National Aeronautics and Space Administration

21st Century Community Learning Center NASA Engineering Design Challenge

M2M: Mission to Mars

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.

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.

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

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.

Multimedia Resources

Take an opportunity to show your students the slide deck that accompanies the educator slides on the You for Youth (Y4Y) site. Here you will find visual representations of NASA's current missions and text for you to share with students.

Share the video "NASA: Why Do We Explore?" to help students connect exploring off world and NASA's role in past and future exploration.
https://www.youtube.com/watch?v=nAPDnQ5aZ6E

Share with students the exciting short video "We Are NASA," which describes what NASA is and what NASA does.
https://www.youtube.com/watch?v=WeA7edXsU40

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Facilitator’s Overview

NASA has created an engineering design challenge (EDC) that will lead students through the engineering design process (EDP) as they develop solutions to a NASA mission-centered challenge. The EDC serves as an authentic, standards-driven investigation that encourages students to collaborate as a team to solve engineering challenges resembling those of NASA scientists and engineers. This EDC provides students with opportunities to gain tangible, 21st century skills that are essential in science, technology, engineering, and mathematics (STEM) careers. The challenge 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 step-by-step instructions for facilitators to use throughout the design challenge.
3. **Student Journal** contains prompts and tools to guide students through the phases of the EDP while documenting their work in each phase. It is suggested that each student have a copy of the Student Journal.

What is the Engineering Design Process (EDP)?

The EDP is a systematic approach to solving an engineering problem. Engineers work through each phase of the EDP to build models, create solutions, and develop new technologies. The EDP begins with identifying a need or a problem. However, there is no “fixed path” through the EDP that will lead to a final solution. Within each of the process phases, students will Communicate, Explain, and Share their discoveries and decisions as they build their models, make improvements, and find a solution to the challenge.

What is an Engineering Design Challenge (EDC)?

The EDC has been created to follow an inquiry-based, 5E instructional design that organizes learning around a shared goal or challenge. Students are presented with a challenge or problem and, using the EDP, collaborate in teams to complete investigations and problems. NASA’s EDCs facilitate teamwork and engage students in problem-solving practices used by real-world engineers.

Introduction to the Engineering Design Challenge

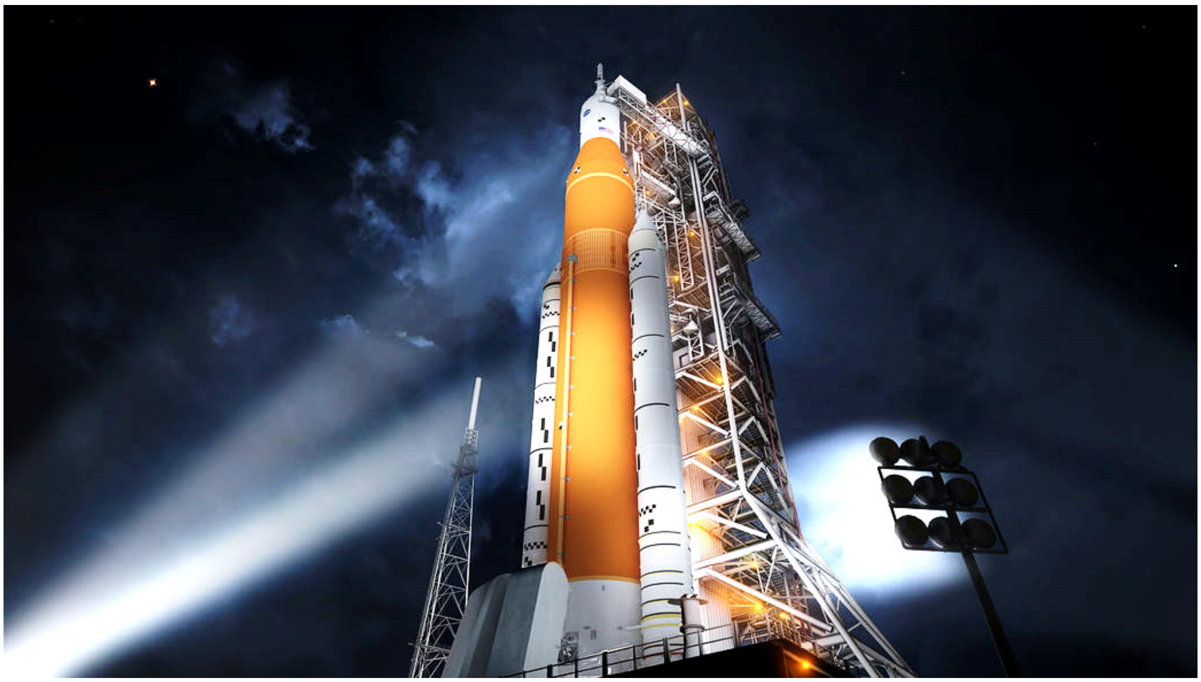


Figure 2. The Space Launch System (SLS) will be the most powerful rocket NASA has ever built. When completed, SLS will help astronauts begin their journey to explore destinations far into the solar system.

Engineering Design Challenge: Mission to Mars

Because spacecraft that land on the surface of Mars travel at extremely high speeds, they need some sort of drag device to slow them down to prevent them from crashing into the planet and becoming damaged. As missions increase in complexity, landers and rovers become heavier and require even more effective drag devices. Engineers must work within the limits (or constraints) of mass and weight to successfully accomplish the mission.

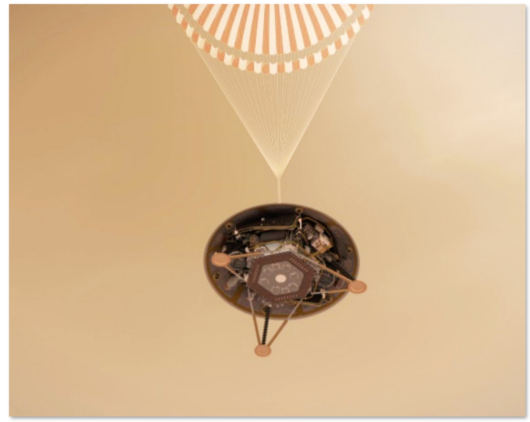


Figure 3. Illustration of NASA's InSight lander descending toward the surface of Mars with its parachute. The lander arrived on Mars in November 2018. (NASA/JPL-Caltech)

The Challenge

Students will work in teams to design and construct a drag device that will slow down the cargo bay when it is dropped from a consistent height. The template for the cargo bay is in the back of this guide. Students should test the cargo bay without the drag device first, as a control test, and then test with the device attached to show that deceleration has been achieved.

Criteria and Constraints

1. Each team **must** design and make a drag device to connect to the cargo bay. The device **must** make the cargo bay slow down when it is tested, or dropped.
2. The entire device **must** be deployed from 2 meters and **must** remain intact throughout the drop.
3. The cargo bay **must** hold 10 grams of cargo secured inside.
4. The overall mass **must not** exceed 50 grams.

Multimedia Resource

To heighten student connections and understanding of the perils of landing on another planet, view "7 Minutes of Terror," a video made by NASA Jet Propulsion Laboratory engineers about the descent and landing system for NASA's Mars rover Curiosity.
https://www.jpl.nasa.gov/video/details.php?id=1090

Engineering Design Process

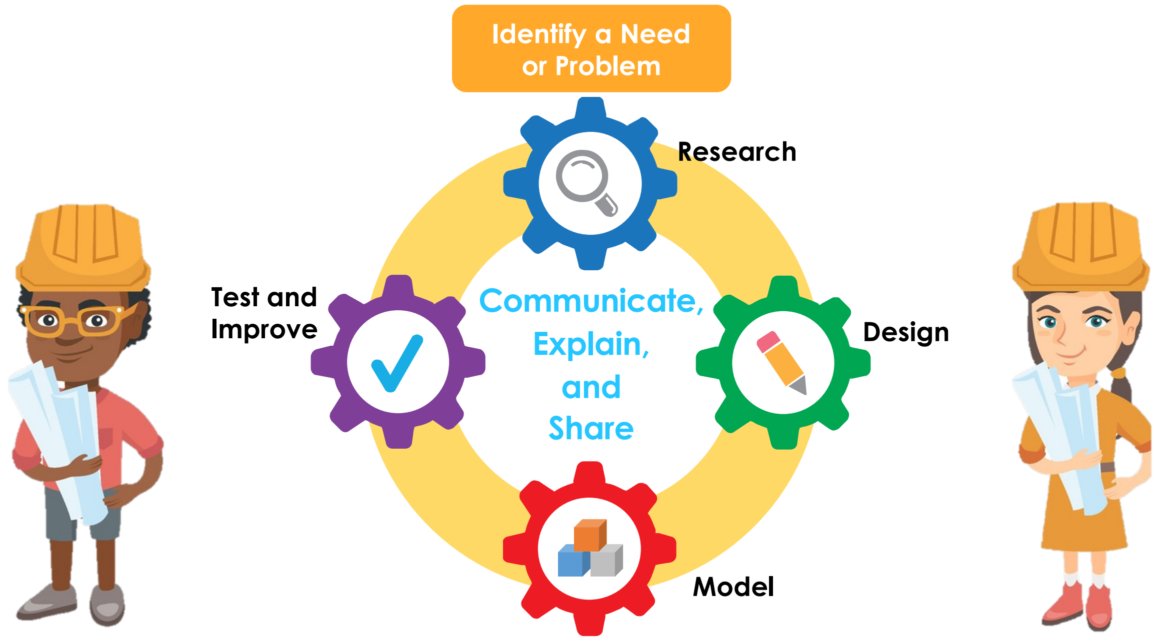


Figure 4. Engineering design process model. Model and accompanying text adapted from the 2016 Massachusetts Science and Technology/Engineering Curriculum Framework, Massachusetts Department of Elementary and Secondary Education, http://www.doe.mass.edu/frameworks/scitech/2016-04.pdf.

Identify a Need or Problem. This phase is designed to ask this question: How can we design a model that will meet the criteria and constraints of the challenge?

Research. During the research phase, students will find the answers to their questions by exploring the internet, visiting a library, or interviewing a NASA scientist or engineer.

Design. In the design phase, each student will draw a model that could solve the challenge. Teams will combine the drawings and design a team model drawing that meets the criteria and constraints.

Model. In the model phase, the team will use their drawing to build their model.

Test and Improve. The model will be tested. Teams will gather and evaluate data to improve the design.

Communicate, Explain, and Share. During each phase, the team will record and share progress. Teams should discuss the design solutions and present ideas to others, describing the engineering design process.

Pacing Guide

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

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

STEM Standards for Grades 3–5

The science, technology, engineering, and mathematics (STEM) standards listed on these pages are supported by the investigations and challenge in this guide. This guide serves as one step toward reaching the performance expectations listed in the following standards. Additional supporting materials, lessons, and activities will be required.

Next Generation Science Standards

Engineering Design

- 3–5–ETS1–1. Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.
- 3–5–EDT1–2. Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.
- 3–5–ETS1–3. Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.

Science Content Standard

- 3–PS2–1. Plan and conduct an investigation to provide evidence of the effects of balanced and unbalanced forces on the motion of an object.

Cross-Cutting Concept of Cause and Effect

- Cause-and-effect relationships are routinely identified, tested, and used to explain change.
- Events that occur together with regularity might or might not be a cause-and-effect relationship.

International Society for Technology in Education

Creative Communicator Standard

Students communicate clearly and express themselves creatively for a variety of purposes using the platforms, tools, styles, formats, and digital media appropriate to their goals. https://www.iste.org/standards/for-students

- Students choose the appropriate platforms and tools for meeting the desired objectives of their creation or communication.
- Students communicate complex ideas clearly and effectively by creating or using a variety of digital objects such as visualizations, models, or simulations.

Common Core State Standards: Mathematics
• CCSS.MATH.CONTENT.3.MD.B.3 **Represent and interpret data**: Draw a scaled picture graph and a scaled bar graph to represent a data set with several categories. Solve one- and two-step "how many more" and "how many less" problems using information presented in the scaled bar graph.

21st Century Skills

The "4 Cs" of 21st century learning are critical thinking, collaboration, communication, and creativity. www.p21.org

Critical Thinking

- Make judgments and decisions by effectively analyzing and evaluating evidence, arguments, claims, and beliefs.
- Interpret information and draw conclusions based on the best analysis.

Collaboration

- Demonstrate ability to work effectively and respectfully with diverse teams.
- Exercise flexibility and willingness to be helpful to making necessary compromises to accomplish a common goal.

Communication

- Articulate thoughts and ideas effectively using oral, written, and nonverbal communication skills in a variety of forms and contexts.
- Use multiple media and technologies.

Creativity

- Use a wide range of idea creation techniques (such as brainstorming).
- Develop, implement, and communicate new ideas to others effectively.
- View failure as an opportunity to learn.

Facilitator Instructions

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 for all laboratory work. 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.
- Maintain a safe environment at all times.

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.
- Follow instructions carefully and completely.

Classroom Management Tip

To help with safety management and materials, students could create and sign a pledge that they will abide by the safety rules listed on this page.

An example of a safety commitment from students:

"I have read and understand the safety rules. I agree to follow these rules for my safety, the safety of my teammates, and the safety of the whole group."

Recommended Materials

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

Each team will require the following items:

- Digital scale or balance
- Measuring tape that includes metric units
- Rulers that include metric units
- Stopwatch
- Small sealable plastic bag to hold cargo inside capsule
- Weights, such as a penny or washer to serve as mass
- Hole reinforcements or stickers with holes
- Each team should have a copy of the Cargo Bay Template provided in this guide. It can be copied on any weight of paper, but all copies need to be the same paper weight.

Figure 5. Household supplies that could be used as construction materials for the challenge.

Examples of additional building materials that may be used:

- Balloons
- Binder clips
- Bubble wrap
- 16-ounce clear drinking cups
- Cardstock
- Craft sticks, lollipop sticks, or tongue depressors
- Clothespins
- Cloth
- Coffee filters
- Cotton balls
- Glue
- Heavy-duty aluminum foil
- Magnifying lenses and mirrors
- Manila folders
- Miniature aluminum foil pie plates
- Modeling clay
- Paper (copier, construction, and waxed)
- Paper bags
- Paper towel tubes
- Plastic eggs
- Plastic wrap (clear and colored)
- Polystyrene cups
- Poster board
- Rubber bands
- Skewers
- Staplers and staples
- Tape (packing, duct, masking, and transparent)
- Yarn
- Washer

Team Building

Figure 6. This Apollo 11 patch depicts an eagle landing on the Moon with a view of the Earth in the background. (NASA)

Teamwork and collaboration are important 21st century skills for students to practice. The following exercises are recommended to help teams begin to work together effectively. There is a page in the Student Journal to go along with this activity.

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.

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 group motto. 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.*"

Suggested Team Roles

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 be rotated throughout the team to give team members an opportunity to experience the different types of engineering and 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

Classroom Management Tip

Spending time on this activity will enhance student teams and contribute to 21st century learning goals of **collaboration, communication, and creativity**.

NASA Mission Background for Facilitators

Mars

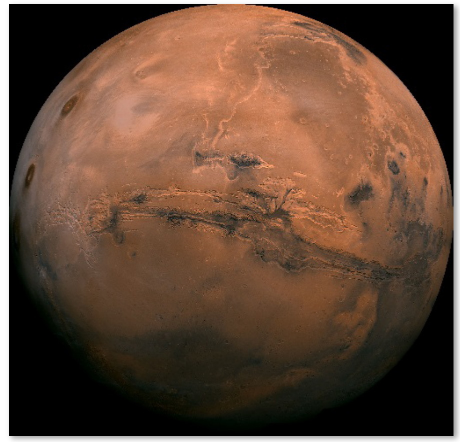


Figure 7. Photograph pieced together from 102 Viking Orbiter images of Mars. (NASA)

Mars is the fourth planet from the Sun and is about 228 million km away from it. Mars is the next planet beyond Earth and is about one-half the size of Earth. Known as the Red Planet, Mars gets its red color from the iron in its soil. Mars is very cold and has an average temperature of –62 °C (–79.6 °F), far below the freezing point of water. Its rocky and dusty red surface is covered with canyons, inactive volcanoes, and craters. Although the Martian atmosphere is considerably different than Earth's, Mars does have clouds, wind, and dust.

Mars and Earth are very different. The gravitational pull on Mars is less than on Earth, meaning that a rock dropped on Mars would fall more slowly than a rock dropped on Earth. A person who weighs 45 kilograms (about 100 pounds) on Earth would weigh only about 17 kilograms (37 pounds) on Mars because of the reduced gravity. The atmosphere of Mars is about 100 times thinner than Earth's. The Martian atmosphere has much less oxygen and far more carbon dioxide than the Earth's atmosphere. It is very difficult for NASA to land spacecraft on the surface of Mars because there are fewer molecules of air for the parachute to "catch."

How is NASA exploring Mars today?

The spacecraft orbiting Mars today use tools to collect scientific information such as the temperature and the kinds of minerals on Mars. These spacecraft take images and search for water. NASA has also landed rovers called Sojourner, Spirit, Opportunity, and Curiosity on the surface of Mars. These rovers are robots that move around taking images, conducting scientific experiments, and collecting data about the planet's soil and rocks. NASA uses the information gathered by the orbiting spacecraft and the rovers on the planet's surface to help determine if life could ever have existed on Mars. Curiosity is still providing images and data to NASA.

What is the InSight lander?

In November 2018, the NASA lander InSight (Interior Exploration using Seismic Investigations, Geodesy and Heat Transport) successfully touched down on Mars. InSight traveled 300 million miles (485 million kilometers) on its journey from Earth to the Red Planet, taking almost 7 months to arrive. InSight's 2-year mission is to study the deep interior of Mars to learn how all celestial bodies with rocky surfaces formed, including Earth and the Moon.

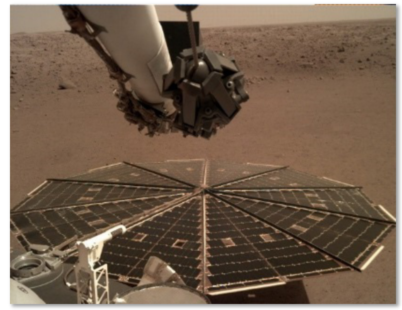


Figure 8. One of InSight's 7-foot- (2.2-meter-) wide solar panels. Photo taken in 2018 by the camera attached to the lander's robotic arm.

Multimedia Resource

For information on Mars exploration, view "Where Does Your Curiosity Lead?" https://mars.nasa.gov/msl/multimedia/videos/index.cfm?v=45

How will NASA explore Mars in the future?

The Mars 2020 rover mission is part of NASA's Mars Exploration Program. The mission is seeking signs of habitable conditions on Mars and also searching for signs of past microbial life. The mission will gather information to help future human expeditions to Mars. This includes improving landing techniques; identifying resources to enable human habitation; and characterizing weather, dust, and other environmental conditions that could affect how future astronauts live and work on Mars.

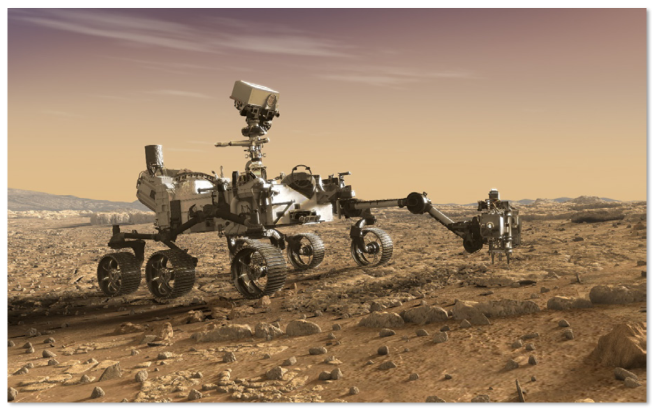


Figure 9. Illustration of the Mars 2020 rover, which has new designs and improvements. The rover carries a drill for taking samples from Martian rocks and soil. (NASA)

Multimedia Resource

View "Rover Ride-Along in the Mars Yard" for a 360-degree tour and test drive of a mock Mars rover similar to Curiosity or the Mars 2020 rover. https://mars.nasa.gov/msl/multimedia/deepzoom/rover-ride-mars-yard-360-video/

How do spacecraft land on the Martian surface?

Devices that slow down moving objects by creating drag come in many shapes, sizes, and materials. NASA has used a basic parachute design as a drag device to land vehicles on the surface of Mars since 1976, when the first Viking lander touched down.

To conduct advanced exploration missions and safely land heavier spacecraft on Mars in the future, NASA must improve the technology of decelerating (slowing down) landing vehicles. NASA is developing large, sturdy, and lightweight systems to deliver the next generation of rovers and landers on the surface of Mars. These new technologies will be able to slow down larger, heavier landers from supersonic speeds to the slower speeds that are necessary for a safe landing on Mars.

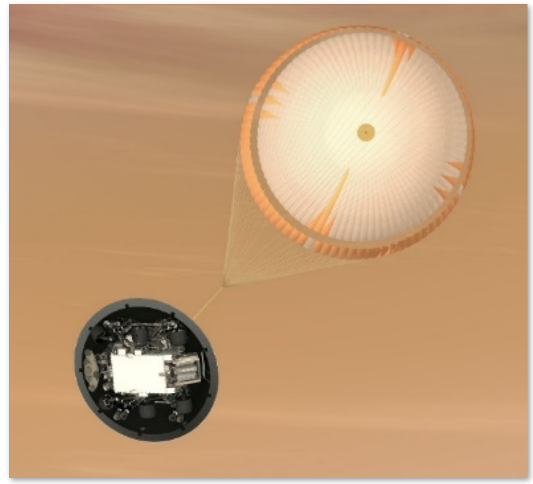


Figure 10. Artist's concept of the parachute system for the Mars Science Laboratory's Curiosity rover. (NASA)

Helping Students Understand Drag

Take time to help students understand the concept of drag, as it is not something they can directly see. Drag is a force created when an object moves through air. The air pushes against the moving object, something people usually refer to as "air resistance." Larger objects have a harder time moving through air than smaller objects. A large object has a larger surface area and creates more drag because air is pushing against the object as it moves. A small object has a smaller surface area and creates less drag because there is less air pushing against the object as it moves. This applies not only to objects like state-of-the-art racecars or airplanes, but also to people. Bike racers and skiers hunch over to try to make themselves as small as possible to reduce drag and go faster.

Ask students if they have ever put their hands out of a moving car window. If so, they have felt the force of drag pushing their hands back and forth. Ask students what they think would happen if they ran a race holding an open umbrella. Do they think it would make them go faster or slow them down? A runner would feel the force of drag on the umbrella as it moved through the air and this would slow the runner down.

Accessing Existing Knowledge

Prior to starting the engineering design challenge (EDC), 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 STEM Investigations to the group, maximizing the educational benefit.

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

- Do you know what a scientist or engineer does at work?
- Do you know what an astronaut does at work?
- Where have you seen parachutes in use?
- What are some objects that create drag?

STEM Investigations

STEM Investigations are included for support prior to the EDC as students work on STEM material that may be unfamiliar to them. Facilitators can provide more assistance to students at the start of the STEM Investigations. As students become comfortable, step back to allow them to become more confident in their problem-solving skills.

Each of these investigations will help students build the STEM knowledge needed to complete the challenge. Refer back to these investigations to help students make connections from all of the experiences in this content guide.

A suggested collaborative strategy to use is Think–Pair–Share, 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.

Vocabulary Support

Engineering design challenges and the engineering design process (EDP) are concepts that may be unfamiliar to your students. Younger students may not have heard words like "criteria" or "constraints," which are commonly associated with engineering design. **Criteria** are characteristics of a successful solution, such as a desired function. **Constraints** are limitations on the design, such as mass or funds.

- Criteria are what the design **MUST** do.
- Constraints are things the design **MUST NOT** do.

Basic Vocabulary Words in the Challenge

This guide includes a list of related STEM vocabulary words. While there are subject-specific vocabulary words embedded in the Student Journal, there are basic vocabulary words students should be familiar with. These words include: describe, design, evaluate, evidence, feedback, investigate, observe, model, process, research, solution, and test.

The Word Box vocabulary activity is an example of an activity to use with students who require additional vocabulary support.

Vocabulary Activity Suggestion: Word Box

Allow students to scan through the Student Journal and highlight or underline any unfamiliar words. Discuss findings as a class. Draw students' attention to the vocabulary words, definitions, sentences, and synonyms in the provided vocabulary list. Review with students the definition of *synonyms* (words with similar meanings) and *antonyms* (words with opposite meanings).

Materials

Blank paper, dictionaries

Procedure

1. Allow each student to pick one word from the vocabulary list to define and share.
2. Pass out the paper and direct students to fold the paper into four parts.
3. In the top left section, students will paraphrase the definition of their chosen word.
4. In the top right section, students will use their chosen word in an original sentence.
5. In the bottom left section, students will write one or two synonyms and one or two antonyms of their chosen word.
6. In the bottom right section, students will draw a visual representation of their chosen word.
7. On the back, students will write their name and the chosen vocabulary word.
8. Allow students to quiz each other on the vocabulary words, taking turns to guess at their peer's chosen vocabulary word using the hints provided.

STEM Investigation 1: It's a Drag

Objectives

- Students will investigate drag as a force that is created as an object interacts with air.
- Students will investigate the amount of drag created by paper of various sizes.
- Students will identify the difference between balanced and unbalanced forces.

Figure 11. A drag chute helped slow down Space Shuttle Endeavour when it landed at Edwards Air Force Base in 2002. (NASA)

Guiding Questions

Use the following questions as discussion prompts:

- Which of the various sizes of folded paper do you think will create more drag and fall to the ground more slowly?
- How will you apply what you learned in this investigation to your design?

Instructional Procedure

1. Prepare the materials for students.
2. Have students think about the different sizes of paper and predict what may happen.
3. Have students follow the procedures in the Student Journal.
4. Remind teams to record the results and observations on the Data Collection Sheet in the Student Journal.
5. Have students answer the questions on the Data Collection Sheet.

Student Connections

Objects fall due to gravity. In order to stop an object or slow it down, a certain amount of drag needs to be applied to oppose the acceleration. As drag increases, an object will slow its rate of fall. In this activity, students will see the effects of drag on a falling object by shaping a large sheet of paper and measuring the time it takes to fall from a fixed distance. Guide students to connect this investigation with the engineering design challenge using these discussion questions:

- What did your team discover about the size of the paper and the amount of time it took to fall to the ground?
- How do you think these ideas will connect to the challenge?

STEM Investigation 2: Touchdown

Objective

- Students will investigate ways to create a shock-absorbing system for a landing device.

Guiding Questions

- What kinds of systems could be used to absorb the shock of an object falling to the ground?
- How will you apply what you learned in this investigation to your design?

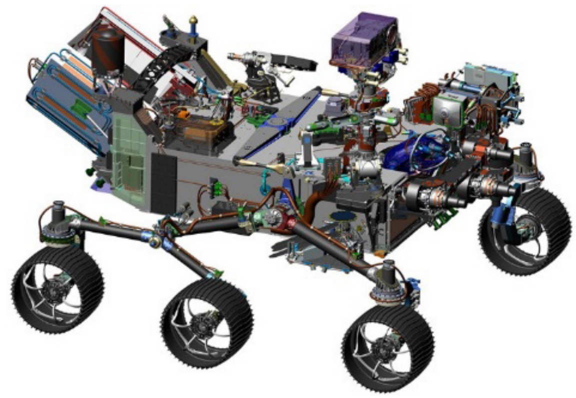


Figure 12. Computer-assisted design of NASA's 2020 Mars rover. (NASA/JPL-Caltech)

Instructional Procedure

1. Prepare materials for students.
2. Have student teams follow the procedures in the Student Journal.
3. Remind students that the goal is to create a shock-absorbing system that will protect the cargo inside the lander and that they may not secure the cargo with tape.
4. Make sure teams record data and observations.
5. Have students answer the questions provided on the Data Collection Sheet.

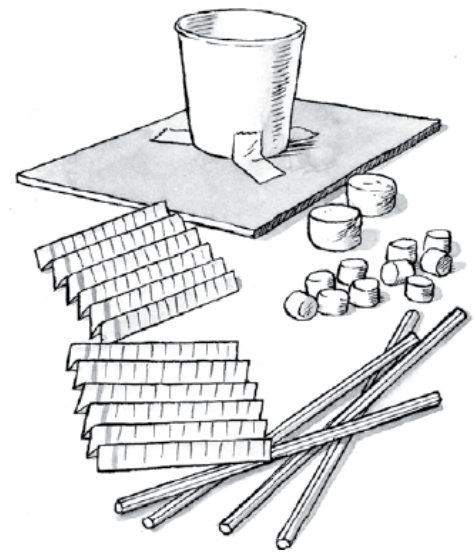


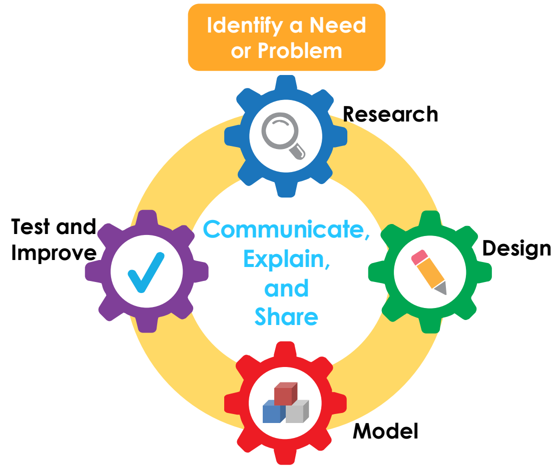
Figure 13. Materials used in the Touchdown investigation.

Student Connections

Teams are challenged to make a shock-absorbing system that absorbs, or softens, the transfer of energy when the lander hits the ground. The marshmallows should stay in the cup, or cargo bay, upon landing. These are concepts some students may find challenging. However, this experience can help students think about the many ways there are to solve a problem. Thinking of alternative answers helps build problem-solving skills. If students are familiar with the basic idea of gravity being a force pulling an object down, it can be mentioned in this investigation. Guide students to connect this investigation with the engineering design challenge using these discussion questions:

- What are some of the ways teams modified the lander to absorb the energy when it hit the ground? Did that protect the cargo?
- How do you think using a shock-absorbing system **and** a drag device would work to protect cargo when landing on another planet?

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 (EDC).

The following pages explain how each phase of the EDP relates to the challenge and how to facilitate the process with students. Explain the EDP sheets and how to use the appropriate pages for recording group ideas.

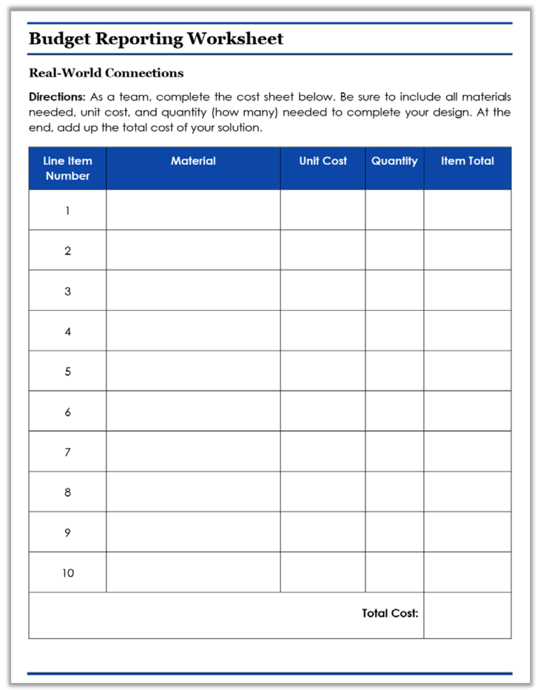
Review with students the information covered within the EDC. Using the background information, talk about current NASA missions and how those relate to this challenge. As a class, discuss the individual components of this challenge. Whenever possible, relate ideas to students' daily lives. Check for student understanding of the words "criteria" and "constraints."

Real-World Connection

A budgetary constraint is added as part of the EDC. Teams should use the Budget Reporting Worksheet to determine the cost of their solution.

How to Use the Budget Reporting Worksheet

- Set specific prices for the materials students will use.
- Set a specific budget for the challenge.
- Provide students with a price sheet so teams can use that list to keep track of the cost of the items for the challenge.



Budget Reporting Worksheet

Real-World Connections

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

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

Differentiation Suggestions

- Facilitators may need to monitor students' attention levels and break for more hands-on or physical activities as needed.
- Students can color code each section of their journals or use highlighters to make the informational text stand out.
- Teams can use a large whiteboard or butcher paper to create a cartoon or flowchart of the EDP as they progress through the challenge.
- Students can use sticky notes or markers to take notes of each phase and then refer to the chart when they create their presentation.

Engineering Design Challenge

The Challenge

Students will work in teams to design and construct a drag device that will slow down the cargo bay when it is dropped from a consistent height. The template for the cargo bay is in the back of this guide. Students should test the cargo bay without the drag device first, as a control test, and then test it with the device attached to show that deceleration has been achieved.

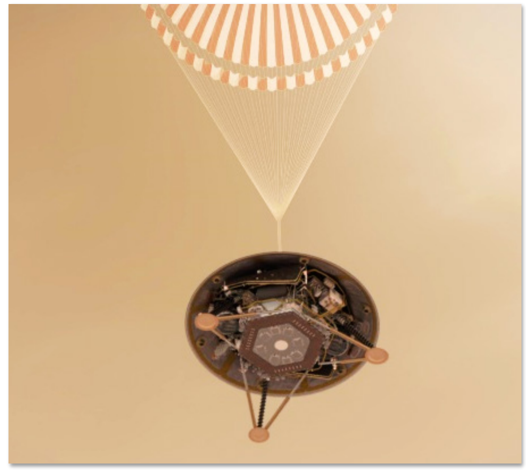


Figure 14. Illustration of NASA's InSight lander descending toward the surface of Mars with its parachute. The lander arrived on Mars in November 2018. (NASA)

Criteria and Constraints

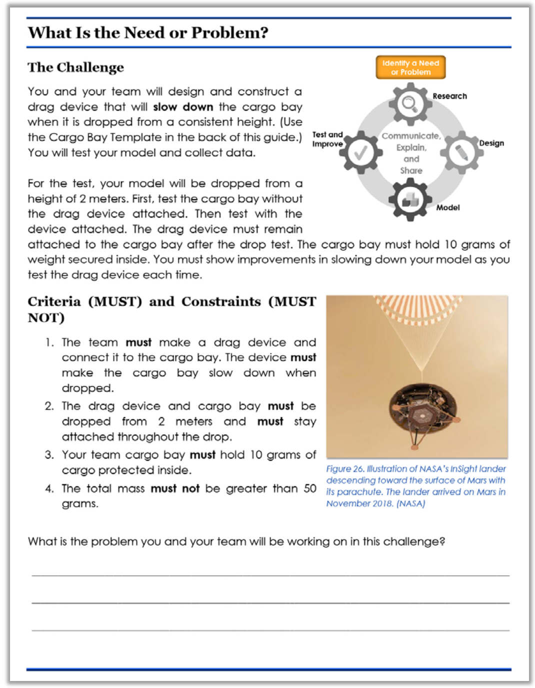
1. Each team **must** design and make a drag device to connect to the cargo bay. The device **must** make the cargo bay slow down when it is tested, or dropped.
2. The entire device **must** be deployed from 2 meters and **must** remain intact throughout the drop.
3. The cargo bay **must** hold 10 grams of cargo secured inside.
4. The overall mass **must not** exceed 50 grams.

Differentiation Suggestions

- Assemble the cargo bay, with the weight inside, for students.
- Eliminate, decrease, or increase the mass restriction.

Identify a Need or Problem

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.



What Is the Need or Problem?

The Challenge

You and your team will design and construct a drag device that will **slow down** the cargo bay when it is dropped from a consistent height. (Use the Cargo Bay Template in the back of this guide.) You will test your model and collect data.

For the test, your model will be dropped from a height of 2 meters. First, test the cargo bay without the drag device attached. Then test with the device attached. The drag device must remain attached to the cargo bay after the drop test. The cargo bay must hold 10 grams of weight secured inside. You must show improvements in slowing down your model as you test the drag device each time.

Criteria (MUST) and Constraints (MUST NOT)

1. The team **must** make a drag device and connect it to the cargo bay. The device **must** make the cargo bay slow down when dropped.
2. The drag device and cargo bay **must** be dropped from 2 meters and **must** stay attached throughout the drop.
3. Your team cargo bay **must** hold 10 grams of cargo protected inside.
4. The total mass **must not** be greater than 50 grams.

Figure 26. Illustration of NASA's InSight lander descending toward the surface of Mars with its parachute. The lander arrived on Mars in November 2018. (NASA)

What is the problem you and your team will be working on in this challenge?

Objectives

- Students will be able to identify the problem of this engineering design challenge (EDC).
- Students will be able to identify the criteria and constraints of this EDC.

Guiding Questions

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

- What needs to be solved or improved?
- How can our team design a _____ that will _____?
- What are the things our solution **must** do?
- What are the things our solution **must not** do?

Instructional Procedure

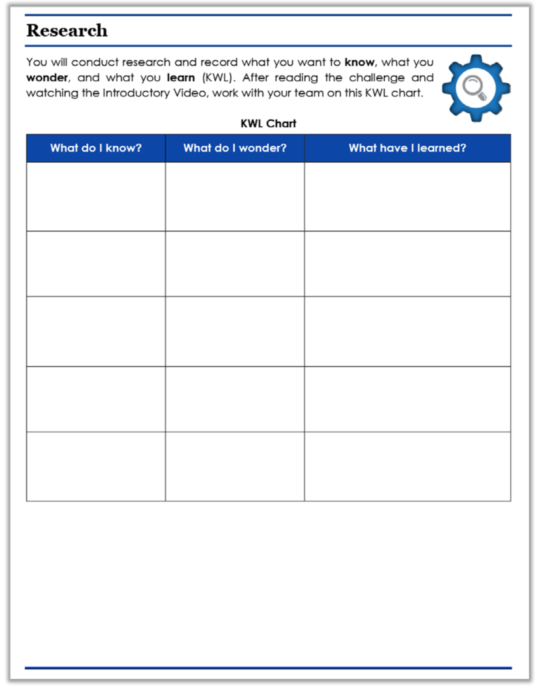
1. Review the engineering design process with students.
2. Ask student teams to read the challenge and discuss within the team.
3. Ask students to identify the specific criteria and constraints of the design challenge.
4. Have students complete the Identify a Need or Problem page in the Student Journal.
5. Show the NASA Beginning Engineering Science and Technology (BEST) video "Repeatability," found here: https://www.youtube.com/watch?v=-2Az1KDn-YM.

Differentiation Suggestions

- 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 and discuss with students.
- Allow student designs to meet one challenge requirement successfully before introducing additional requirements.

Research

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.



Research

You will conduct research and record what you want to **know**, what you **wonder**, and what you **learn** (KWL). After reading the challenge and watching the Introductory Video, work with your team on this KWL chart.

KWL Chart

What do I know?	What do I wonder?	What have I learned?

This phase connects student thinking about the problem in the challenge, what questions they have, and how they may begin to think about possible solutions. Use these pages to launch student interest.

As students prepare to connect with a NASA scientist or engineer, they should think about and then research specific questions using books, NASA websites, and other reliable websites. Students will have the opportunity to ask a NASA person questions regarding the challenge, the engineering design process, or their job.

Objectives

- Students will be able to analyze the need or problem and research possible solutions.
- Students will be able to think about questions to ask a NASA scientist or engineer about the challenge problem.

Guiding Questions

- Where can you find more information about the topic?
- What questions would you ask a NASA scientist or engineer who is currently working on this problem?
- Why are we trying to solve this problem?
- What objects in this room have been made or developed by a scientist?

Instructional Procedure

1. The facilitator should connect to the You for Youth (Y4Y) website and arrange a time for the group to connect with a NASA scientist or engineer. A good time for a first connection is when students have completed this phase of the EDP.

2. Brainstorm a list of five questions to be included in the NASA Connection KWL (Know, Wonder, Learn) chart.
3. Help students answer any questions they have about the challenge. Use the internet or a school library to research answers.
4. Have students spend research time on this problem and possible solutions.

Differentiation Suggestions

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

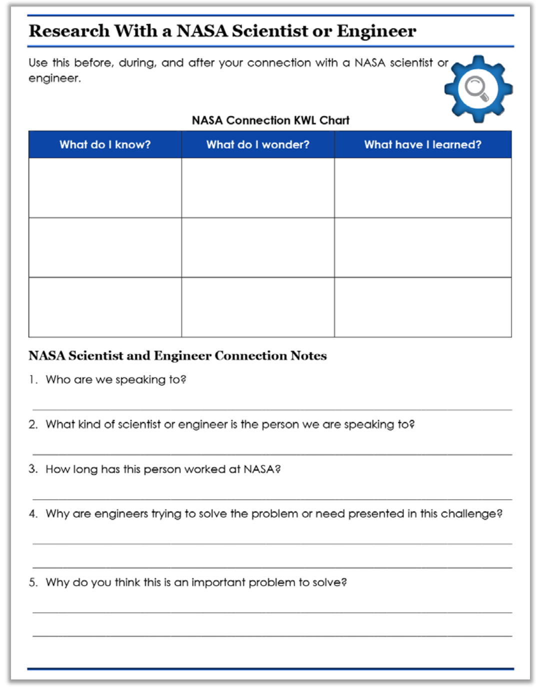
Career Connection

Arrange for different types of engineers to visit and allow students to discuss engineering with them.

Technology Connection

Have students build QR codes containing the information they learn. Teams can then create questions for a Family Night scavenger hunt. Community participants can search for answers by using an app to scan the QR codes.

Research With a NASA Scientist or Engineer



Research With a NASA Scientist or Engineer

Use this before, during, and after your connection with a NASA scientist or engineer.

NASA Connection KWL Chart

What do I know?	What do I wonder?	What have I learned?

NASA Scientist and Engineer Connection Notes

1. Who are we speaking to?
2. What kind of scientist or engineer is the person we are speaking to?
3. How long has this person worked at NASA?
4. Why are engineers trying to solve the problem or need presented in this challenge?
5. Why do you think this is an important problem to solve?

Part of a NASA engineering design challenge is an opportunity for your students to virtually connect with a NASA scientist or engineer. Think about your program's schedule and when the best time for this connection may be. It is recommended to make a virtual connection at least once throughout the challenge. Optimal times for this vary, depending on your students, but these connections may be especially advantageous during the research, design, and testing phases.

Prepare students for the NASA connection by viewing this video in which Commander Sunita Williams gives a tour of the International Space Station. This will help answer students' basic questions about space travel and living in space.

https://www.youtube.com/watch?v=ukws3oLMDc8

Use the following guiding questions to help students create authentic questions for the NASA scientist or engineer. Have students use the NASA Connection KWL chart in their Student Journals to document the questions they are interested in asking.

Guiding Questions for a NASA Scientist or Engineer Connection

- What do NASA scientists and engineers design that may affect our daily lives?
- What kinds of jobs are found at NASA?
- Is working in a team important at NASA?

The following videos may be helpful for students who need extra support in visualizing what kind of work an engineer does.

Career Connections

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

NASA employees meet needs and identify problems every day, and not just in space. To find out more about the people who work at NASA, have students visit "My Everyday Extraordinary." https://www.nasa.gov/careers/my-everyday-extraordinary

To learn more about what astronauts and engineers do, watch NASA's YouTube series "In Their Own Words."
https://www.youtube.com/user/NASAgovVideo/search?query=in+their+own+words

Design

The design phase includes drawing models of possible solutions, refining the models, and collaborating as a team to choose the idea that best meets the original need or problem. First, students work independently. This allows students to define the ideas they have on their own before they work in a group. Next, teams collaborate to create a team design combined from the individual ideas. All designs should be drawn precisely and labeled with a key. Facilitators should approve final drawings before building begins.

Design Your Idea

Individual Design: How can I solve the problem?

Sketch your initial design and label each part of your drawing.

Notes (list what materials you may use, how big the model will be, how it will be constructed, etc.):

Approved by: ______

Objectives

- Students will use knowledge gained to design a possible solution.
- Student teams will compare and contrast designs within the team and collaborate to create a team design that meets the criteria and constraints.

Guiding Questions

- What are all the different ways each member of the team can imagine to solve the problem?
- How can the team collaborate to design our best solution idea?
- Do the drawings address all the criteria and constraints?

Instructional Procedure

1. Ask each team member to brainstorm individually and make a sketch representing their ideas for a solution. Students must clearly label and identify each part of their drawing.
2. Remind students to make sure designs meet all criteria and constraints. Also remind students to think about what they learned in the STEM Investigations.
3. Ask team members to discuss their ideas and drawings with the rest of the team.
4. Based on a team discussion, students will collaborate to determine which design elements will be used to solve the problem and what features will be included to create the team's model. The most promising solution should include elements from more than one design. Teams will need time to discuss and agree on what their model design will include.

5. Have students record the strengths of each of the designs on the Team Discussion and Selection page in the Student Journal.
6. When their group collaboration is complete, students should take a moment to pause and reflect on the work so far. Students can work individually or as a team to complete the first Stop and Check page in the Student Journal.

Debriefing Questions

- How does my model represent the criteria and the constraints of the challenge?
- What are the strengths and weaknesses of my individual drawing of my model?
- How does our drawing of our team model meet the criteria and constraints of the challenge?

Differentiation Suggestions

- Show students the building materials prior to beginning the drawing.
- Allow students to experiment with different materials to build their model before they draw their design.
- Give students an 11- by 17-inch sheet of paper to construct a collaborative team drawing.
- Require students to make a scale drawing using proper ratios.

Math Connection

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

Technology Collection

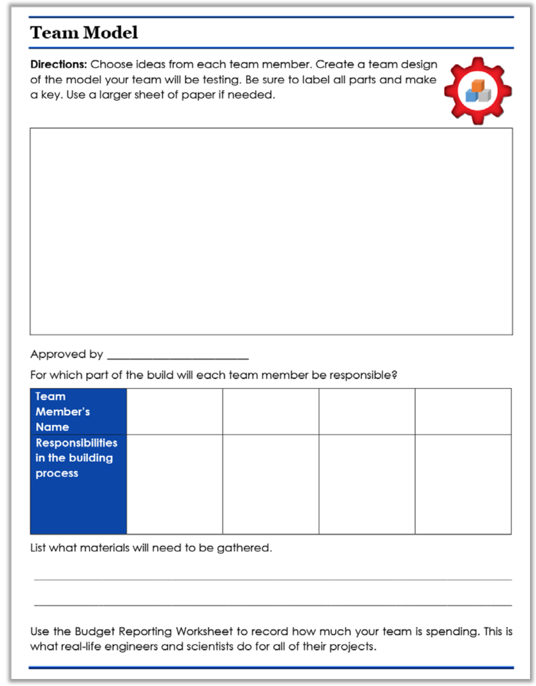
Have students use a computer program to design a 3D model of the team prototype and, if time permits, present to the whole group.

Multimedia Resource

To learn more about NASA aeronautics research and design, visit https://www.nasa.gov/centers/armstrong/features/afrc-interns-create-new-way-to-explore-flight.html

Model

A model is constructed based on the design from the team collaboration. Its purpose is 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.



Team Model

Directions: Choose ideas from each team member. Create a team design of the model your team will be testing. Be sure to label all parts and make a key. Use a larger sheet of paper if needed.

Approved by ______________

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

Team Member's Name				
Responsibilities in the building process				

List what materials will need to be gathered.

Use the Budget Reporting Worksheet to record how much your team is spending. This is what real-life engineers and scientists do for all of their projects.

Taking a photograph or video recording at intermittent points in this phase will allow students to make more complete comparisons when they begin to analyze their engineering work.

Objectives

- Students will create a model representing the team's design from available materials.
- Students will create a budget sheet that will record and calculate the material cost of the team's model within an established budget.

Guiding Questions

- How can our team create a model representing the team's design from available and provided building materials?
- How can our team create a budget sheet that will record and calculate the material cost of the team's model within an established budget?
- How can our team Communicate, Explain, and Share the reasons for the team's decisions, research, and improvements?

Instructional Procedure

1. Predetermine the cost of the materials that will be available to students. Label those items and decide on a total budget amount, for example, $5.
2. Introduce the budget sheet to student teams and have them complete it while working on this phase of the engineering design process. Younger students may struggle with the budget on this engineering design challenge (EDC); it can be optional if the facilitator feels students are not ready for this concept.
3. This is a good point in the EDC to show teams the materials for the first time.
4. Have each team determine what materials they will need to build their design and encourage team members to do their assigned jobs within the group. Group

roles and collaboration can be critical during this phase. Students within a collaborative team and defined roles will be best prepared for success.

5. Remind teams to check the criteria and constraints as they begin hands-on work.
6. Have teams construct their models using the drawing.
7. As the students are constructing their models, encourage them to explain their engineering thinking as they adapt the building materials to their model. Students can demonstrate the cause-and-effect relationships as they construct their model.
8. Remind teams to discuss and record the reasons for the team's decisions, research, improvements, and budget during this phase.

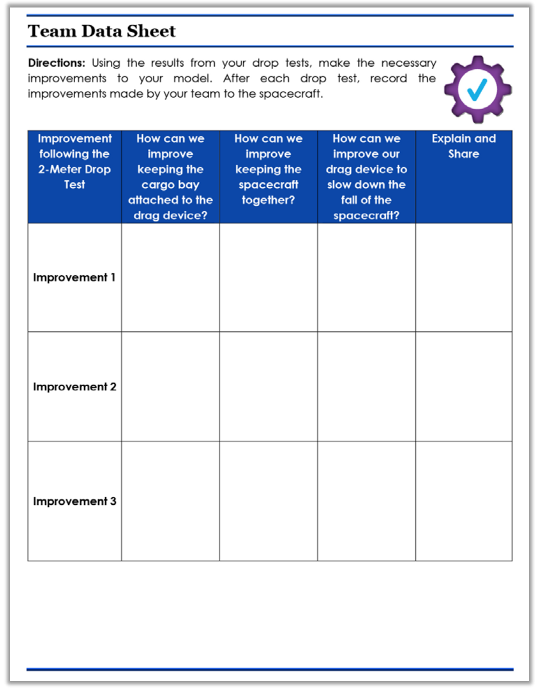
Differentiation Suggestions

- Give students extra time to explore various materials prior to building the model.
- Limit materials to add complexity (e.g., only 1 meter of duct tape).
- Students can compare and contrast their models and write a persuasive paragraph arguing for what should and should not be in their final design and why.

Debriefing Questions

- How can we create a model representing the team's design from available materials?
- How did we create a model within the established budget for materials?
- Did we make sure we met all of the criteria and constraints?
- What are two engineering ideas the team had during this phase?
- How can we Communicate, Explain, and Share the reasons for the team's decisions, research, and improvements?

Test and Improve


Team Data Sheet

Directions: Using the results from your drop tests, make the necessary improvements to your model. After each drop test, record the improvements made by your team to the spacecraft.

Improvement following the 2-Meter Drop Test	How can we improve keeping the cargo bay attached to the drag device?	How can we improve keeping the spacecraft together?	How can we improve our drag device to slow down the fall of the spacecraft?	Explain and Share
Improvement 1				
Improvement 2				
Improvement 3				

During this phase of the engineering design process (EDP), student teams will conduct drop tests, record observations, and make improvements to their models. During each of the drop tests, students will need to collect and record data and observe how their models have met the criteria and constraints of the challenge.

Objectives

- Students will conduct tests of the model solution.
- Students will identify areas for improvement based on test data.
- Students will identify whether any part of the model needs to be redesigned.
- Student teams will move forward or return to previous EDP phases if they need to redesign the model based on new research or test data.

Guiding Questions

- How can our team conduct tests that represent the criteria and constraints of the challenge?
- How will our team identify areas for model improvements based on test data?
- What were the reasons for the model failure during the tests? How will we address these issues during the redesign of the model?
- When will our team need to progress forward or return to previous EDP phases to redesign the model based on new research or test data?

Instructional Procedure

1. Using the model student teams made with the available building materials, teams will conduct a drop test from a height of 2 meters. Students will record observations, paying close attention to the specified criteria.
2. Based on the data, teams can make improvements to the model and the design.
3. Allow teams time to collaborate with each other and with other teams to identify the cause-and-effect relationships that contribute to the failure or success of the model.

4. As testing continues, teams may need to return to previous phases in the EDP to research new questions, modify the model design, and/or reconstruct the model itself.
5. Students should take a moment and pause to reflect on the work so far. Students can work individually or as a team to complete the second Stop and Check page in the Student Journal.
6. Encourage teams to Communicate, Explain, and Share the reasons for the team's decisions, research, improvements, and budget as they create a presentation script.

Debriefing Questions

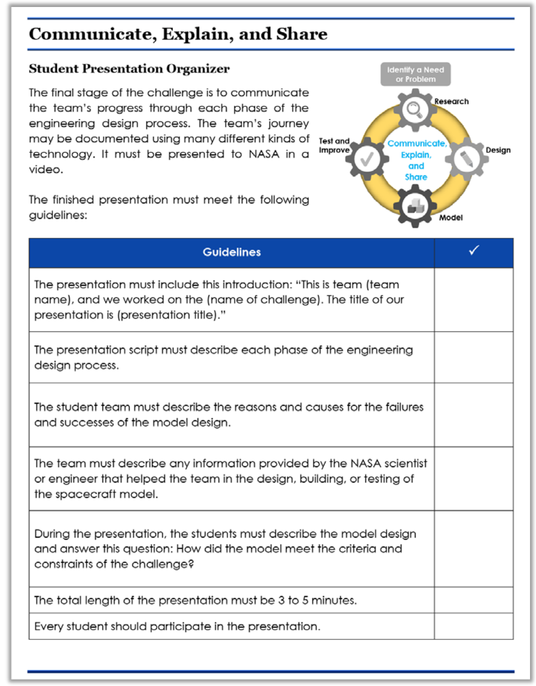
- How did the data from our tests represent the criteria and the constraints of the challenge?
- What areas of our model need to be improved based on the test data?
- What were the reasons for the model's failure during the tests? How can these issues be addressed during the redesign of the model?

Differentiation Suggestions

- Encourage students to test only one criteria or constraint at a time rather than all of them at once.
- Allow students extra time to test and record their model's iterations.

Communicate, Explain, and Share

For the final phase of the challenge, teams will create a presentation. The Student Journal is designed to help document each phase of the engineering design process (EDP). Encourage students to use their journals to help build the presentation.



Communicate, Explain, and Share

Student Presentation Organizer

The final stage of the challenge is to communicate the team's progress through each phase of the engineering design process. The team's journey may be documented using many different kinds of technology. It must be presented to NASA in a video.

The finished presentation must meet the following guidelines:

Guidelines	✓
The presentation must include this introduction: "This is team (team name), and we worked on the (name of challenge). The title of our presentation is (presentation title)."	
The presentation script must describe each phase of the engineering design process.	
The student team must describe the reasons and causes for the failures and successes of the model design.	
The team must describe any information provided by the NASA scientist or engineer that helped the team in the design, building, or testing of the spacecraft model.	
During the presentation, the students must describe the model design and answer this question: How did the model meet the criteria and constraints of the challenge?	
The total length of the presentation must be 3 to 5 minutes.	
Every student should participate in the presentation.	

Objective

- Students will communicate complex ideas clearly and effectively by creating or using a variety of digital objects such as visualizations, models, or simulations to create a final presentation of the engineering design challenge.

Guiding Questions

- How can our team Communicate, Explain, and Share the reasons for the team's decisions, research, and improvements?
- How can the team use technology to represent and describe their solution to the challenge?

Instructional Procedure

1. Review the presentation submission guidelines with students.
2. Using an appropriate software platform, student teams will assemble, edit, and produce a video that describes their journey through each phase of the EDP.
3. Allow student teams plenty of time to be creative and to use all of the documentation recorded during this challenge to clearly communicate the team's work.
4. Remind teams to use the rubric as a guide when creating the presentation.

Debriefing Questions

- How can we Communicate, Explain, and Share the reasons for the team's decisions, research, and improvements?
- Were complex ideas communicated clearly through digital means?
- How was technology used to describe the team's progress through the EDP?

Student Presentation Guidelines

Each student presentation must be submitted as a video but can be documented using any communication method. Remind students to use the pages of the Student Team Challenge Journal to help complete the presentation.

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)."

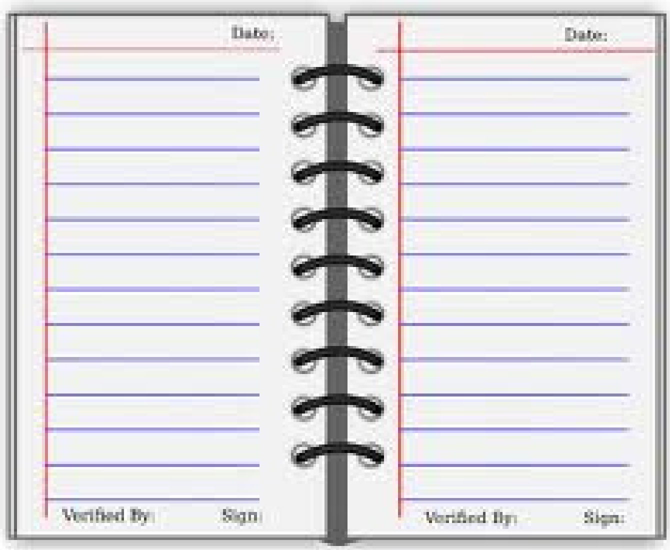
  Do not identify by name any student, teacher, school, group, city, or region in the presentation. Submissions that do not follow these directions will be disqualified.
- ❏ The presentation must document every step teams took to complete the challenge, including
  - STEM Investigations
  - Each phase of the engineering design process
  - Any problems in design or teamwork that happened and how they were resolved
- ❏ Student teams must identify any information provided by a NASA scientist or engineer that helped in the design or testing.
- ❏ Presentations must explain which characteristics of the design provided the most reliable results and why.
- ❏ Presentations must describe the final design.
- ❏ Total length of the presentation must be 3 to 5 minutes.
- ❏ Every student should participate in the presentation.

Help guide students to think of creative ways to share what they have learned. Exciting ways to present a video with team information might include these:

- Stop-gap animation movie of photos taken during the process
- Trifold display similar to a science fair presentation as part of the video
- Video presentation using a virtual slide deck with videos, photos, and narration
- Cartoon depicting how the team progressed through the challenge
- Virtual storybooks created on a website as part of the video
- Photos and video documentation

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

Student Journal



NASA Mission Background

What is NASA?

Figure 15. Raja Chari is a member of NASA's 2017 Astronaut Candidate Class.(NASA)

NASA is short for a much longer name: The National Aeronautics and Space Administration. NASA is many different people and places. Everyone at NASA has the same vision: *To discover and expand knowledge for the benefit of humanity*.

For more than 50 years, the people of NASA have worked to change the history of the human race. From walking on the Moon to sending spacecraft to the Sun and every planet in the solar system, we continue to be curious and work together as a team to reach our goals.

What is Mars like?

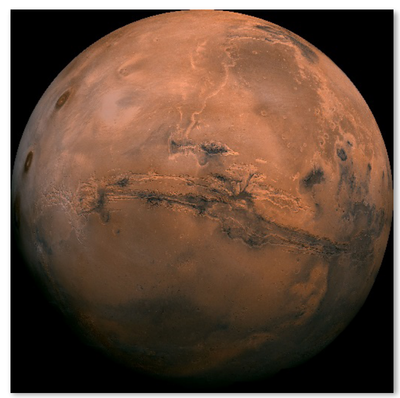


Figure 16. Photograph pieced together from 102 Viking Orbiter images of Mars. (NASA)

Mars is the fourth planet from the Sun. The surface of Mars is rocky. Red dust covers almost all of the planet. It has clouds and wind. Sometimes the wind blows the red dust into a storm. Tiny dust storms can look like tornados, and large dust storms can cover the whole planet.

Mars is smaller than Earth and has less gravity. This means that a rock dropped on Mars would fall more slowly than a rock dropped on Earth. All objects weigh less on Mars, even you. A person who weighs 45 kilograms (about 100 pounds) on Earth would only weigh about 17 kilograms (37 pounds) on Mars.

The atmosphere of Mars is different from Earth in two major ways. Mars has less oxygen than Earth and more carbon dioxide. This is why it is very difficult for NASA to land spacecraft on the surface of Mars.

How do spacecraft land on Mars?

Spacecraft need a safe way to land on Mars. They must not hit the surface too hard or they will be damaged. NASA uses devices that slow down moving objects. These devices use the air resistance to create **drag,** which slows the object that is landing. These **drag devices** come in many shapes, sizes, and materials. NASA has used a basic parachute design to land vehicles on the surface of Mars since 1976, when the first Viking lander touched down.

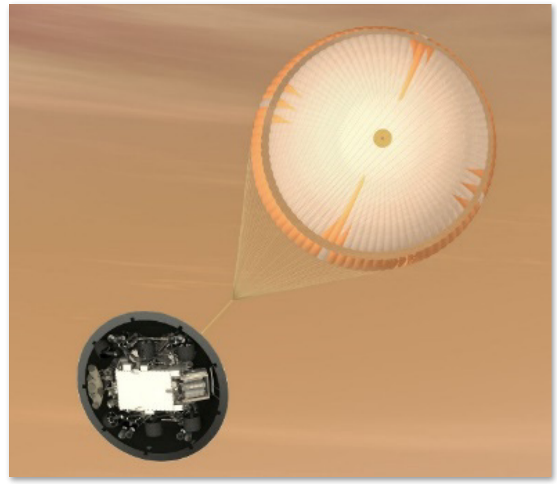


Figure 17. Artist's concept of the parachute system for the Mars Science Laboratory's Curiosity rover. (NASA)

How is NASA exploring Mars?

NASA has landed rovers called Sojourner, Spirit, Opportunity, and Curiosity on the surface of Mars. These rovers are robots that move around the planet taking images and collecting science data. Curiosity is the only rover still moving on the Mars surface.

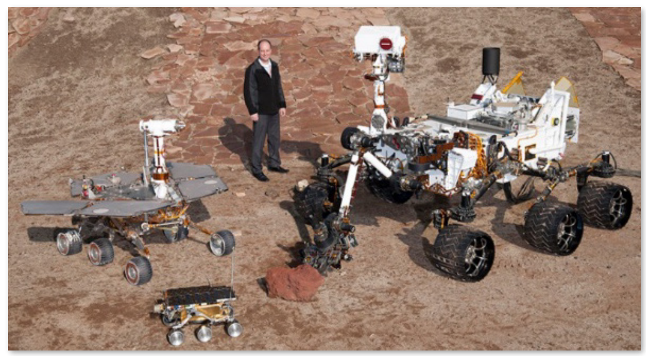


Figure 18. Models of successful Mars rovers. (NASA)

InSight Lander

In November 2018, the InSight lander touched down on Mars after a 7-month trip from Earth. A lander usually stays in one place to collect data. InSight's 2-year mission is to study the interior, or what is under the surface, of Mars. The lander will collect data on how Mars changes over time. Parts of the lander can record sound and dig down into the red soil.

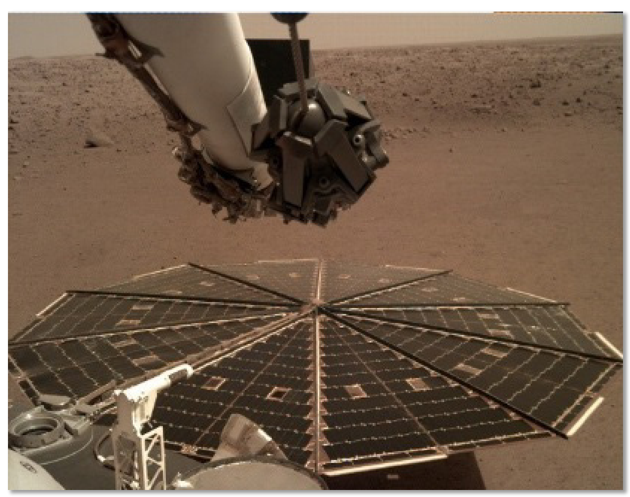


Figure 19. One of InSight's 2.2-meter- (7-foot-) wide solar panels. Photo taken in 2018 by the camera attached to the lander's robotic arm. (NASA/JPL-Caltech)

Mars 2020 Rover

The Mars 2020 rover mission is part of NASA's Mars Exploration Program. The mission is looking for places on Mars where astronauts may be able to live someday. It is also searching for signs of life in the past. The mission will collect data to help future humans who may travel to Mars.

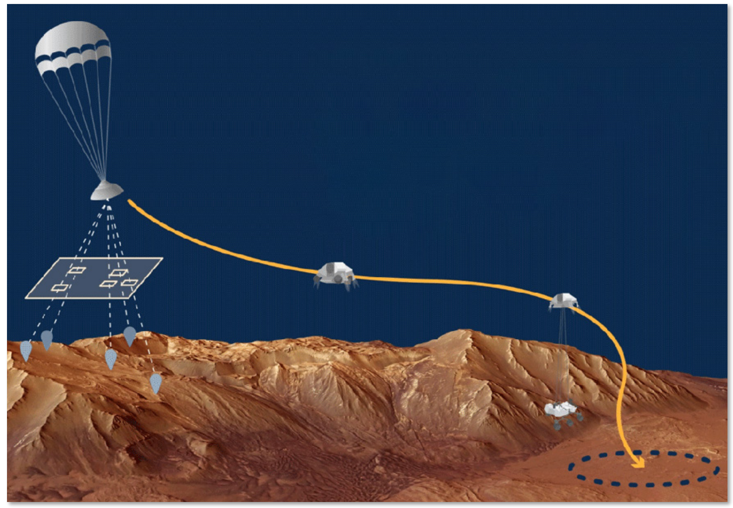


Figure 20. Illustration of the Mars 2020 Rover landing on the surface of Mars. (NASA)

What is drag?

Drag is a force made by an object moving through air. People often call this air resistance. Have you ever put your hand out of a car window while the car was moving and felt your hand being pushed back and forth? If so, you have felt the force that is called drag.

What do you think would happen if you tried to run a race holding an open umbrella? Do you think the umbrella would make you go faster or slow you down? If you guessed it would slow you down, you are correct! Drag caused by the umbrella moving through air will slow you down. This is why the front of an airplane is pointed—it helps the airplane move faster through the air. Why do you think fish have a pointed shape? This makes them move faster through the water by reducing drag.

Quick Check: Balanced and Unbalanced Forces

What are balanced and unbalanced forces? Think of a pencil resting on your desk. Because it is not moving, it is experiencing a balanced force. Now, what would happen if you shook your desk? The pencil would move and experience an unbalanced force.

- Balanced forces DO NOT cause a change in motion.
- Unbalanced forces DO cause a change in motion.

STEM Investigation 1: It's a Drag

Mission

Use a piece of paper to investigate drag. You and your partner will take turns dropping and timing a falling object.

Figure 21. A drag chute helped slow down Space Shuttle Endeavour when it landed at Edwards Air Force Base in 2002. (NASA)

Materials

- Meter stick
- Large sheet of paper
- Stopwatch
- Table

Procedure

1. Place the meter stick on top of the table so that it is standing up. The bottom of the meter stick should be placed at the edge of the table. You will safely drop the paper from the top of the meter stick to the floor. You may need your facilitator's help.
2. One student in each group takes the UNFOLDED paper and holds the sheet of paper horizontally, or flat, at the top of the meter stick. Release the paper.
3. Your partner will use the stopwatch to time how long it takes the paper to fall to the floor.
4. Complete three trials.
5. Record all of the times on your Data Collection Sheet.
6. Next, fold the paper in half and hold the sheet of paper horizontally, or flat, at the top of the meter stick.
7. Release the paper while your partner times how long it takes to fall to the floor.
8. Complete three trials.
9. Record the time on your Data Collection Sheet.
10. Fold the sheet of paper into quarters
11. Release the paper while your partner times how long it takes to fall to the floor.
12. Complete three trials.
13. Fold the sheet of paper into eighths.
14. Release the paper while your partner times how long it takes to fall to the floor.
15. Complete three trials.
16. Answer the questions provided on the Data Collection Sheet.

Data Collection Sheet

Directions: Record the data and observations from this investigation.

1. What size paper was the slowest? Why do you think that is?

____

____

2. When did you see balanced and unbalanced forces at work on your model?

____

____

3. What did you learn in this investigation that makes you think about slowing down your vehicle for the engineering design challenge?

____

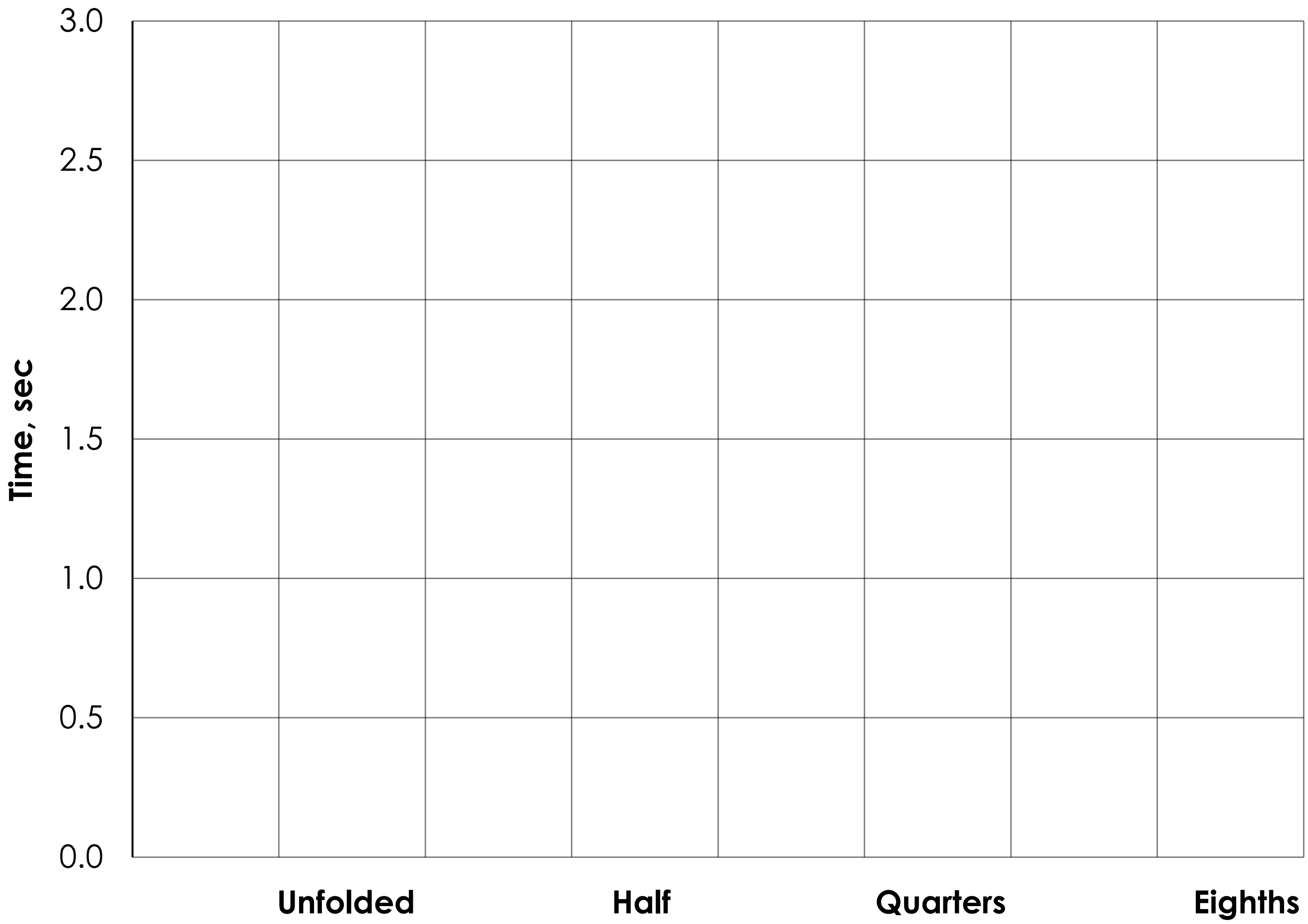
____

Paper shape	Drop 1 time, sec	Drop 2 time, sec	Drop 3 time, sec	Observations
Unfolded				
Folded in half				
Folded in quarters				
Folded in eighths				

Bar Graph

Using a different color for each paper shape, make a bar graph of the results. Use the third test time for each shape.

Title: ________________________



1. Describe the graph. How did the shape of the paper affect the speed at which it fell? Use the data in your answer.

____

____

____

2. Why do you think that happened?

____

____

____

STEM Investigation 2: Touchdown

Mission

Design and build a shock-absorbing system that allows two marshmallows to stay in a cup when landing.

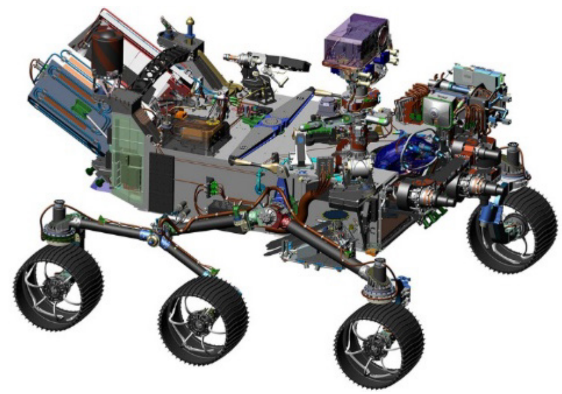


Figure 22. Computer-assisted design of NASA's Mars 2020 rover. (NASA/JPL-Caltech)

Materials

- Piece of stiff paper or cardboard (lander)
- Small paper or plastic cup (cargo hold)
- 4 small index cards
- Tape measure with metric measurements
- 2 regular-size marshmallows (cargo)
- 10 miniature marshmallows
- 3 rubber bands
- 8 plastic straws
- Scissors
- Tape

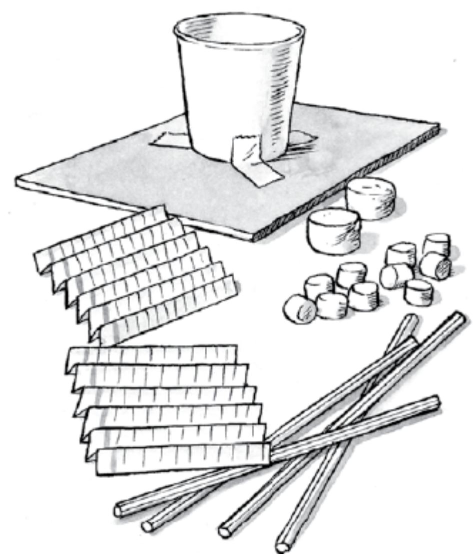


Figure 23. Materials used in the "Touchdown" investigation.

Procedure

1. Secure the cargo hold (cup) on the lander (cardboard).
2. Work in pairs to design a shock-absorbing system with the materials provided.
3. Build your shock-absorbing system and attach it to the cardboard lander.
4. With the cargo hold attached to the lander, put two pieces of cargo (the large marshmallows) in the cargo hold. <u>They cannot be secured with tape</u>.
5. Drop the lander from heights of 50, 100, and 150 centimeters and record your observations.
6. If the cargo does not stay in the cup, work with your team to redesign the shock-absorbing system.

Student Connections

Have you ever been in a car on a bumpy road? Did you get knocked back and forth and up and down? If so, the shock-absorbing system in the car was not working very well. Turn and talk with your neighbor (not your partner for the experiment) about what might happen if a car did not have a shock-absorbing system. Now think about the investigation. Did your team protect the cargo? How might you improve on the design?

Data Collection Sheet

Fill in the table below with descriptions of what happened in your experiments.

Drop Height	Cargo protected? Yes/No	Changes Needed
50 centimeters (cm)		
100 cm		
150 cm		

1. Describe the results. Did your design protect the cargo? If not, describe the changes your team had to make to continue working on the problem.

___

___

___

2. Did you create a shock-absorbing system that held together for a 150-centimeter drop? If not, what do you think can be done differently?

___

___

___

Student Team Building

Directions: Work together to decide on a team name, design a mission patch, and create a group motto.

Figure 24. This Apollo 11 patch depicts an eagle landing on the Moon with a view of the Earth in the background. (NASA)

Team Name

Team Patch

NASA's vision statement: To discover and expand knowledge for the benefit of humanity.

Team Motto

Engineering Design Process

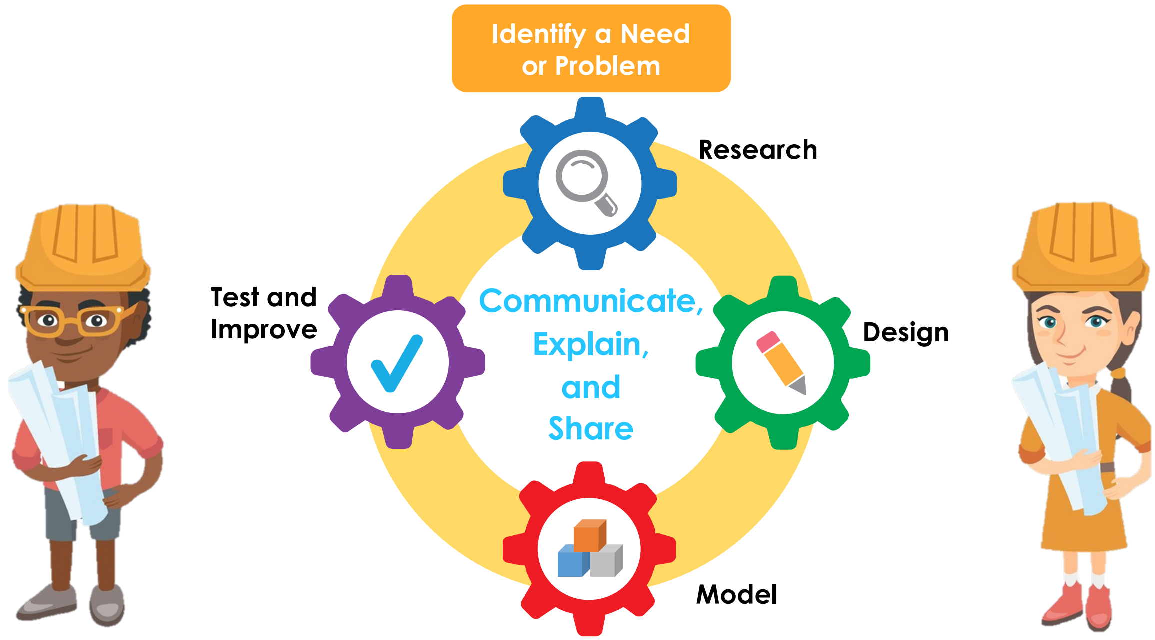


Figure 25. Engineering design process model. Model and accompanying text adapted from the 2016 Massachusetts Science and Technology/Engineering Curriculum Framework, Massachusetts Department of Elementary and Secondary Education, http://www.doe.mass.edu/frameworks/scitech/2016-04.pdf.

Identify a Need or Problem. This phase is designed to ask this question: How can we design a model that will meet the criteria and constraints of the challenge?

Research. During the research phase, students will find the answers to their questions by exploring the internet, visiting a library, or interviewing a NASA scientist or engineer.

Design. In the design phase, each student will draw a model that could solve the challenge. Teams will combine the drawings and design a team model drawing that meets the criteria and constraints.

Model. In the model phase, the team will use their drawing to build their model.

Test and Improve. The model will be tested. Teams will gather and evaluate data to improve the design.

Communicate, Explain, and Share. During each phase, the team will record and share progress. Teams should discuss the design solutions and present ideas to others, describing the engineering design process.

Engineering Design Process

Directions: Use the diagram of the engineering design process to answer the questions.

Questions

1. What is the first phase of the engineering design process?

____

____

____

2. What do you think is the second phase of the engineering design process? Why?

____

____

____

3. What is the phase of the engineering design process when your team observes whether your possible solution works or not? Is it okay to have your model fail?

____

____

____

4. When using the engineering design process, can you repeat phases? Why?

____

____

____

Presentation Script

Directions: Use the prompts to create your script for the final presentation.

Talk about two things you learned about the engineering design process.

____

____

____

____

Is there a phase of the engineering design process that you have used before?

____

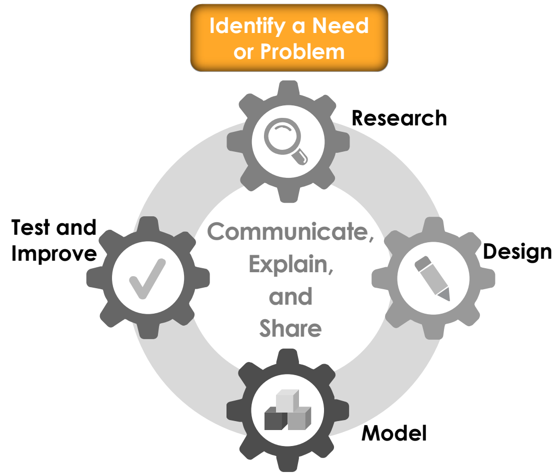
____

____

____

What Is the Need or Problem?

The Challenge



You and your team will design and construct a drag device that will **slow down** the cargo bay when it is dropped from a consistent height. (Use the Cargo Bay Template in the back of this guide.) You will test your model and collect data.

For the test, your model will be dropped from a height of 2 meters. First, test the cargo bay without the drag device attached. Then test with the device attached. The drag device must remain attached to the cargo bay after the drop test. The cargo bay must hold 10 grams of weight secured inside. You must show improvements in slowing down your model as you test the drag device each time.

Criteria (MUST) and Constraints (MUST NOT)

1. The team **must** make a drag device and connect it to the cargo bay. The device **must** make the cargo bay slow down when dropped.
2. The drag device and cargo bay **must** be dropped from 2 meters and **must** stay attached throughout the drop.
3. Your team cargo bay **must** hold 10 grams of cargo protected inside.
4. The total mass **must not** be greater than 50 grams.

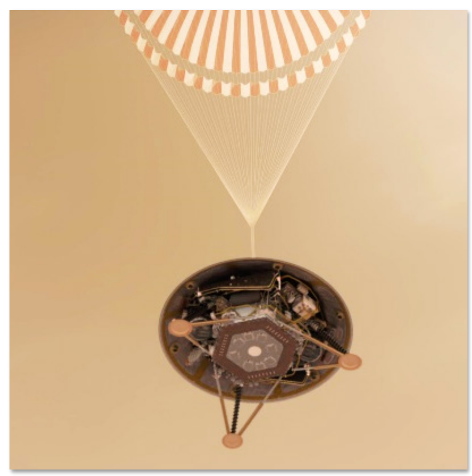


Figure 26. Illustration of NASA's InSight lander descending toward the surface of Mars with its parachute. The lander arrived on Mars in November 2018. (NASA)

What is the problem you and your team will be working on in this challenge?

____

____

____

Our design MUST ____

Our design MUST NOT ____

Presentation Script

Directions: Use the prompts to create your script for the final presentation.

Write an introduction to your video that describes your team and the challenge. Start with the following sentence:

"This is team (team name) and we worked on the (name of challenge). The title of our presentation is (title)."

____

____

____

____

____

____

Research

Directions: You will conduct research and record what you already **know**, what you **wonder**, and what you **learn** (KWL). After reading the challenge and watching the Introductory Video, work with your team on this KWL chart.

KWL Chart

What do I know?	What do I wonder?	What have I learned?

Research With a NASA Scientist or Engineer

Directions: Use this before, during, and after your connection with a NASA scientist or engineer.

NASA Connection KWL Chart

What do I know?	What do I wonder?	What have I learned?

NASA Scientist and Engineer Connection Notes

1. Who are we speaking to?

____

2. What kind of scientist or engineer is the person we are speaking to?

____

3. How long has this person worked at NASA?

____

4. Why are engineers trying to solve the problems or need presented in this challenge?

____

____

5. Why do you think this is an important problem to solve?

____

____

Presentation Script: Research

Directions: Use the prompts to create your script for the final presentation.

1. We learned two facts about this challenge:

____

____

____

2. We also researched our problem and learned

____

____

____

3. We found our information (internet, books, library). (Write down the name of the site or book where you found the information.)

____

____

____

4. We talked with a NASA person whose name is

____

5. This person is a ______________________ engineer or scientist who works on

____

6. One interesting fact we learned from this person is

____

____

____

Include a photo of your NASA Connection KWL chart or your discussion with a NASA scientist or engineer and any videos you may have taken during this phase of the engineering design process.

Design Your Idea

Individual Design: How can I solve the problem?

____

____

____

Sketch your initial design and label each part of your drawing.

Notes (list what materials you may use, how big the model will be, how it will be constructed, etc.):

____

____

____

Approved by: ________________

Team Discussion and Selection

Directions: Meet with your team to discuss each team member's final drawing using the table below. The most promising solution ideas should include elements from more than one design. Remember what the criteria and constraints are!

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

Stop and Check

Directions: Review the engineering design process by answering the following questions. If you answered "No" to any of the questions, go back and review the material.

Questions	Response (circle one)	
Did we determine what needed to be solved or resolved?	**Yes**	**No**
Did we research how to solve the problem?	**Yes**	**No**
Did we ask a NASA scientist or engineer our questions?	**Yes**	**No**
Did we design a solution that met all the criteria and constraints?	**Yes**	**No**
Have we included ideas from all team members' drawings in our team design?	**Yes**	**No**
Do we have a team drawing?	**Yes**	**No**

Team Model

Directions: Choose ideas from each team member. Create a team design of the model your team will be testing. Be sure to label all parts and make a key. Use a larger sheet of paper if needed.

Approved by___________________________

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

Team Member's Name				
Responsibilities in the building process				

List what materials will need to be gathered.

____

____

Use the Budget Reporting Worksheet to record how much your team is spending. This is what real-life engineers and scientists do for all of their projects.

Budget Reporting Worksheet

Real-World Connections

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

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

Model Data Sheet

1. Does the model meet all of the criteria and constraints?

   Yes **No**

2. Does the spacecraft stay together when tested?

   Yes **No**

3. If not, explain what happened.

____

____

Construction Checklist

The drag device slows down the fall of the cargo bay	The drag device and cargo bay stay attached during the test	The cargo bay has 10 grams of cargo secured inside	The total mass of the model is less than 50 grams
Yes **No**	**Yes** **No**	**Yes** **No**	**Yes** **No**

Presentation Script

Directions: Use the prompts to create your script for the final presentation.

These are two ways the team worked together to build our model:

1.____

____

____

2.____

____

____

This is how we included all of the data in our presentation:

____

____

____

____

____

____

____

____

Test Data Sheet

Directions: Before your team puts the drag device on the cargo bay, do a drop test on the item. This is called a control test and will help your team know how well the drag device design is working. Then attach the drag device and test the model three times to see how well it performs. For each test, observe how the spacecraft reacts to the impact with the ground. Record your observations here.

2-Meter Drop Test	Did the cargo bay remain attached to the drag device?	Did the drag device slow down the fall of the spacecraft?	Time of Drop	Observations
Control Test Without the drag device attached			Trial 1:	
			Trial 2:	
			Trial 3:	
Test 1 With the drag device			Trial 1:	
			Trial 2:	
			Trial 3:	
Test 2 With an improvement			Trial 1:	
			Trial 2:	
			Trial 3:	
Test 3 With an improvement			Trial 1:	
			Trial 2:	
			Trial 3:	

Team Data Sheet

Directions: Using the results from your drop tests, make the necessary improvements to your model. After each drop test, record the improvements made by your team to the spacecraft.

Improvement following the 2-Meter Drop Test	How can we improve keeping the cargo bay attached to the drag device?	How can we improve keeping the spacecraft together?	How can we improve our drag device to slow down the fall of the spacecraft?	Explain and Share
Improvement 1				
Improvement 2				
Improvement 3				

Stop and Check

Directions: Review the engineering design process by answering the following questions. If you answered "No" to any of the questions, go back and review the material.

Questions	Response (circle one)	
Did we create a plan to solve the engineering design challenge?	**Yes**	**No**
Did we decide a role for everyone in our group?	**Yes**	**No**
Did the design meet all the criteria and constraints?	**Yes**	**No**
Was the model tested 3 times?	**Yes**	**No**
Did we describe what did or did not work in our design?	**Yes**	**No**
Did we describe how the design could be improved?	**Yes**	**No**
Did we provide feedback to our team members and document the discussion?	**Yes**	**No**
Did we use all the phases of the engineering design process in the engineering design challenge?	**Yes**	**No**

Communicate, Explain, and Share

Presentation Script

Use this page to share details about your data and your final model.

The data we collected during the engineering design process (EDP) support the challenge. Here are the data that show how we met ALL the criteria (include photos or use video to communicate this phase of the EDP):

____

____

____

____

____

Does the final design solve the challenge?

Yes **No**

What were the strengths of the team model(s)? What were the concerns?

____

____

____

Describe the improvements the team made to the model.

____

____

What two suggestions does your team have for future engineers who would like to solve this challenge?

1. ____

____

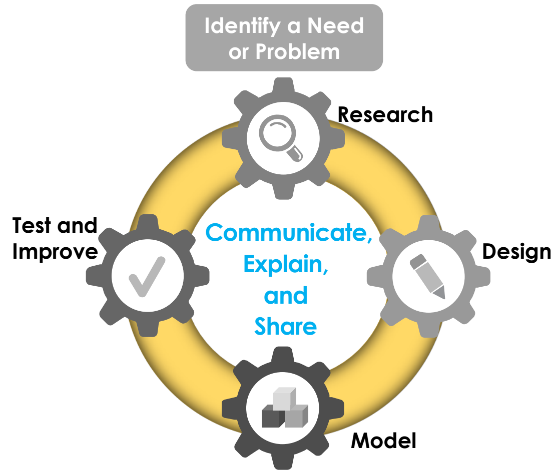
2. ____

____

____

Communicate, Explain, and Share

Student Presentation Organizer



The final stage of the challenge is to communicate the team's progress through each phase of the engineering design process. The team's journey may be documented using many different kinds of technology. It must be presented to NASA in a video.

The finished presentation must meet the following guidelines:

Guidelines	✓
The presentation must include this introduction: "This is team (team name), and we worked on the (name of challenge). The title of our presentation is (presentation title)."	
The presentation script must describe each phase of the engineering design process.	
The student team must describe the reasons and causes for the failures and successes of the model design.	
The team must describe any information provided by the NASA scientist or engineer that helped the team in the design, building, or testing of the spacecraft model.	
During the presentation, the students must describe the model design and answer this question: How did the model meet the criteria and constraints of the challenge?	
The total length of the presentation must be 3 to 5 minutes.	
Every student should participate in the presentation.	

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 model.

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

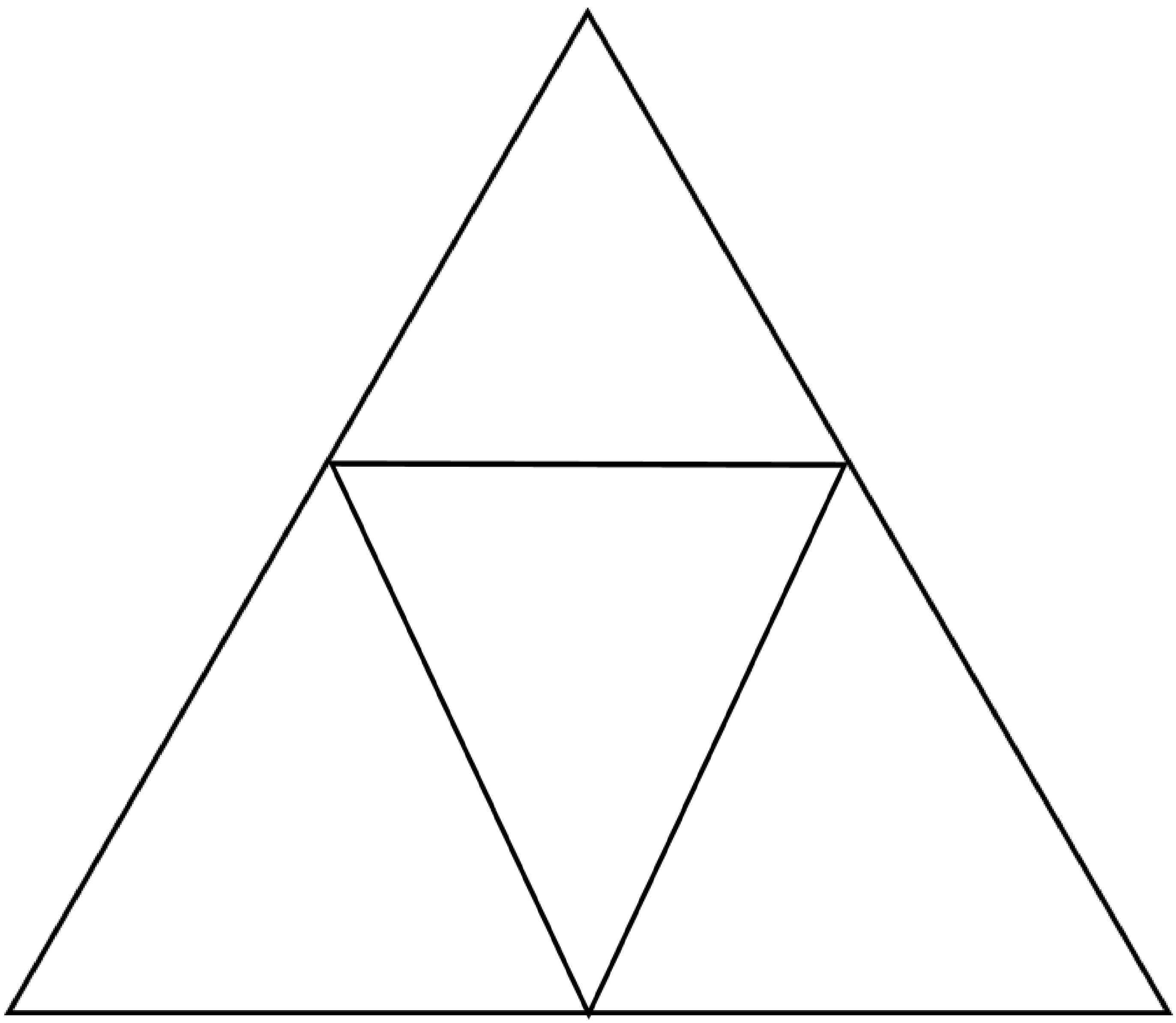
5. As a conclusion, the team described the challenges and successes they experienced as they built, tested, and improved their model.

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

Comments and Encouragement

Cargo Bay Template

1. Cut out the large triangle.
2. Fold up each corner triangle to create a pyramid shape.
3. Put your payload (the pennies) inside and tape up the sides. Try not to use too much tape because you may need to open it up again.



Vocabulary List

Astronaut. A person trained to travel and work in space. Sentence: An astronaut trains a long time before traveling into space. Synonym: space explorer.

Cargo. Items carried by an aircraft or other transportation vehicles. Sentence: The capsule must include all of the cargo the astronauts might need. Synonym: supplies.

Cargo bay. The area inside a spacecraft where the cargo is packed. Sentence: The cargo bay doors were opened to help cool the shuttle after it was in orbit. Synonym: payload bay.

Constraints. Limits on the design. Things a model MUST NOT do. Sentence: The constraints on my kite's design were that I could only use paper and wood to make it. Synonym: limit.

Criteria. Characteristics of a successful solution. What a design MUST do. Standards by which something may be judged or decided. Sentence: The criteria for my kite's design were that my kite must fly for 5 minutes at least 5 feet above the ground. Synonym: requirement.

Drag. Resistance to motion through the air. Sentence: The force of drag tried to pull our kite down. Synonym: delay.

Engineer. A person who uses a process to solve a problem or a need people have. Sentence: The engineer figured out a way to build a better space shuttle. Synonym: designer.

Exploration. Investigation of the unknown. Sentence: Space exploration has fascinated many people for centuries. Synonym: discovery.

Gravity. The force by which a planet or other object draws objects toward its center. Sentence: The force of gravity keeps all the planets in orbit around the Sun.

Mass. What an object contains. Sentence: My mass stays the same whether I am on Earth or the Moon, but I my weight is different due to gravity.

> The difference between mass and weight can be confusing. Mass is how much matter an object contains, and mass does not change. Weight does change based on the strength or pull of gravity in a given location (e.g., Mars versus Earth).

Model. A small object, usually built to scale, that represents another, larger object. Sentence: I like to build models of famous spacecraft. Synonym: prototype.

Observation. The act of noting and recording something with an instrument. Sentence: We made notes of our observations during our testing phase. Synonym: recording.

Orbit. Noun: The path followed by a moon, planet, or artificial satellite as it travels around another body in space. Verb: To travel around something, such as a planet or moon, in a curved path; to make an orbit around something. Sentences: Earth is in orbit around the Sun, and our Moon is in orbit around the Earth. All of the planets in the solar system orbit the Sun.

Spacecraft. A vehicle used to explore space, the region beyond Earth's atmosphere. Sentence: The first spacecraft did not land on the Moon or Mars but orbited the Earth. Synonym: space shuttle.

Template. A picture used to help make something accurately. Sentence: The template for the lunar lander showed that it had four legs. Synonym: diagram, plan.

Weight. The measure of the pull of gravity on an object. Sentence: Because NASA astronauts do not feel the effect of gravity while they are in space, they feel weightless (like they have no weight). Synonym: heaviness.

Suggested Adaptations

Management Tips

- Allowing for more reflection time may help students connect to topics for enduring understanding.
- Modifying the pacing of activities may help students who struggle or are unfamiliar with the content to establish appropriate background knowledge.
- Extending time for self-reflection and peer reflection may help students develop deeper understanding of topics.
- Designing lessons incorporating various learning styles and abilities may help students reach greater understanding of the content.
- Creating quiet or safe spaces for students where there are no distractions may allow students to decompress and refocus.

Content Tips

- Brainstorming, developing, and creating visual and/or multimedia representations of the challenge's solution may help students imaginatively express understanding of challenging or unfamiliar topics.
- Using real-world scenarios from students' lives in their community, neighborhood, and school may help students develop deeper understanding of how STEM learning intersects with their daily lives.
- Providing different sets of reading comprehension activities on the same material may allow students with differing abilities to participate in whole-class instruction.
- Using the language of science allows students to value and mirror the work and expertise of real-world scientists and engineers.
- Modifying the rubric for student variation is encouraged.
- Reviewing guiding questions with students is encouraged at any point in the process when students appear to be struggling to make connections.

Challenge Tips

- Creating wall or anchor charts may help students visually connect and remember topics of discussion throughout the challenge.
- Planning for additional instruction time may help students understand and use vocabulary words appropriately throughout the challenge.
- Sharing how various science disciplines such as physics, the branch of science concerned with the nature and properties of matter and energy, correlate with topics such as gravity and velocity may help students connect more advanced scientific thinking to the challenge.
- Addressing historical examples of flight and/or space flight may help students gain additional scientific information and make deeper connections to the challenge.

NASA Resources

NASA Missions and Information

Learn more about NASA's Orion Spacecraft:
http://www.nasa.gov/exploration/systems/orion

Learn more about NASA's Space Launch System:
http://www.nasa.gov/exploration/systems/sls

Watch an exciting NASA video about Orion's development:
https://www.youtube.com/watch?v=KyZqSWWKmHQ

Science Connections for Facilitators and Students

Soda-Straw Rockets activity:
https://www.jpl.nasa.gov/edu/teach/activity/straw-rocket/

Build a Bubble-Powered Rocket activity: https://spaceplace.nasa.gov/pop-rocket/en/

Mathematics Connections for Facilitators and Students

How Math Is Used on the ISS:
https://www.youtube.com/watch?v=8IUKHJ2wlhA&list=PLiuUQ9asub3SHQEcguTiKTd1DkmFXNnnH&index=4

For students who need some extra support:

NASA's 3-2-1-Liftoff! Pre-K–2 guide offers facilitators several activity options to help students prepare for this engineering design challenge.
https://www.nasa.gov/pdf/58149main_3.2.1.Liftoff.pdf

A brief introduction to the metric system:
https://www.nasa.gov/audience/foreducators/topnav/materials/listbytype/How_Long_is_a_Meter.html

Technology Connections for Facilitators and Students

An activity about building a robotic hand:
https://www.nasa.gov/audience/foreducators/topnav/materials/listbytype/I_Want_to_Hold_Your_Hand.html

What astronauts do if they get sick:
https://www.nasa.gov/audience/forstudents/k-4/home/F_Sick_Astronauts.html

Engineering Design Process

For a brief introduction to engineering, use this read and write activity page:
https://www.nasa.gov/sites/default/files/atoms/files/sls_aerospace_block_1.pdf

An experiment that demonstrates Newton's Laws of Motion:
https://www.nasa.gov/audience/foreducators/topnav/materials/listbytype/3-2-1_POP.html

A quick background on the engineering design process, including a model of the process, definition of the phases, and a video:
https://www.nasa.gov/audience/foreducators/best/edp.html

Engagement and Exploration Links

The following websites, videos, and other online resources may help facilitators access prior knowledge through guided questions, graphic organizers, and other activities.

Information on being an astronaut

Interview with astronaut Leland Melvin:
https://www.youtube.com/watch?v=ZGPpNcRmZ5s

Life on the International Space Station:
https://www.nasa.gov/mission_pages/station/videos/index.html

So You Want To Go to Mars: What Does It Take To Be a NASA Hero?
https://www.youtube.com/watch?v=TGQx5todiHM

What astronauts wear when they are in space (Don't Eat the Pumpkin Suits!):
https://www.youtube.com/watch?v=Mo6lcG6woZY

Information on Orion

What Is Orion?
https://www.nasa.gov/audience/forstudents/k-4/stories/nasa-knows/what-is-orion-k4.html

How do we get to Mars, and what are the challenges? A basic overview of Orion: https://www.youtube.com/watch?v=GLgnZ89b8Po

NASA sites and publications that provide background knowledge

What Is the Solar System?
https://www.nasa.gov/audience/forstudents/k-4/stories/what-is-the-solar-system.html

Extreme space facts about the solar system:
https://www.jpl.nasa.gov/edu/pdfs/ss_extreme_poster.pdf

Mars facts poster: https://www.nasa.gov/pdf/173749main_Mars_Poster.pdf

What Is NASA?
https://www.nasa.gov/audience/forstudents/k-4/stories/nasa-knows/what-is-nasa-k4.html

Stories about NASA interns, who work on a variety of projects while they are in college and even high school:
https://www.nasa.gov/education/interns/index.html

What Is an Orbit?
https://www.nasa.gov/audience/forstudents/k-4/stories/nasa-knows/what-is-orbit-k4.html

What Is the International Space Station?
https://www.nasa.gov/audience/forstudents/k-4/stories/nasa-knows/what-is-the-iss-k4.html

Further information about Mars

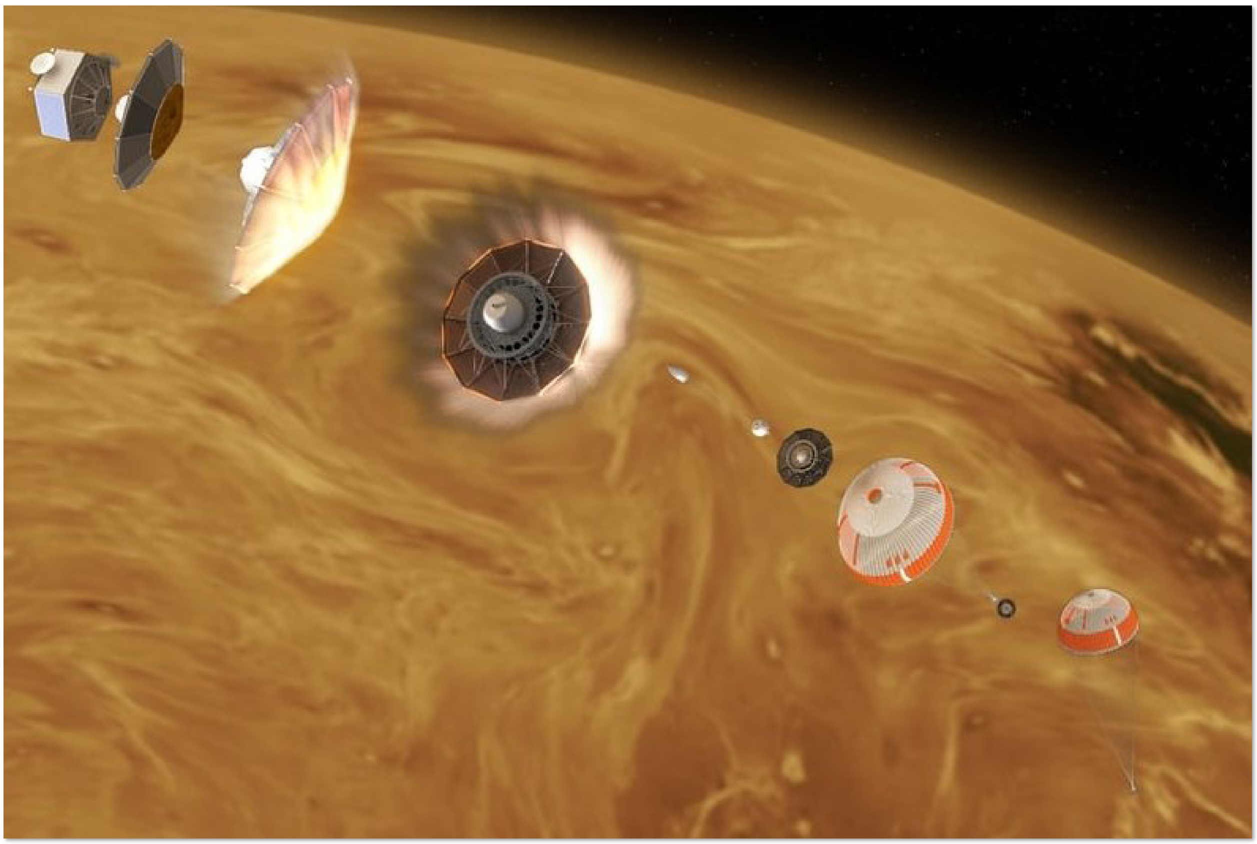
All About Mars: https://spaceplace.nasa.gov/all-about-mars/en/

What Is Mars?
https://www.nasa.gov/audience/forstudents/k-4/stories/nasa-knows/what-is-mars-k4.html

Mars Exploration Program: https://mars.jpl.nasa.gov/

Starchild: A Learning Center for Young Astronomers (basic information about the solar system, the universe, and space, with differentiated levels):
https://starchild.gsfc.nasa.gov/docs/StarChild/StarChild.html

Back cover: Artistic rendering of an entry, descent, and landing system concept designed to safely deploy scientific payloads or enable long-term human exploration to other planets. (NASA)



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