Facilitator Instructions

Recommended Materials

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

Each team will require the following items:

- Digital scale or balance
- Measuring tape
- Rulers
- Mailing tube, oatmeal canister, or small coffee can (simulated rocket for meeting size constraint)
- 2 plastic people figures, 3 to 7 cm tall (e.g., Lego® or Playmobil®)
- Grid paper

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

Examples of additional materials that may be used:

- 16-oz clear drinking cups
- Cardstock
- Craft sticks, lollipop sticks, or tongue depressors
- Dowel rods (various sizes)
- Glue
- Heavy-duty aluminum foil
- Magnifying lenses and mirrors
- Manila folders
- Paper (copier, construction, and waxed)
- Paper bags
- Plastic wrap (clear and colored)
- Polystyrene cups
- Poster board
- Rubber bands
- Skewers
- Staplers and staples
- Tape (packing, duct, masking, and transparent)

Safety

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

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

Facilitators should

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

Students should

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

Team Building

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

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

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

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

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

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

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

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

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

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

NASA Mission Background

What is NASA's Orion Spacecraft?

For the first time in a generation, NASA is building a human spacecraft that will usher in a new era of space exploration. A series of increasingly challenging missions awaits, and NASA's new spacecraft will take us farther than we have gone before.

Figure 9. Illustration of NASA's Orion multi-purpose crew vehicle. (NASA)

Named after one of the largest constellations in the night sky, the Orion spacecraft is designed to meet the evolving needs of our Nation's deep space exploration program for decades to come. Orion will be the safest, most advanced spacecraft NASA has built. The new spacecraft will be designed to take humans beyond low-Earth orbit to many destinations. Serving as NASA's exploration vehicle, Orion will carry the crew to space, provide emergency abort capability, sustain the crew during space travel, and provide safe reentry from deep space at return velocities.

Figure 10. Launch Abort System. (NASA)

Orion features dozens of technological advancements and innovations that have been incorporated into the spacecraft's new design. NASA included a crew compartment with the capacity to hold four crew members. It also has a service module, a spacecraft adaptor, and a revolutionary launch abort system that will significantly increase the safety of the crew. Orion will utilize advances in propulsion, communications, life support, structural design, navigation, and power, and it will draw from the extensive space flight experience of NASA.

Figure 11. Orion splash testing at Langley Research Center. (NASA)

Orion has been rigorously tested by NASA engineers to prepare it for the journey beyond low-Earth orbit. In order to simulate the final phases of landing, tests in the ocean and at NASA's Hydro Impact Basin at Langley Research Center recreated how Orion will behave during splashdown in the Pacific Ocean.

Orion's flight test began on top of a Delta IV Heavy rocket at Cape Canaveral Air Force Station's Space Launch Complex in December 2014. This test was a two-orbit, 4-hour flight that evaluated launch and high-speed reentry systems such as avionics, attitude control, parachutes, the heat shield, and many of the systems most critical to safety. The uncrewed test flight sent Orion farther from Earth than any spacecraft built to carry humans has gone since the Apollo 17 astronauts landed on the Moon in 1972. On reentry, Orion endured temperatures twice as hot as molten lava to put its critical systems to the test. This test provided NASA engineers with invaluable data on Orion's performance in every phase of launch, reentry, and landing.

The crewed Orion vehicle will be launched aboard NASA's new Space Launch System (SLS). More powerful than any rocket ever built, SLS will be capable of sending humans to deep space destinations. Exploration Mission-1 will be the first mission to join Orion and the SLS into NASA's Deep Exploration Space System. Orion will carry astronauts into a new era of exploration to destinations including near-Earth asteroids, our own Moon, the moons of Mars, and eventually Mars itself.

How much fuel is stored on the Space Launch System?

The SLS rocket holds 520,456 gallons of liquid hydrogen and 194,443 gallons of liquid oxygen. The three tanks at the launch pad hold 300,000 gallons of fuel each. Although oxygen gas is colorless, the liquid and solid forms of oxygen are blue. All of the fuel used to launch the SLS is used up in the first 8 minutes of flight. To lift the heavy payload of the rocket and all of its cargo, NASA engineers will need to calculate the amount of extra fuel needed to complete the journey into space.

Figure 12. Orion uncrewed test December 5, 2014. (NASA)

How is Orion's hatch designed?

The hatch is located on the side of the capsule so that four crew members can enter and exit easily. The Orion crew module will serve as both a transport vehicle and a home vehicle for the astronauts. NASA engineers designed a hatch that can be locked and sealed securely to protect the astronauts during the journey. Engineers also designed the hatch so that it could be easily opened in case of an emergency.

Figure 13. Astronauts Nicole Stott and Michael Barratt practice getting into the recumbent seats of the shuttle prior to launch of STS–133. (NASA)

How do astronauts stay in their seats?

Seating is one of the most critical components to consider during design of a spacecraft. Because astronauts must be securely fastened in their seats during all launch and landing operations, great effort is taken to ensure that seats are both safe and functional. Seat arrangement drives the layout of all other components in the crew cabin, including windows, displays, controls, and forms of entry and exit.

Seats are designed with consideration to factors such as acceleration forces (also called g-forces), comfort, and variation in human shape and size. Spacecraft have contained both upright and recumbent (lying down) seats. Both seat configurations are constructed with multipoint harness systems, which refers to the number of places where the harnesses connect to the seats. For example, cars come with two-point harnesses (a single belt across the lap) and three-point harnesses (a lap belt and another belt connected over one shoulder). Even though NASA has tested four-, five-, six-, and seven-point harnesses, tests for Orion focused on potential four- and five-point systems.

Engagement: Accessing Existing Knowledge

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

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

- Where is Mars?
- How is Mars different from Earth?
- Could we live on Mars today? Why not?
- What would we need on Mars in order to live?
- What is spacecraft safety?
- Have you seen or heard about NASA's Orion spacecraft on television or the Internet?
- How can we slow a falling object?
- What items do we have on our vehicles to help prevent injury during sudden stops?

STEM Vocabulary

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

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

Student Team Challenge Journal

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

Exploration: Supporting Science Investigations

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

Figure 14. Tunnel view looking up from level 5 of the Zero Gravity Research Facility, one of two drop towers at the NASA Glenn Research Center. This tower provides researchers with a near-weightless environment for 5.18 seconds. (NASA)

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

- Investigation 1: Egg Drop Challenge
  - A falling object has energy.
  - A falling object hitting the ground transfers that energy to the ground.
  - The more quickly energy is transferred to the ground, the greater the amount of damage that is caused to the falling object.
  - Packaging materials can absorb energy on impact.

- Investigation 2: Wall Smashers
  - A rolling object has energy.
  - A rolling object hitting another object transfers that energy to the second object.
  - The more quickly energy is transferred to the second object, the greater the amount of damage that is caused. A faster rate of speed will cause more damage to both objects.
  - Friction materials help dissipate that energy prior to reaching the second object.

Figure 15. Crash-test dummies were installed into Orion test capsule crew seats before being dropped into NASA Langley Research Center's Hydro Impact Basin. (NASA)

Supporting Science Investigation 1: Egg Drop Challenge

Concept

In this activity, students will discover how to protect a falling object using readily available classroom materials.

Students will create a package to contain and successfully land a raw egg, unbroken, from a fall to the ground. They will learn how velocity and acceleration from falling objects relate to force upon landing.

Figure 16. A mechanical engineering technician retrieves a drop vehicle after its 432-foot free fall in NASA Glenn's Zero Gravity Research Facility. (NASA)

Materials

For each pair of students:

- 1 egg, uncooked
- Small zip-top plastic bag
- Packing material (gelatin, popcorn, foam, bubble wrap, etc.—enough variety so each group of students may use a different type of material)
- Masking tape
- Meter stick or yardstick
- Stopwatch

Procedure

1. Each team of two students will build their own egg protector.
2. Allow students to select just one type of packing material for their device.
3. Put the egg into a zip-top bag and seal the bag, removing as much air as possible.
4. Using the selected packing material, wrap the egg to protect it during its fall.
5. Holding the meter stick vertically, drop the egg from a height of 30 cm (12 in.). During the drop, have one student time how long it takes for the egg to fall.
6. Repeat the drop at additional 10-cm (5-in.) increments (40 cm, 50 cm, etc.). Repeat until the egg breaks.
7. Answer the questions provided on the Data Collection Sheet.
8. As a class, review the results from each packing material to determine the best- and worst-performing materials and discuss the reasons why they performed as they did.

Options for Differentiating Instruction

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

Modifications

- Consider having all teams use the same packing material.
- Consider placing the egg inside an outer container and prefill the container with packing material.

Enrichment

- Include scientific discussion to identify the forms of energy transfer taking place.

Supporting Science Investigation 2: Wall Smashers

Concept

Figure 17. This investigation shows the effect of drag on a moving object by controlling the speed of a ball hitting a wall.

The key to stopping an object safely is to disperse its energy. For example, if a ball was released on a ramp and hit a wall at the bottom of the ramp, the speed of the ball would drop to zero almost instantly. In terms of energy, this means that the energy of the ball would transfer to the wall quickly, causing damage to both the wall and the ball.

In contrast, if the ball was slowed down on the ramp prior to hitting the wall so that it was barely moving by the point of impact, the energy would have been slowly released by the ball before it hit the wall. This would result in a safe bump against the wall, and no damage would occur.

In this activity, students will see the effects of drag on a moving object by controlling the speed of a ball hitting a wall. They will learn ways to disperse energy by transferring it at the point of impact. Explain to the class that their goal is to use the friction material provided to line the tube so that the ball will roll down the ramp and come to a complete stop just as it touches the wall.

Materials

For each pair of students:

- Ball, approximately 5 cm in width (e.g., a racquetball)
- Toy bricks, building blocks, logs, or other interconnecting blocks to create a wall (e.g., Lincoln Logs® or Lego® pieces)
- Stopwatch
- Mailing tube section, 55 cm long and 8 cm wide (large enough for the ball to roll through)
- Friction material such as cloth, sandpaper, waxed paper, or bubble wrap
- Stack of books 5 cm high (to rest one end of the tube on)
- Straws, small pom-poms, string, or yarn
- Scissors
- Masking tape
- Ruler

Procedure

1. Students place one end of the mailing tube on the stack of books to create a ramp the ball can roll down. Secure using tape as needed.
2. Using the toy bricks, build a wall 55 cm from the lower end of the tube. Use tape to mark the location for the wall to be rebuilt as necessary.
3. Allow student pairs to run a control iteration. Place the ball at the top of the ramp and allow it to roll down the tube. Remind students to record the control time on the Data Collection Sheet.
4. Have teams use different materials to create friction to slow the ball as it rolls down the ramp. Materials can be placed inside the tube and also on the surface between the end of the tube and the wall.
5. For each iteration, students will record the materials and the combination of materials, as well as the time it takes for the ball to roll down the tube, on the Data Collection Sheet.
6. Allow students time to explore and think about the various combinations and the friction materials used in order to achieve the stated goal of the ball slowing to a stop just as it touches the wall.
7. Complete the remaining questions on the Data Collection Sheet.

Options for Differentiating Instruction

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

Modification

- Have students attempt to get the ball to stop at the bottom of the mailing tube.

Enrichments

- Add additional restrictions to the design by limiting the quantity of friction material being used.
- Increase the height of the ramp to generate a faster speed.

Explanation: Supporting Science Investigations Discussion

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

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

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

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

Procedure

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

Investigation Discussion 1: Egg Drop Challenge

Concepts Learned

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

- A falling object has energy.
- A falling object hitting the ground transfers that energy to the ground.
- The more quickly energy is transferred to the ground, the greater the amount of damage that is caused.
- Packaging materials can absorb energy on impact.

Discussion Questions

The Egg Drop Challenge activity showed that an object gains energy (speed) as it falls due to gravity pulling downward on the object. To prevent the egg from being damaged as it landed, it had to be protected using energy-absorbing materials.

1. If this experiment were performed on Mars, would the egg fall differently?
2. Which of the available materials performed best in this challenge? Would this material work in space? Why or why not?
3. Guide students to help them make the connection between this investigation and the engineering design challenge.

Investigation Discussion 2: Wall Smashers

Concepts Learned

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

- A rolling object has energy.
- A rolling object hitting another object transfers that energy to the second object.
- The more quickly energy is transferred to the object, the greater the amount of damage that is caused.
- Friction materials help dissipate that energy prior to reaching the second object.

Discussion Questions

The Wall Smashers activity used a ball traveling down a ramp to simulate an object entering the atmosphere from space, with the wall simulating the surface of the planet.

1. When an object reenters the atmosphere, it is not traveling on a ramp, so how could you use friction material to help slow down the object?
2. Why was it important to find just the right mix of friction materials in order to make the ball "just" touch the wall? In terms of a spacecraft entering the atmosphere of a planet, what would happen if there was too much friction? Too little friction?
3. Help guide students to make the connection between this investigation and the engineering design challenge.

Elaboration: The Engineering Design Challenge

Using the Engineering Design Process

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

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

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

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

Engineering Design Process

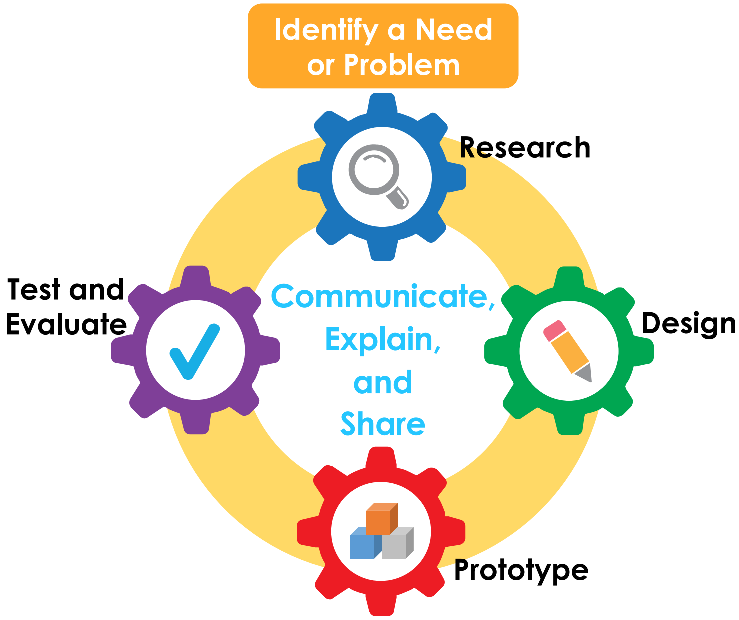


Figure 18. Engineering design process model. Model and accompanying text adapted from 2016 Massachusetts Science and Technology/Engineering Curriculum Framework, Massachusetts Department of Elementary and Secondary Education, http://www.doe.mass.edu/frameworks/scitech/2016-04.pdf.

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

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

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

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

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

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

The Engineering Design Challenge

The Challenge

Teams of up to four students will design and build a model of a spacecraft that can safely transport two astronauts on a mission to the Moon, Mars, or other destinations in space. A drop test will determine how well the spacecraft will protect the astronauts during landing. During the drop test, the spacecraft will be deployed, or dropped, from a height of at least 2 m to simulate landing. The astronauts must stay securely in their seats during the drop test. The spacecraft must also have an internal tank for fuel.

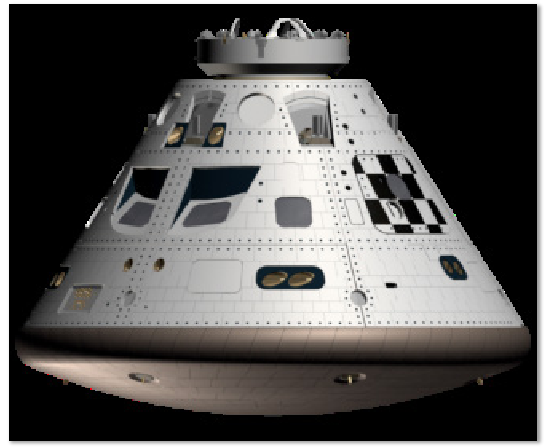


Figure 19. Illustration of the Orion command module. (NASA)

Criteria and Constraints

1. The spacecraft must carry two astronauts safely. Each astronaut is 3 to 7 cm tall. Each student team must design and build secure seats for both astronauts. The astronauts should stay in their seats during each drop test without being glued or taped in place.
2. The spacecraft must have one hatch that opens and closes and is sized so the astronauts can enter or exit easily. The hatch should remain closed during all drop tests.
3. The spacecraft must fit within the simulated rocket. This item serves simply as a size constraint, and the spacecraft will not be stored in or launched from this item.
4. The spacecraft must include an internal holding tank for fuel with a volume of 30 cm^3.
5. The total mass cannot exceed 100 g.

Options for Differentiating Instruction

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

Modification

- Consider making the spacecraft in advance. Have students concentrate on securing the crew inside and testing the design.

Enrichment

- Advise students that the spacecraft had to be reduced in mass due to an issue with the rocket and their job is to reduce the mass of their vehicle.

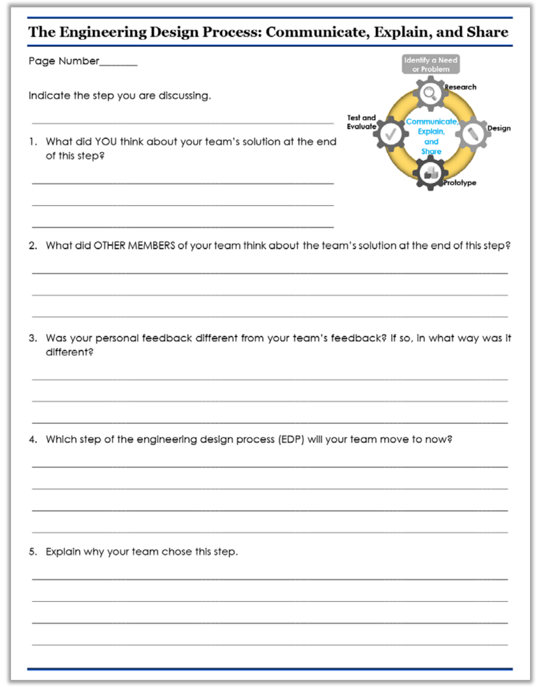
Student Team Challenge Journals

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

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

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

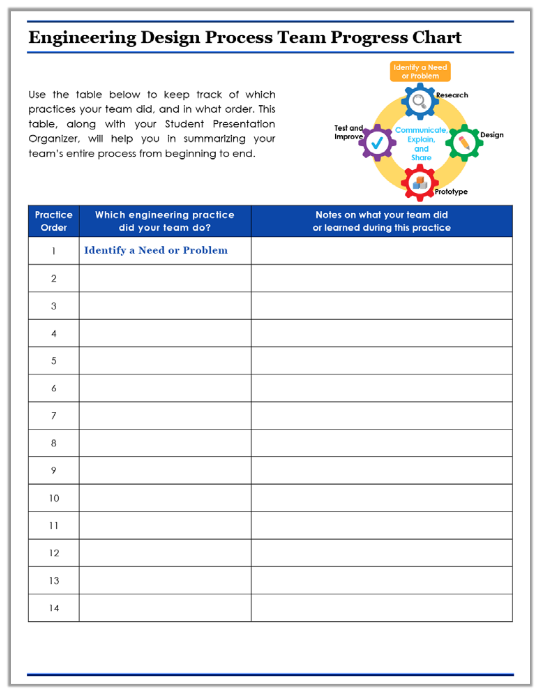
In order to successfully complete the engineering design challenge, teams must use the EDP. As they work the steps of the EDP, students will be engaging in authentic engineering practices.


The Engineering Design Process: Communicate, Explain, and Share

Page Number______

Indicate the step you are discussing.

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


Engineering Design Process Team Progress Chart

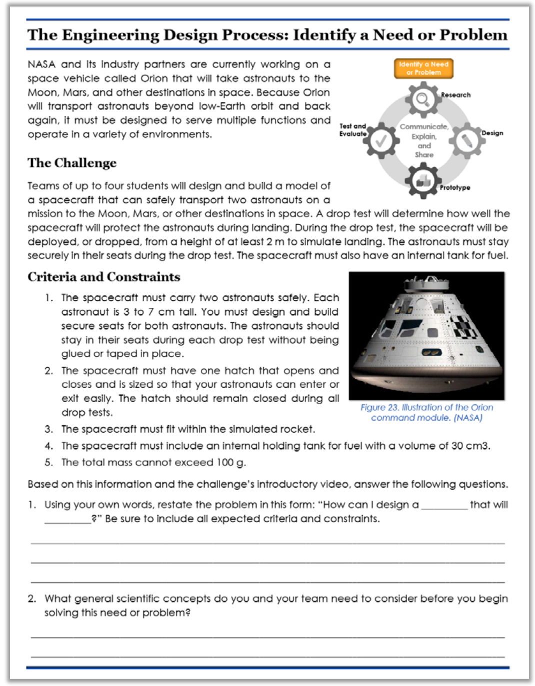
Use the table below to keep track of which practices your team did, and in what order. This table, along with your Student Presentation Organizer, will help you in summarizing your team's entire process from beginning to end.

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

Identify a Need or Problem

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

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



The Engineering Design Process: Identify a Need or Problem

NASA and its industry partners are currently working on a space vehicle called Orion that will take astronauts to the Moon, Mars, and other destinations in space. Because Orion will transport astronauts beyond low-Earth orbit and back again, it must be designed to serve multiple functions and operate in a variety of environments.

Identify a Need or Problem
Research
Design
Prototype
Test and Evaluate
Communicate, Explain, and Share

The Challenge

Teams of up to four students will design and build a model of a spacecraft that can safely transport two astronauts on a mission to the Moon, Mars, or other destinations in space. A drop test will determine how well the spacecraft will protect the astronauts during landing. During the drop test, the spacecraft will be deployed, or dropped, from a height of at least 2 m to simulate landing. The astronauts must stay securely in their seats during the drop test. The spacecraft must also have an internal tank for fuel.

Criteria and Constraints

1. The spacecraft must carry two astronauts safely. Each astronaut is 3 to 7 cm tall. You must design and build secure seats for both astronauts. The astronauts should stay in their seats during each drop test without being glued or taped in place.
2. The spacecraft must have one hatch that opens and closes and is sized so that your astronauts can enter or exit easily. The hatch should remain closed during all drop tests.
3. The spacecraft must fit within the simulated rocket.
4. The spacecraft must include an internal holding tank for fuel with a volume of 30 cm3.
5. The total mass cannot exceed 100 g.

Figure 23. Illustration of the Orion command module. (NASA)

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

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

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

Guiding Questions

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

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

Instructional Procedure

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

Differentiation Suggestions

Modifications

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

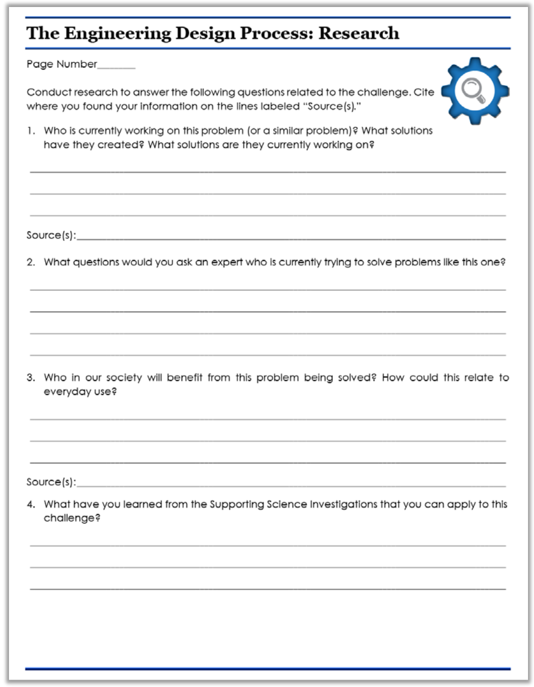
Enrichment

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

Research

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

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.


The Engineering Design Process: Research

Page Number______

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

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

Source(s):______

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

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

Source(s):______

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

Guiding Questions

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

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

Instructional Procedure

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

Differentiation Suggestions

Modifications

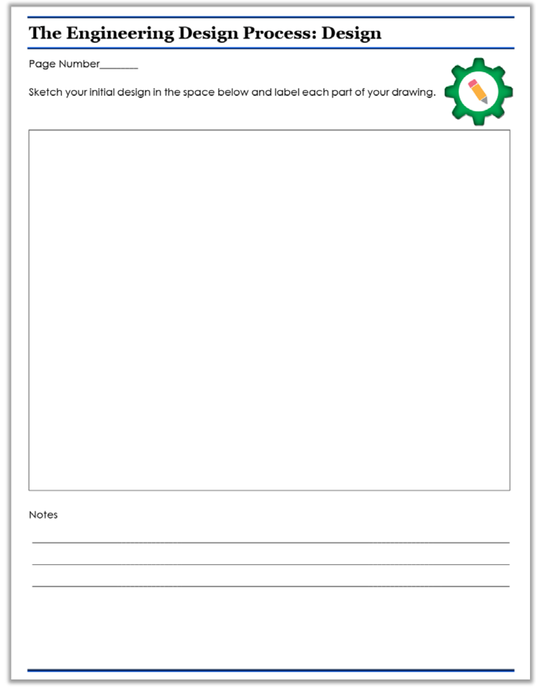
- Provide a list of reputable online resources students can use.
- Arrange a visit to a library.
- Pair up students to complete their research together.

Enrichment

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

Design

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


The Engineering Design Process: Design

Page Number______

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

Notes

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

Guiding Questions

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

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

Instructional Procedure

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

Differentiation Suggestions

Modifications

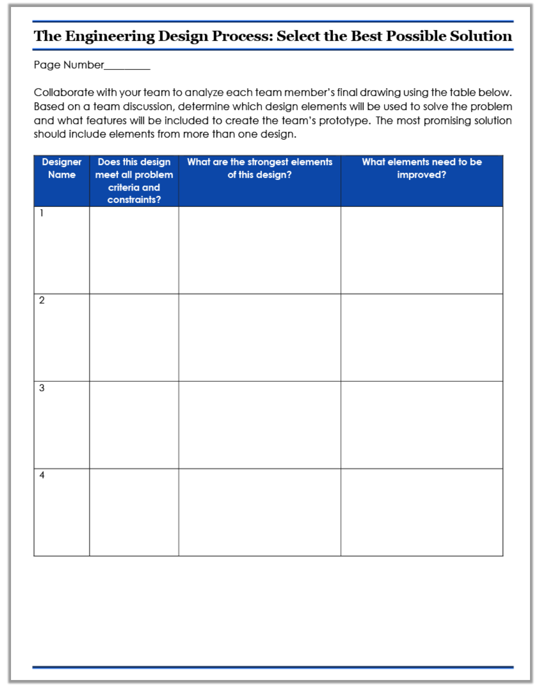
- Encourage students to create a series of storyboards rather than a single complete drawing.
- Show students the building materials to help them visualize their sketch prior to beginning the drawing.

Enrichment

- Require students to specify measurements.

Analyzing the Designs

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


The Engineering Design Process: Select the Best Possible Solution

Page Number________

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

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

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

Guiding Questions

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

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

Differentiation Suggestions

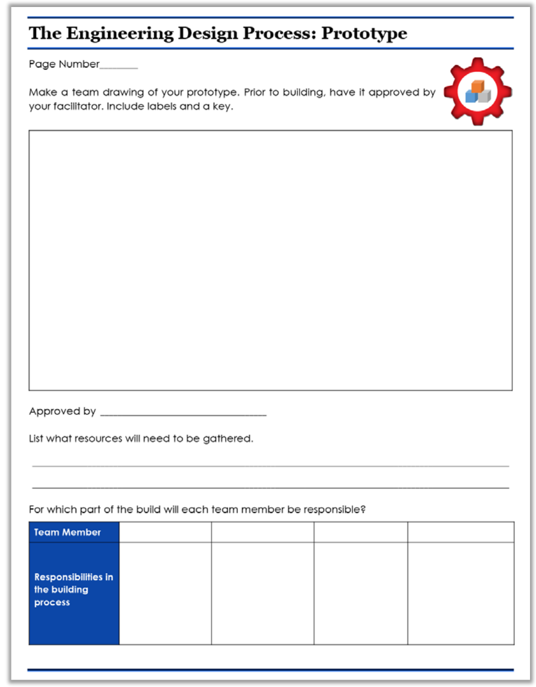
Modification

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

Enrichment

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

Prototype


The Engineering Design Process: Prototype

Page Number______

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

Approved by ________________________

List what resources will need to be gathered.

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

Team Member				
Responsibilities in the building process				

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

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

Guiding Questions

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

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

Instructional Procedure

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

Differentiation Suggestions

Modification

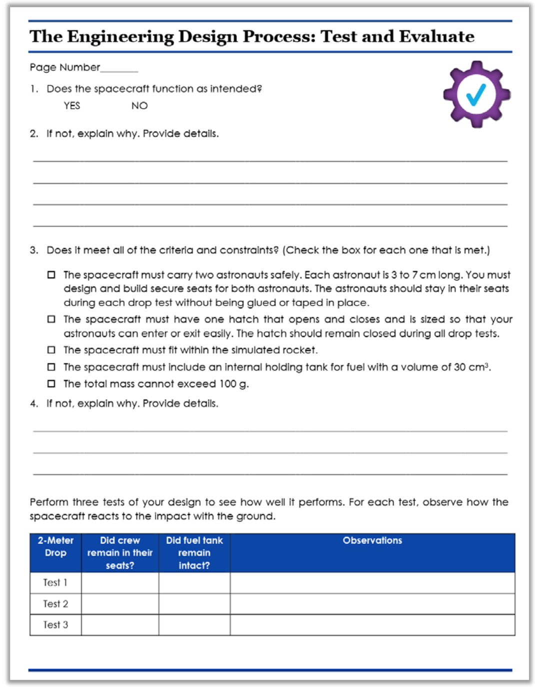
- Give students extra time to explore various materials prior to building the model.

Enrichment

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

Test and Evaluate

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



The Engineering Design Process: Test and Evaluate

Page Number_______

1. Does the spacecraft function as intended?

   YES NO

2. If not, explain why. Provide details.

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

   - ☐ The spacecraft must carry two astronauts safely. Each astronaut is 3 to 7 cm long. You must design and build secure seats for both astronauts. The astronauts should stay in their seats during each drop test without being glued or taped in place.
   - ☐ The spacecraft must have one hatch that opens and closes and is sized so that your astronauts can enter or exit easily. The hatch should remain closed during all drop tests.
   - ☐ The spacecraft must fit within the simulated rocket.
   - ☐ The spacecraft must include an internal holding tank for fuel with a volume of 30 cm^3.
   - ☐ The total mass cannot exceed 100 g.

4. If not, explain why. Provide details.

Perform three tests of your design to see how well it performs. For each test, observe how the spacecraft reacts to the impact with the ground.

2-Meter Drop	Did crew remain in their seats?	Did fuel tank remain intact?	Observations
Test 1			
Test 2			
Test 3			

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

Guiding Questions

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

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

Instructional Procedure

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

Differentiation Suggestions

Modification

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

Enrichment

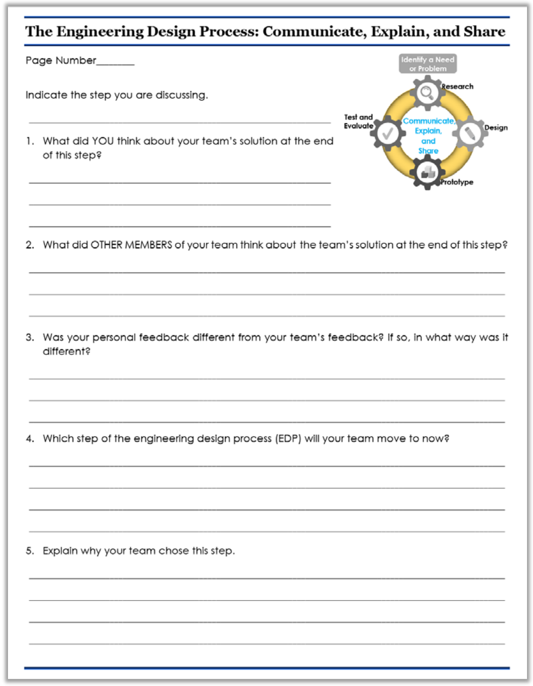
- Create a scatter plot of test results.

Communicate, Explain, and Share

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

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

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

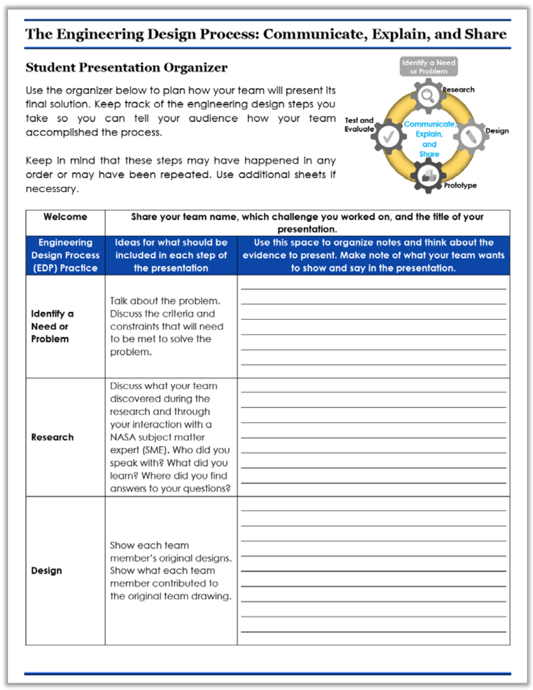


The Engineering Design Process: Communicate, Explain, and Share

Page Number______

Indicate the step you are discussing.

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



The Engineering Design Process: Communicate, Explain, and Share

Student Presentation Organizer

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

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

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

Guiding Questions

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

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

Instructional Procedure

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

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

Differentiation Suggestions

Modification

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

Enrichment

- Have student teams create a public service announcement on the importance of wearing seatbelts.

Evaluation: Student Debriefing Questions

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

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

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

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

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

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

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

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

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

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

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

8. What concerns must be considered in constructing a safe spacecraft?

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

9. What specific problems did you have to address in designing the spacecraft?

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

10. If you were an astronaut heading to Mars, would you trust your team's spacecraft to bring you safely to the surface of the planet? Why or why not?

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

Creating Solution Presentations

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

Submission Guidelines

The finished presentation must meet the following guidelines:

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

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

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

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

Budget Reporting Worksheet

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

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