanying text adapted from 2016 Massachusetts Science and Technology/Engineering Curriculum Framework, Massachusetts Department of Elementary and Secondary Education, http://www.doe.mass.edu/frameworks/scitech/2016-04.pdf.*

**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

Figure 17. A current NASA pressure suit. (NASA)

Students will work in teams to design and build a pressure suit that will protect pilots and astronauts from the dangers of low-pressure environments. All materials used for the spacesuit must be tested in a vacuum to make sure they are safe in low-pressure environments. Student teams can use a marshmallow or a balloon to represent the pilot or astronaut.

## Criteria and Constraints

1. The protective suit must be constructed of materials that are not affected by near-vacuum or absolute-vacuum environments.
2. The pressure suit must completely surround the marshmallow or balloon astronaut.
3. The astronaut must fit completely within the vacuum chamber and have a total mass of less than 50 g.
4. The pressure suit must prevent the astronaut from expanding and constricting while in the vacuum chamber.

## Options for Differentiating Instruction

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

### *Modification*

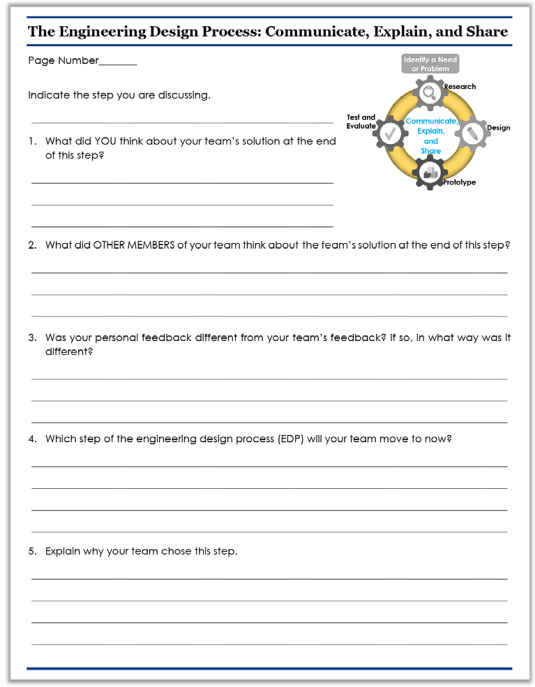
- Allow students to put their astronaut inside a plastic egg to begin their designs.

### *Enrichment*

- Require students to use at least three different materials to protect the astronaut while testing.

# 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.


The Engineering Design Process: Communicate, Explain, and Share

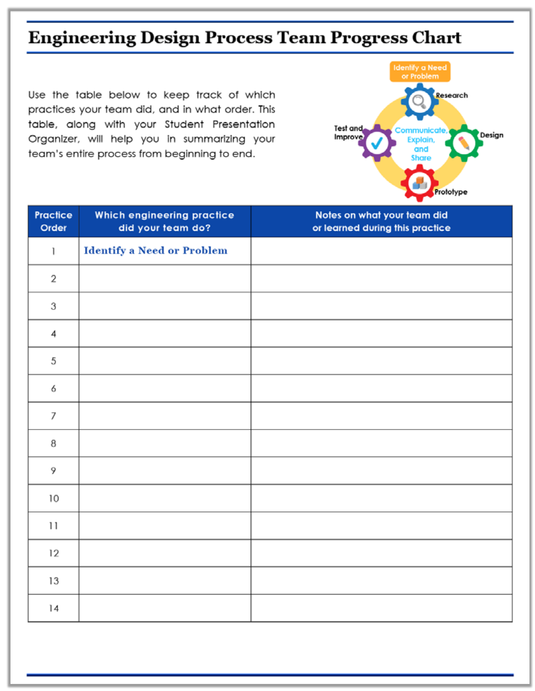
Page Number______

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.



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.


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 | | |

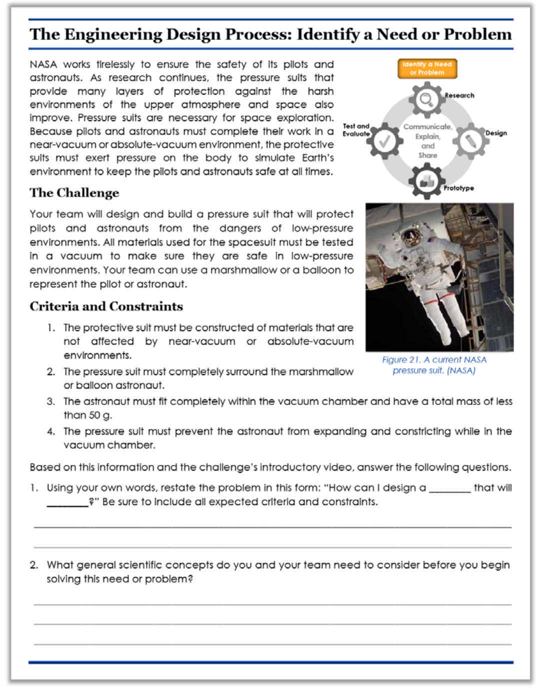
As students proceed through the process, they should record steps accomplished on the Team Progress Chart, found at the back of the Student Team Challenge Journal. Think of this chart as a Table of Contents for the journals that are being created as students move through the process.

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.

# 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**

NASA works tirelessly to ensure the safety of its pilots and astronauts. As research continues, the pressure suits that provide many layers of protection against the harsh environments of the upper atmosphere and space also improve. Pressure suits are necessary for space exploration. Because pilots and astronauts must complete their work in a near-vacuum or absolute-vacuum environment, the protective suits must exert pressure on the body to simulate Earth's environment to keep the pilots and astronauts safe at all times.



**The Challenge**

Your team will design and build a pressure suit that will protect pilots and astronauts from the dangers of low-pressure environments. All materials used for the spacesuit must be tested in a vacuum to make sure they are safe in low-pressure environments. Your team can use a marshmallow or a balloon to represent the pilot or astronaut.

*Figure 21. A current NASA pressure suit. (NASA)*

**Criteria and Constraints**

1. The protective suit must be constructed of materials that are not affected by near-vacuum or absolute-vacuum environments.
2. The pressure suit must completely surround the marshmallow or balloon astronaut.
3. The astronaut must fit completely within the vacuum chamber and have a total mass of less than 50 g.
4. The pressure suit must prevent the astronaut from expanding and constricting while in the vacuum chamber.

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?

## 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*

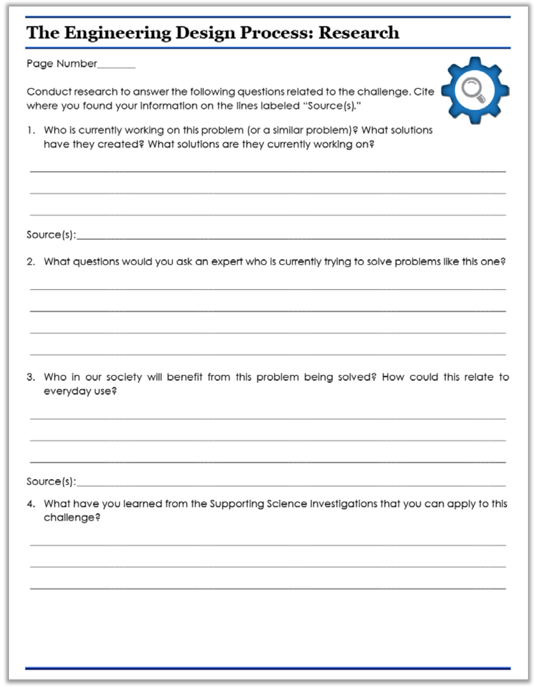
- Allow students extra time to discuss the challenge itself, the problem that needs to be solved, and how the problem could be solved.
- Introduce criteria and constraints one at a time. Allow student designs to meet one challenge requirement successfully before introducing additional requirements.

### *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*

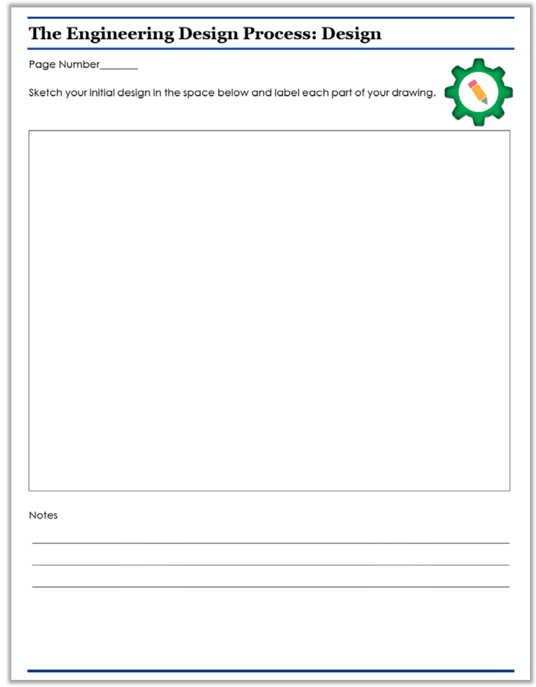
- Provide a list of reputable online resources students can use.
- Arrange a visit to a library.
- Pair up students to complete their research together.

*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.

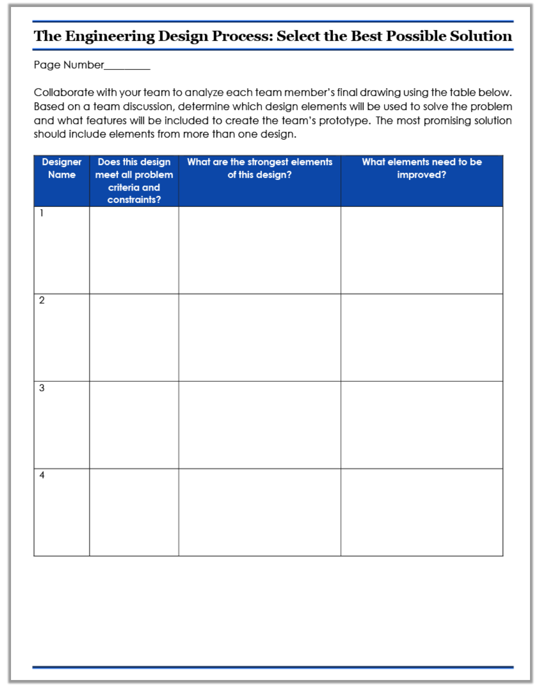
*Enrichment*

- Require students to specify measurements.

# Analyzing the Designs

**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.


**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 | | | |

## 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*

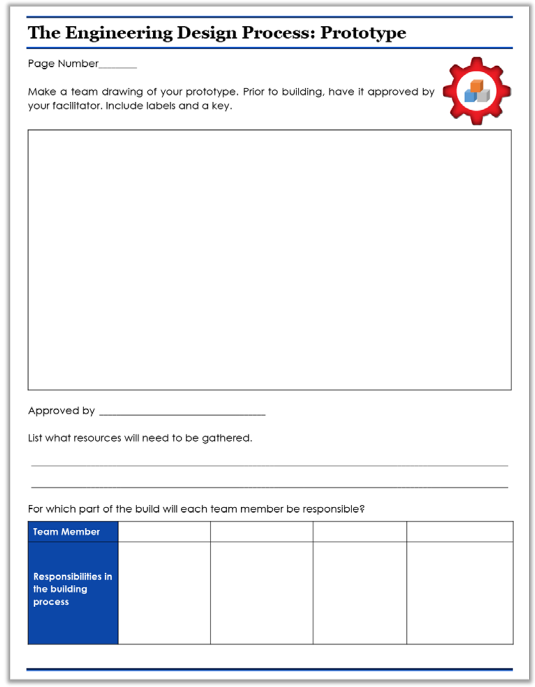
- Have students pick one aspect or characteristic at a time from each team member's drawing to discuss in the group.

*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*

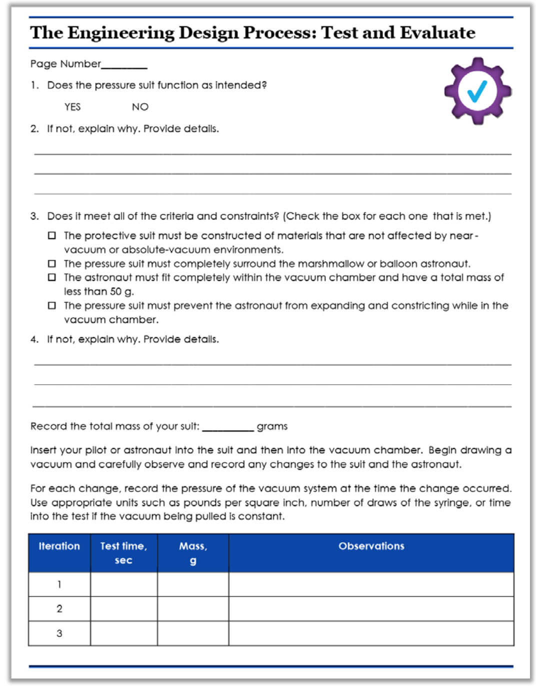
- Give students extra time to explore various materials prior to building the model.

### *Enrichment*

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

# Test and Evaluate

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


**The Engineering Design Process: Test and Evaluate**

Page Number______

1. Does the pressure suit 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.)
   - ☐ The protective suit must be constructed of materials that are not affected by near-vacuum or absolute-vacuum environments.
   - ☐ The pressure suit must completely surround the marshmallow or balloon astronaut.
   - ☐ The astronaut must fit completely within the vacuum chamber and have a total mass of less than 50 g.
   - ☐ The pressure suit must prevent the astronaut from expanding and constricting while in the vacuum chamber.
4. If not, explain why. Provide details.

Record the total mass of your suit: ________ grams

Insert your pilot or astronaut into the suit and then into the vacuum chamber. Begin drawing a vacuum and carefully observe and record any changes to the suit and the astronaut.

For each change, record the pressure of the vacuum system at the time the change occurred. Use appropriate units such as pounds per square inch, number of draws of the syringe, or time into the test if the vacuum being pulled is constant.

| Iteration | Test time, sec | Mass, g | Observations |
|---|---|---|---|
| 1 | | | |
| 2 | | | |
| 3 | | | |

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 page 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*

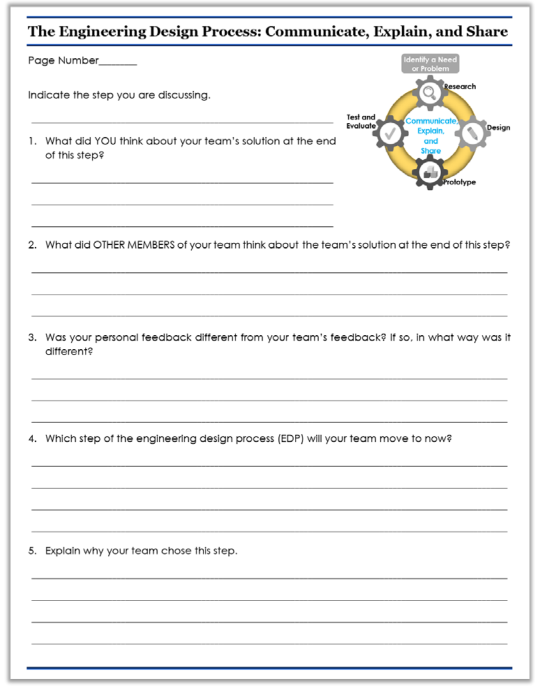
- Create a scatter plot of test results.

# 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.

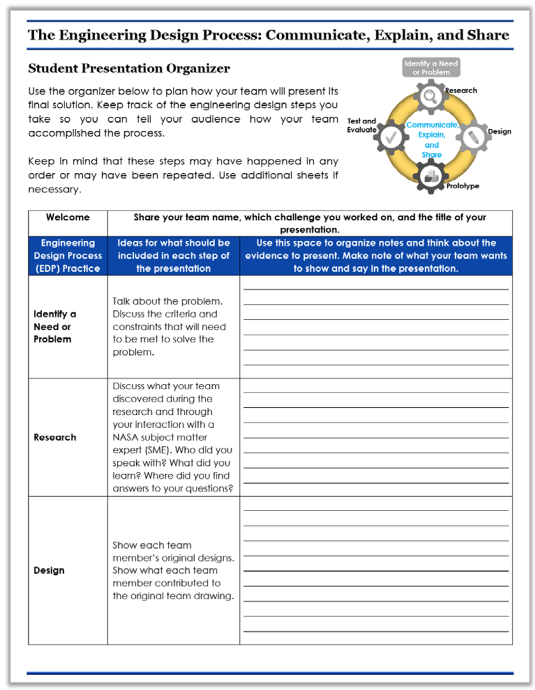

**The Engineering Design Process: Communicate, Explain, and Share**

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 the 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 pressure suit?

   *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 pressure suit?

   *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 Mars, would you trust your team's pressure suit to allow you to safely travel on the surface of Mars? 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.

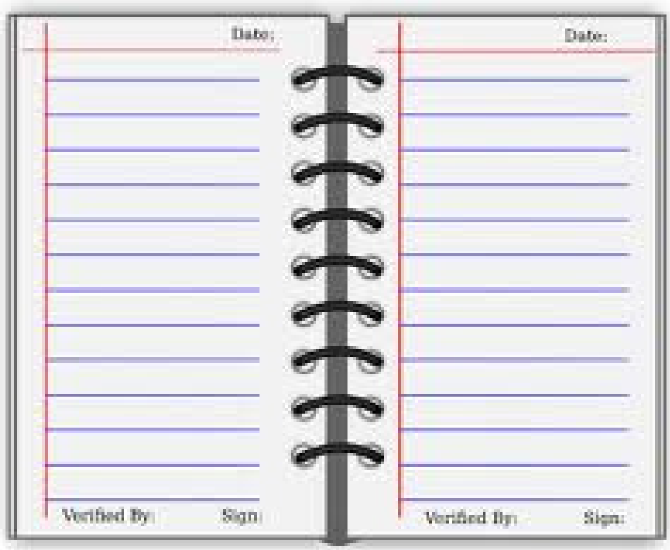
Once the video or slide document is complete, submit the presentations using the process explained on the Y4Y (You for Youth) website.

# 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: Balloons in Space

## Concept

Balloons will expand in a vacuum environment. Your skin and your lungs, which are somewhat similar to a balloon, can expand and stretch, but only to a certain point. Placing a small balloon inside a vacuum chamber will show you what would happen to your lungs if you were in a vacuum environment such as space.

*Figure 18. Spacesuit training in a vacuum chamber at Johnson Space Center. (NASA)*

## Materials

For each group of 3 students:

- Vacuum pump and bell jar
- 2 small balloons (1 transparent)
- Water (optional)
- Tape measure
- Permanent marker

## Procedure

1. Using the permanent marker, put a line around the largest part of the balloon before it is inflated. This will help you measure the circumference after it is inflated.
2. Inflate a small balloon. Do not overinflate the balloon. Measure the circumference of the balloon prior to testing and record your findings on your Data Collection Sheet.
3. Place the balloon inside the bell jar. It will expand to many times its normal size, so leave plenty of room for expansion in the jar.
4. Turn on the vacuum pump and observe what is happening to the balloon in the vacuum. Record your observations and answer the questions on your Data Collection Sheet. Measure and record the circumference of the balloon after you have tested it.
5. Optional: Place a small transparent balloon filled with water in the chamber and turn on the vacuum pump. Record your observations and answer the questions on your Data Collection Sheet.

## Data Collection Sheet

1. Make a drawing of the inflated balloon prior to placing it in the vacuum jar. Use the tape measure to find the exact circumference of the inflated balloon. Record the measurement on the drawing.

2. Draw and describe what happened to the balloon while it was in the vacuum jar. Measure the circumference of the balloon after testing and record below.

3. Why do you think this happened?

______________________________________________________________________________

______________________________________________________________________________

______________________________________________________________________________

4. If you performed the optional water-filled balloon experiment, describe the difference in how the balloon reacted to the vacuum. Why do you think this happened?

______________________________________________________________________________

______________________________________________________________________________

______________________________________________________________________________

## Discussion Questions

The Balloons in Space investigation uses a vacuum pump to demonstrate how a water-filled balloon reacts when subjected to the vacuum of space.

1. How do you think the water-filled balloon would react if the glass broke and the pressure equalized immediately?

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

# Supporting Science Investigation 2: Hands-On Vacuum

## Concept

In this activity, you and your team will take small marshmallows and place them in a large plastic syringe. You will create a miniature pressure chamber that will allow you to change the amount of pressure acting on your marshmallows. Your team will make observations about the effects of varying amounts of air pressure on the marshmallows.


*Figure 19. The Altitude/Environmental/Space Testing facilities at Johnson Space Center provide vacuum, thermal, and thermal-vacuum chamber test operations for both manned and unmanned test environments. (NASA)*

## Materials

For each group of 2 students:

- Large plastic syringes with caps, pieces of clay, or electrical tape to plug the ends of the syringes
- Small marshmallows

## Procedure

To avoid injury, always use the syringe cap, a piece of clay, or electrical tape to cover the syringe tip opening. Do not use your finger as a cap.

1. Place a small marshmallow inside your syringe.
2. Put the plunger back into the syringe, making sure the rubber piece is about halfway down the syringe.
3. Once the plunger is in place, put the cap, the piece of clay, or electrical tape on the tip of the syringe.
4. Pull back on the plunger, creating a lower-pressure environment. Use your Data Collection Sheet to record what happens to the marshmallow.
5. Push the plunger in as far as you can to create a higher-pressure environment. Record on your Data Collection Sheet what happens to the marshmallow.
6. In teams, experiment with the marshmallow. Use your Data Collection Sheet to record the effects of changes in air pressure inside the syringe

## Data Collection Sheet

1. What is happening to the pressure as you pull back on the plunger? Explain this in a complete sentence and draw a picture.

2. What happened to the marshmallow when a vacuum was applied? Explain this in a complete sentence and draw a picture.

3. What is happening to the pressure as you push forward on the plunger? Explain this in a complete sentence and draw a picture.

4. What happened to the marshmallow when pressure was applied? Explain this in a complete sentence and draw a picture.

## Discussion Questions

The Hands-On Vacuum activity uses a syringe to create a vacuum and a high-pressure environment.

1. Imagine the syringe was three times larger. Do you think it would create three times the change in pressure?

2. Think about the characteristics of a rock as compared to the marshmallow. If we used a small rock inside the syringe instead of a marshmallow, what do you think would happen to the rock? Why?

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.

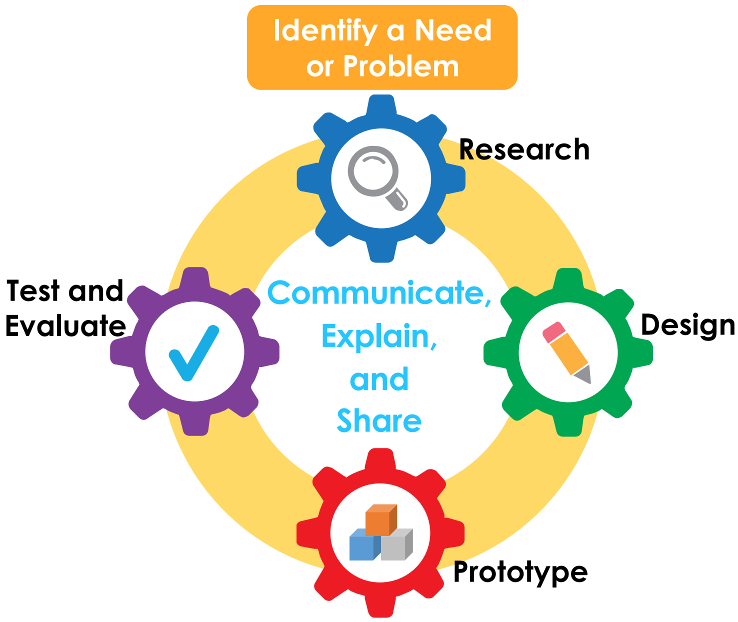



*Figure 20. Engineering design process model. Model and accompanying text adapted from 2016 Massachusetts Science and Technology/Engineering Curriculum Framework, Massachusetts Department of Elementary and Secondary Education, http://www.doe.mass.edu/frameworks/scitech/2016-04.pdf.*

**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.

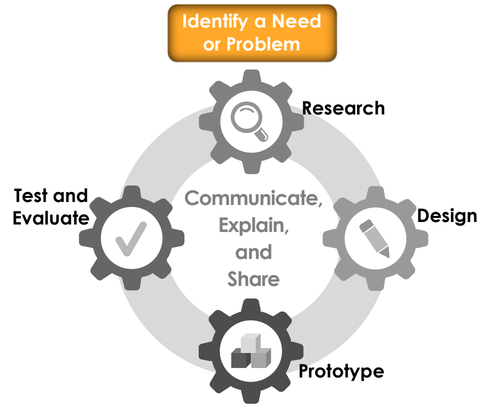
**Design**. Use all information gathered to create the design(s). Design includes modeling possible solutions, refining models, and choosing the model(s) that best meets the original need or problem.

**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




NASA works tirelessly to ensure the safety of its pilots and astronauts. As research continues, the pressure suits that provide many layers of protection against the harsh environments of the upper atmosphere and space also improve. Pressure suits are necessary for space exploration. Because pilots and astronauts must complete their work in a near-vacuum or absolute-vacuum environment, the protective suits must exert pressure on the body to simulate Earth's environment to keep the pilots and astronauts safe at all times.

## The Challenge

Your team will design and build a pressure suit that will protect pilots and astronauts from the dangers of low-pressure environments. All materials used for the spacesuit must be tested in a vacuum to make sure they are safe in low-pressure environments. Your team can use a marshmallow or a balloon to represent the pilot or astronaut.

*Figure 21. A current NASA pressure suit. (NASA)*

## Criteria and Constraints

1. The protective suit must be constructed of materials that are not affected by near-vacuum or absolute-vacuum environments.
2. The pressure suit must completely surround the marshmallow or balloon astronaut.
3. The astronaut must fit completely within the vacuum chamber and have a total mass of less than 50 g.
4. The pressure suit must prevent the astronaut from expanding and constricting while in the vacuum chamber.

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 pressure suit 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.)
   - ☐ The protective suit must be constructed of materials that are not affected by near-vacuum or absolute-vacuum environments.
   - ☐ The pressure suit must completely surround the marshmallow or balloon astronaut.
   - ☐ The astronaut must fit completely within the vacuum chamber and have a total mass of less than 50 g.
   - ☐ The pressure suit must prevent the astronaut from expanding and constricting while in the vacuum chamber.

4. If not, explain why. Provide details.

_______________________________________________

_______________________________________________

_______________________________________________

Record the total mass of your suit: __________ grams

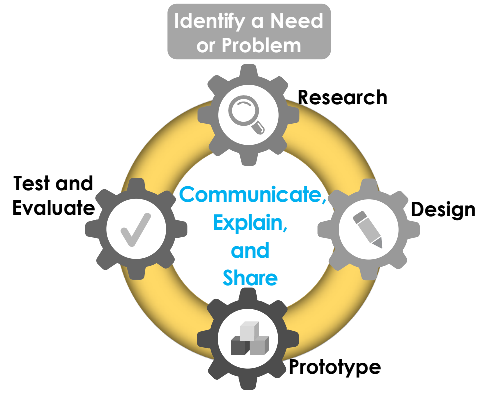
Insert your pilot or astronaut into the suit and then into the vacuum chamber. Begin drawing a vacuum and carefully observe and record any changes to the suit and the astronaut.

For each change, record the pressure of the vacuum system at the time the change occurred. Use appropriate units such as pounds per square inch, number of draws of the syringe, or time into the test if the vacuum being pulled is constant.

| Iteration | Test time, sec | Mass, g | Observations |
|---|---|---|---|
| 1 | | | |
| 2 | | | |
| 3 | | | |

# 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.

___________________________________________________________

___________________________________________________________

___________________________________________________________

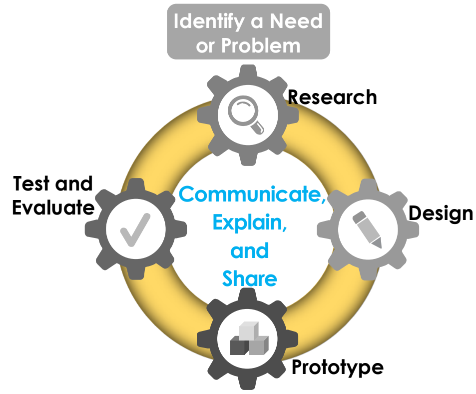
___________________________________________________________

# 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.

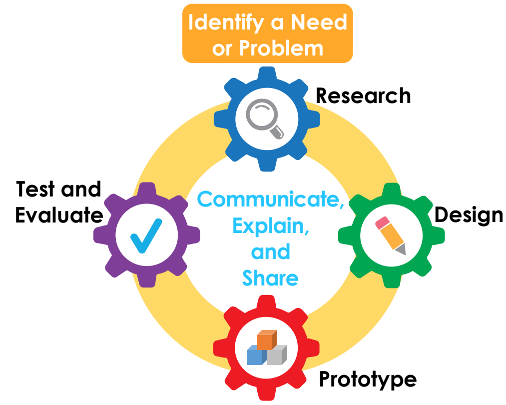



| Welcome | Share your team name, which challenge you worked on, and the title of your presentation. | |
|---|---|---|
| **Engineering Design Process (EDP) Practice** | **Ideas for what should be included in each step of the presentation** | **Use this space to organize notes and think about the evidence 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.<br><br>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

**Air density**. The amount of air per unit measure in an area

**Air pressure**. The force exerted on an object by the weight of tiny particles of air

**Constraints**. The limits placed on a design due to available resources and environment

**Criteria**. Standards by which something may be judged or decided

**Hypoxia.** An inadequate oxygen supply to the cells and tissues of the body

**Iteration**. One cycle of a repetitive process

**Spacesuit.** A self-contained living environment for humans that consists of everything needed for short-term survival, including breathing oxygen, pressure exerted on the body, and a heating and cooling system

**Vacuum.** The nearly total absence of gas molecules

**Vacuum chamber.** A rigid enclosure from which air and other gases are removed, resulting in a low-pressure, space-like environment

**Vacuum pump**. A mechanical device used to draw air out of a chamber, creating a low-pressure environment

# NASA Resources

## Online Resources

**A Pilot's Life at 65,000 Feet Over Alaska**
http://earthobservatory.nasa.gov/blogs/fromthefield/2014/07/28/a-pilots-life-at-65000-feet-over-alaska/

**Advanced Suit Development**
http://www.nasa.gov/exploration/technology/advanced_space_suits/

**NASA Spacesuit Development**
https://www.youtube.com/watch?v=P32j17FI5L0

*Back cover: Space shuttle astronauts Ken Ham and Piers Sellers demonstrate the flexibility of the training version of the S105 pressure suit by playing a combination of baseball and cricket at Minute Maid Park in Houston, Texas. (NASA)*

National Aeronautics and Space Administration

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**www.nasa.gov**

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