Engineering Design Challenge
Facilitation Guide
Grades 6–8

Spacecraft Safety
Above: NASA’s Glenn Research Center in Cleveland, Ohio, is one of 10 NASA centers. Serving as an essential component of NASA and an integral contributor to the region, Glenn Research Center investigates, designs, develops, and tests innovative technology for aeronautics and space flight.

“The most important thing we can do is inspire young minds and to advance the kind of science, math and technology education that will help youngsters take us to the next phase of space travel.”

John H. Glenn, Jr., 1921–2016
NASA Astronaut and United States Senator
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 reach for new heights and reveal the unknown for the benefit of humankind.

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.

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

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

Some examples of NASA-engineered products include the following:

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

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

Figure 4. Artist’s rendering of the Space Launch System. (NASA)
Facilitator’s Overview

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

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

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

For more information, visit the NASA Glenn Research Center EDC website at [https://www.nasa.gov/glenn-engineering-design-challenges](https://www.nasa.gov/glenn-engineering-design-challenges)

**What is the Engineering Design Process?**

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

**What is an Engineering Design Challenge?**

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

Identify a Need or Problem. Engineering design begins by identifying a need or problem to be solved, improved, and/or fixed. This typically includes articulation of criteria and constraints that will define a successful solution.

Research. Constructive investigation is performed to learn more about the identified need or problem and potential solution strategies. Research can include primary resources such as research websites, peer-reviewed journals, and other academic services, and it can be an ongoing part of design.

Design. All gathered information is used to inform the creation of designs. Design includes modeling possible solutions, refining models, and choosing the model(s) that best meets the original need or problem.

Prototype. A prototype is constructed based on the design model(s) and is used to test the proposed solution. A prototype can be a physical, computer, mathematical, or conceptual instantiation of the model that can be manipulated and tested.

Test and Evaluate. The feasibility and efficiency of the prototype must be tested and evaluated relative to the problem criteria and constraints. This includes the development of a method of testing and a system of evaluating the prototype’s performance. Evaluation includes drawing on mathematical and scientific concepts, brainstorming possible solutions, testing and critiquing models, redesigning, and refining the need or problem.

Provide Feedback. Oral or written feedback provides constructive criticism to improve a solution and design. Feedback can be asked for and/or given at any point during engineering design. Determining how to communicate and act on feedback is critical.

Communicate, Explain, and Share. Communicating, explaining, and sharing the solution and design is essential to convey 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. Communication of explanations must be clear and analytical.
Engineering Design Challenge: Spacecraft Safety

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.

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 model 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. 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. The rocket serves 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 cm³.
5. The total mass cannot exceed 100 g.

Figure 6. Illustration of the Orion command module. (NASA)
Suggested Pacing

The following pacing guide serves to assist facilitators in planning each session. Facilitators should feel free to condense or expand the structure of these activities or add additional engineering design process (EDP) iterations to fit their specific needs. It is estimated that the entire EDP for this challenge will take between 12 and 20 hours.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Approximate Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Facilitator Preparatory Work</td>
<td>2 hours</td>
</tr>
<tr>
<td><strong>Engagement:</strong></td>
<td></td>
</tr>
<tr>
<td>- Access prior knowledge</td>
<td>1 hour</td>
</tr>
<tr>
<td>- Watch the introductory video</td>
<td></td>
</tr>
<tr>
<td>- Present background information</td>
<td></td>
</tr>
<tr>
<td><strong>Exploration and Explanation:</strong></td>
<td></td>
</tr>
<tr>
<td>- Supporting Science Investigation 1: Egg Drop Challenge</td>
<td>30 minutes</td>
</tr>
<tr>
<td>- Supporting Science Investigation 2: Wall Smashers</td>
<td>30 minutes</td>
</tr>
<tr>
<td><strong>Elaboration:</strong></td>
<td></td>
</tr>
<tr>
<td>- Introduction to the Engineering Design Process (EDP)</td>
<td>30 minutes</td>
</tr>
<tr>
<td>- Identify a Need or Problem</td>
<td>30 minutes</td>
</tr>
<tr>
<td>- Research</td>
<td>1 hour</td>
</tr>
<tr>
<td>- Design</td>
<td>1 hour</td>
</tr>
<tr>
<td>- Prototype</td>
<td>1 hour</td>
</tr>
<tr>
<td>- Test, Evaluate, and Redesign</td>
<td>2 hours</td>
</tr>
<tr>
<td>- Communicate, Explain, and Share</td>
<td>30 minutes</td>
</tr>
<tr>
<td><strong>Evaluation:</strong></td>
<td></td>
</tr>
<tr>
<td>- Creating solution presentations</td>
<td>1.5 hours</td>
</tr>
<tr>
<td>- Student debriefing questions</td>
<td></td>
</tr>
</tbody>
</table>
Spacecraft Safety

Learning Outcomes

Education Standards

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

Standards Addressed

<table>
<thead>
<tr>
<th>Next Generation Science Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Engineering Design</strong></td>
</tr>
<tr>
<td>• <strong>MS-ETS1-1</strong> Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.</td>
</tr>
<tr>
<td>• <strong>MS-ETS1-2</strong> Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.</td>
</tr>
<tr>
<td>• <strong>MS-ETS1-3</strong> Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.</td>
</tr>
<tr>
<td>• <strong>MS-ETS1-4</strong> Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.</td>
</tr>
<tr>
<td>• <strong>MS-PS2-1</strong> Apply Newton’s Third Law to design a solution to a problem involving the motion of two colliding objects.</td>
</tr>
</tbody>
</table>

Connected Concepts

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

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

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

Student Team Challenge Journal

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

Solution Presentation Criteria

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

Once the video or slide presentation is complete, submit according to the guidelines on the Glenn engineering design challenge website: https://www.nasa.gov/glenn-engineering-design-challenges
Student Presentation Rubric

This rubric can be used to review and assess the quality of each final presentation. Each category will be scored from 0 to 3 points. Totals for each column will be added for a final score.

Team name: ___________________________  Total score: ___________________________

<table>
<thead>
<tr>
<th>Engineering Design Process</th>
<th>Exemplary = 3</th>
<th>Proficient = 2</th>
<th>Novice = 1</th>
<th>Not Included = 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>We can <strong>identify</strong> the challenge and the criteria.</td>
<td>Challenge was restated and all criteria and constraints were described.</td>
<td>Challenge was restated with only the challenge criteria.</td>
<td>Only the challenge story was stated.</td>
<td>Team did not include a description of the challenge or the criteria.</td>
</tr>
<tr>
<td>We can discuss the results of our <strong>research</strong>, the Supporting Science Investigations, and connections with a NASA scientist or engineer.</td>
<td>Three or more facts relating to the challenge were discussed.</td>
<td>Two facts relating to the challenge were discussed.</td>
<td>One fact relating to the challenge was discussed.</td>
<td>No facts relating to the challenge were discussed.</td>
</tr>
<tr>
<td>Each of our team members sketched an original <strong>design</strong> that demonstrated the challenge criteria and constraints.</td>
<td>All criteria and constraints were represented (sketches and photos) in each team member’s design.</td>
<td>Two criteria were represented (sketches and photos) in each team member’s design.</td>
<td>One criterion was represented (sketches and photos) in each team member’s design.</td>
<td>No criteria were represented.</td>
</tr>
<tr>
<td>Our final team <strong>design</strong> represented elements from each team member’s original design.</td>
<td>Team design included the best from each member’s design to represent the challenge and the criteria.</td>
<td>Team design included ideas from two team members’ designs to represent the challenge and the criteria.</td>
<td>Team design included ideas from one team member’s design to represent the challenge and the criteria.</td>
<td>Team was not able to provide a design to represent the challenge and the criteria.</td>
</tr>
<tr>
<td>Our team constructed a <strong>prototype</strong> to represent the challenge criteria and constraints.</td>
<td>A prototype was completed that met all of the challenge criteria and constraints.</td>
<td>A prototype was completed that met only two of the challenge criteria and constraints.</td>
<td>A prototype was completed that met only one of the challenge criteria and constraints.</td>
<td>A prototype was completed that did not meet the challenge criteria or constraints.</td>
</tr>
<tr>
<td>Our team collected and recorded data to <strong>test and evaluate</strong> our model’s solutions.</td>
<td>Data were collected by testing to represent all of the criteria and constraints.</td>
<td>Data were collected by testing to represent only two criteria.</td>
<td>Data were collected by testing to represent only one criterion.</td>
<td>No data were collected and/or no testing was completed.</td>
</tr>
<tr>
<td>Our team was able to explain our design, gather <strong>feedback</strong>, and explain how we solved the challenge.</td>
<td>Difficult issues were explained and their solutions described.</td>
<td>Difficult issues were explained with no solutions offered.</td>
<td>Discussion of difficult issues was unclear and no solutions were presented.</td>
<td>No discussion of difficult issues was included.</td>
</tr>
<tr>
<td>Our team made <strong>design</strong> improvements after testing the prototype.</td>
<td>All improvements to the prototype were described.</td>
<td>Two improvements to the prototype were described.</td>
<td>One improvement to the prototype was described.</td>
<td>No improvements to the prototype were described.</td>
</tr>
<tr>
<td>Our team followed the <strong>presentation process</strong> to communicate our team <strong>design</strong>.</td>
<td>All the presentation requirements and procedures were met.</td>
<td>Three or more of the presentation requirements and procedures were met.</td>
<td>One or two of the presentation requirements and procedures were met.</td>
<td>The presentation requirements and procedures were not met.</td>
</tr>
</tbody>
</table>
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

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.

**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 reach for new heights and reveal the unknown so that what we do and learn will benefit all humankind.”

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.

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.

Many innovations have been featured in the Orion spacecraft’s new design. The spacecraft includes a crew compartment with the capacity to hold four crew members. Orion also has a service module, a spacecraft adaptor, and a new launch abort system. NASA’s Glenn Research Center has tested a number of Orion’s parts to improve safety and reliability. The launch abort system, which was tested in Glenn wind tunnels, increases the safety of the crew by quickly separating their capsule from the rocket in case of a launch emergency. Glenn engineers also tested Orion’s fuel pumps and propulsion system, ensuring that the engines run smoothly. They tested coatings that reduce static on solar panels, improving how much electric power is available for the capsule. They verified that special bolts explode apart as they should to separate parts of the launch system in space. They worked on radiators to keep the crew cool and proposed ways to strengthen solar panel arms so they do not snap off when the vehicle speeds up. Glenn engineers also evaluated the rubber ring seals that hold in the air when Orion connects to space stations, and they devised a way to allow the power cables on the launch tower to disconnect from Orion for launch.

![Figure 9. Illustration of NASA’s Orion spacecraft. (NASA)](image)

![Figure 10. Aeroacoustic test of launch abort system in NASA Glenn’s 8- by 6-Foot Supersonic Wind Tunnel. (NASA)](image)

![Figure 11. A NASA Glenn researcher checks for leaks on seals for the Orion spacecraft. (NASA)](image)
Orion’s flight testing 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.

How is Orion’s hatch designed and tested?

The hatch is located on the side of the capsule so that 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 at NASA Glenn’s Plum Brook Station used super-strong sound energy to test the hatch to be sure it stays in place during the intense vibration of launch and that no air leaks out.

Plum Brook’s Space Environments Complex was also used to test Orion’s capsule and service module. A huge vibrating table shook Orion to make sure none of the parts would come loose or break off. Orion was then placed in the world’s largest vacuum chamber to see if any air would leak out when it finally got into space.

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, like 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). Tests for Orion focused on potential four- and five-point systems.

After launch, harnesses are also used to hold astronauts in place when they exercise. NASA Glenn developed a compact exercise device with a special padded harness that helps astronauts stay fit during long space missions.

**How much fuel is stored on the Space Launch System?**

When all systems are built, tested, and perfected, Exploration Mission-1 will be the first mission to launch Orion aboard NASA’s new Space Launch System (SLS). The SLS rocket holds 520,456 gallons of liquid hydrogen and 194,443 gallons of liquid oxygen. All of the fuel used to launch the SLS into space is used up in the first 8 minutes of flight. To lift the heavy payload and all of its cargo, NASA engineers will have to calculate the amount of extra fuel needed to complete the journey. 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.
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.

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 17. 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)

Figure 18. 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.

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

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 yam
- 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.

A budgetary constraint can also be added as follows:

- 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.
- Next, 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

**Identify a Need or Problem.** Engineering design begins by identifying a need or problem to be solved, improved, and/or fixed. This typically includes articulation of criteria and constraints that will define a successful solution.

**Research.** Constructive investigation is performed to learn more about the identified need or problem and potential solution strategies. Research can include primary resources such as research websites, peer-reviewed journals, and other academic services, and it can be an ongoing part of design.

**Design.** All gathered information is used to inform the creation of designs. Design includes modeling possible solutions, refining models, and choosing the model(s) that best meets the original need or problem.

**Prototype.** A prototype is constructed based on the design model(s) and is used to test the proposed solution. A prototype can be a physical, computer, mathematical, or conceptual instantiation of the model that can be manipulated and tested.

**Test and Evaluate.** The feasibility and efficiency of the prototype must be tested and evaluated relative to the problem criteria and constraints. This includes the development of a method of testing and a system of evaluating the prototype’s performance. Evaluation includes drawing on mathematical and scientific concepts, brainstorming possible solutions, testing and critiquing models, redesigning, and refining the need or problem.

**Provide Feedback.** Oral or written feedback provides constructive criticism to improve a solution and design. Feedback can be asked for and/or given at any point during engineering design. Determining how to communicate and act on feedback is critical.

**Communicate, Explain, and Share.** Communicating, explaining, and sharing the solution and design is essential to convey 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. Communication of explanations must be clear and analytical.

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Figure 21. 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](http://www.doe.mass.edu/frameworks/scitech/2016-04.pdf)).
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.

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 cm³.
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.

Figure 22. Illustration of the Orion command module. (NASA)
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. On the Provide Feedback sheet, use the “Next Steps” section to justify your next step in the process. As an example: “We are moving back to the design phase as the prototype failed to meet the criteria. It was 50 g over the limit.”

3. When documenting the prototype stage, make note of any challenges you faced building your design and how you resolved them.

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

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

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

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

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.

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

Guiding Questions

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

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

Instructional Procedure

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

Differentiation Suggestions

Modifications

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

Enrichment

- Require students to specify measurements.
Analyzing the Designs

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

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

Guiding Questions

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

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

Differentiation Suggestions

Modification

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

Enrichment

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

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

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).
Spacecraft Safety

Test and Evaluate

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

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

Guiding Questions

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

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

Instructional Procedure

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

The Engineering Design Process: Test and Evaluate

Page Number

1. Does the spacecraft function as intended? (Check the box for each one that is met.)
   - 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 latched so that your astronaut can enter or exit safely. The hatch should remain closed during all drop tests.
   - The spacecraft must fit within the simulated rocket. Theoverall dimensions are limited. The minimum dimension for the test is 30 cm.
   - The total mass cannot exceed 100 grams.
   - If not, explain why. Provide details.

<table>
<thead>
<tr>
<th>Test</th>
<th>Did nose remain in place?</th>
<th>Did fuel leak?</th>
<th>Summary</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1</td>
<td>Yes</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test 2</td>
<td>Yes</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test 3</td>
<td>Yes</td>
<td>No</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Provide Feedback and Communicate, Explain, and Share

Students complete the Provide Feedback page from the Student Team Challenge Journal as frequently as necessary.

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 exchange feedback 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 Provide Feedback page after each step to maintain direction and focus during the engineering design process (EDP).

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

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. This step will be achieved through the production of a video or slide presentation that will be submitted at the end of this challenge.

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 process 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.
Spacecraft Safety

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 NASA Glenn engineering design challenge website: https://www.nasa.gov/glenn-edcs-submit-student-solutions
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.

<table>
<thead>
<tr>
<th>Line Item Number</th>
<th>Material</th>
<th>Unit Cost</th>
<th>Quantity</th>
<th>Item Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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</tbody>
</table>
|                  |          |           |          | Total Cost:


Spacecraft Safety
Student Team Challenge Journal
Supporting Science Investigation 1: Egg Drop Challenge

Concept

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

Your team will create a package to contain and successfully land a raw egg, unbroken, from a fall to the ground.

Think about how velocity and acceleration from falling objects relate to force on landing.

Materials

For each pair of students:

- 1 egg, uncooked
- Small zip-top plastic bag
- Packing material (gelatin, popcorn, foam, bubble wrap, etc.)
- Masking tape
- Meter stick or yardstick
- Stopwatch

Procedure

1. Work with your partner to design a prototype of your container and the materials you will use.
2. Select one type of packing material for your container.
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. Once your team has contained and sealed the egg, hold the meter stick vertically and drop the egg from a height of 30 cm.
6. One team member will time how long it takes for the egg to fall. Report findings on the Data Collection Sheet in the Student Team Challenge Journal.
7. Repeat the drop at additional 10-cm increments (40 cm, 50 cm, etc.) until the egg breaks.
8. Record all times on the Data Collection Sheet and calculate the speed using the formula
   \[ \text{Speed} = \frac{\text{Distance}}{\text{Time}}. \]
9. Next, answer the questions on the Data Collection Sheet.
10. Report findings to the whole group. 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.
Data Collection Sheet

Use the chart below to record the results of each egg drop. To calculate the speed of the egg, use the formula \( \text{Speed} = \text{Distance}/\text{Time} \).

<table>
<thead>
<tr>
<th>Drop Height</th>
<th>Time, sec</th>
<th>Speed, ( \text{m/s}^2 )</th>
<th>Did it break?</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 cm</td>
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</table>

Type of packing material used: ____________________________________________________________

Using the graph paper provided, create a graph of the speed of the egg for each drop.
1. Describe the graph you plotted. What happened to the speed of the egg as the drop height increased? Discuss the findings in your answer.

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2. At what height and speed did the egg finally break? ______________________________

3. How do you think you could have prevented the egg from breaking at this speed? Be as specific as possible and think about what you would do differently. Discuss all future possibilities in your answer.

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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. In order to prevent the egg from being damaged on landing, we had to protect it using energy-absorbing materials.

1. If your team designed a new iteration of the container, how would you apply what you learned in this investigation to your design?

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2. We know that gravity is less on Mars than on Earth. How do you think your container would hold up if your team performed this investigation on Mars?

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Supporting Science Investigation 2: Wall Smashers

Concept

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.

The goal of this investigation is to create friction where the ball meets the tube so that the ball will roll down the ramp and slow to a complete stop just as it touches the wall.

Materials

For each team of two 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, wax 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. 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. Place the ball at the top of the ramp and allow it to roll down the tube. Make an observation. Record the control time on the Data Collection Sheet.

4. 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. Record the materials and the time on the Data Collection Sheet for each iteration.

6. Continue trying various combinations and amounts of friction materials 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.
**Data Collection Sheet**

Complete the table below using the results from your experiments.

<table>
<thead>
<tr>
<th>Iteration (Attempt) Number</th>
<th>Time to Wall, sec</th>
<th>Observations, Friction Material Used, Placement of Materials</th>
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</thead>
<tbody>
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</table>

What type of friction material did you use? How do you think it affected the speed of the ball? Use your data to answer this question.

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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 on a ramp, so how could you use friction material to help slow down the object?

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2. Why was it important to find just the right mix of friction materials in order to make the ball “just” touch the wall?

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

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The Engineering Design Process

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

Identify a Need or Problem. This step is designed to ask one of these general questions:

• How can I design a ________ that will ________?
• How can I improve a ________ to make it better?

The criteria and constraints are defined during this step.

Research. Use resources such as the Internet, a library, or NASA subject matter experts (SMEs) to examine how this problem (or a similar problem) is currently being solved.

Design. Think of solutions that might solve the problem. Select the solution you think is most likely to succeed. Refine it into a full design. Keep other solutions for future reference.

Prototype. Construct a full-size or scale model of the selected solution.

Test and Evaluate. Test the prototype to see how effective it is in solving the need or problem. Compare the data to the design criteria to see if the goals were met.

Provide Feedback. Record and share lessons learned about the design based on testing. Discuss how improvements can be made, or if the design should be discarded and another design attempted.

Communicate, Explain, and Share. Present your solution and explain how the solution has been improved through the EDP.
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.

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.

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

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

__________________________________________________________________________________________

__________________________________________________________________________________________

__________________________________________________________________________________________

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

__________________________________________________________________________________________

__________________________________________________________________________________________

__________________________________________________________________________________________
The Engineering Design Process: Research

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?

_______________________________________________________________________________________________________________

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_______________________________________________________________________________________________________________

Source(s): __________________________________________________________________________________

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

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_______________________________________________________________________________________________________________

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

_______________________________________________________________________________________________________________

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Source(s): ____________________________________________________________________________________________________

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

_______________________________________________________________________________________________________________

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The Engineering Design Process: Design

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

Notes

_______________________________________________________________________________________________________________
_______________________________________________________________________________________________________________
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The Engineering Design Process: Select the Best Possible Solution

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.

<table>
<thead>
<tr>
<th>Designer Name</th>
<th>Does this design meet all problem criteria and constraints?</th>
<th>What are the strongest elements of this design?</th>
<th>What elements need to be improved?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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</tbody>
</table>
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?

<table>
<thead>
<tr>
<th>Team Member</th>
<th>Responsibilities in the building process</th>
</tr>
</thead>
<tbody>
<tr>
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</tbody>
</table>
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 cm³.
   □ 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.

<table>
<thead>
<tr>
<th>2-Meter Drop</th>
<th>Did crew remain in their seats?</th>
<th>Did fuel tank remain intact?</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1</td>
<td></td>
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<td>Test 2</td>
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<tr>
<td>Test 3</td>
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</tbody>
</table>
The Engineering Design Process: Provide Feedback

Page Number_________

Indicate the step you are providing feedback on.

_________________________________________

1. What did YOU think about your team's solution at the end of this step?
_______________________________________________________________________________________________________________
_______________________________________________________________________________________________________________
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2. What did OTHER MEMBERS of your team think about the team’s solution at the end of this step?
_______________________________________________________________________________________________________________
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3. Was your personal feedback different from your team’s? 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.

<table>
<thead>
<tr>
<th>Welcome</th>
<th>Share your team name, which challenge you worked on, and the title of your presentation.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Engineering Design Process (EDP) Practice</strong></td>
<td><strong>Ideas for what should be included in each step of the presentation</strong></td>
</tr>
<tr>
<td><strong>Identify a Need or Problem</strong></td>
<td>Talk about the problem. Discuss the criteria and constraints that will need to be met to solve the problem.</td>
</tr>
<tr>
<td><strong>Research</strong></td>
<td>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?</td>
</tr>
<tr>
<td><strong>Design</strong></td>
<td>Show each team member’s original designs. Show what each team member contributed to the original team drawing.</td>
</tr>
<tr>
<td>Spacecraft Safety</td>
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<tr>
<td>------------------</td>
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</tr>
<tr>
<td><strong>Prototype</strong></td>
<td>Show materials used and how you put the prototype together.</td>
</tr>
<tr>
<td><strong>Test and Evaluate</strong></td>
<td>Talk about how your team tested the design and discuss the results. Using the data, discuss the strengths and weaknesses of your team prototype.</td>
</tr>
<tr>
<td><strong>Provide Feedback</strong></td>
<td>Describe how your team members communicated with each other to improve the solution. Also describe how you discussed options with people outside your group.</td>
</tr>
<tr>
<td><strong>Communicate, Explain, and Share</strong></td>
<td>Talk about your data. Was your team able to solve the problem or not? What improvements did your team make to reach your final solution? Discuss any further action your team would take to improve this solution.</td>
</tr>
</tbody>
</table>
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 assist you in summarizing your team’s entire process from beginning to end.

<table>
<thead>
<tr>
<th>Practice Order</th>
<th>Which engineering practice did your team do?</th>
<th>Notes on what your team did or learned during this practice</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Identify a Need or Problem</td>
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</table>
Solution Presentation

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

The finished presentation must meet the following guidelines:

- The introduction must say this: “This is team (team name), and we worked on the (name of challenge). The title of our presentation is (presentation title).”
  
  **Do not identify by name any student, teacher, school, group, city, or region in your presentation. Submissions that do not follow these directions will be disqualified.**

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

This rubric will be used to assess your final presentation. Use it as a checklist to make sure you have included something from every category. Try to achieve as many 3’s as you can!

<table>
<thead>
<tr>
<th>Engineering Design Process</th>
<th>Exemplary = 3</th>
<th>Proficient = 2</th>
<th>Novice = 1</th>
<th>Not Included = 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>We can identify the challenge and the criteria.</td>
<td>Challenge was restated and all criteria and constraints were described.</td>
<td>Challenge was restated with only the challenge criteria.</td>
<td>Only the challenge story was stated.</td>
<td>Team did not include a description of the challenge or the criteria.</td>
</tr>
<tr>
<td>We can discuss the results of our research, the Supporting Science Investigations, and connections with a NASA scientist or engineer.</td>
<td>Three or more facts relating to the challenge were discussed.</td>
<td>Two facts relating to the challenge were discussed.</td>
<td>One fact relating to the challenge was discussed.</td>
<td>No facts relating to the challenge were discussed.</td>
</tr>
<tr>
<td>Each of our team members sketched an original design that demonstrated the challenge criteria and constraints.</td>
<td>All criteria and constraints were represented (sketches and photos) in each team member’s design.</td>
<td>Two criteria were represented (sketches and photos) in each team member’s design.</td>
<td>One criterion was represented (sketches and photos) in each team member’s design.</td>
<td>No criteria were represented.</td>
</tr>
<tr>
<td>Our final team design represented elements from each team member’s original design.</td>
<td>Team design included the best from each member’s design to represent the challenge and the criteria.</td>
<td>Team design included ideas from two team members’ designs to represent the challenge and the criteria.</td>
<td>Team design included ideas from one team member’s design to represent the challenge and the criteria.</td>
<td>Team was not able to provide a design to represent the challenge and the criteria.</td>
</tr>
<tr>
<td>Our team constructed a prototype to represent the challenge criteria and constraints.</td>
<td>A prototype was completed that met all of the challenge criteria and constraints.</td>
<td>A prototype was completed that met only two of the challenge criteria and constraints.</td>
<td>A prototype was completed that met only one of the challenge criteria and constraints.</td>
<td>A prototype was completed that did not meet the challenge criteria or constraints.</td>
</tr>
<tr>
<td>Our team collected and recorded data to test and evaluate our model’s solutions.</td>
<td>Data were collected by testing to represent all of the criteria and constraints.</td>
<td>Data were collected by testing to represent only two criteria.</td>
<td>Data were collected by testing to represent only one criterion.</td>
<td>No data were collected and/or no testing was completed.</td>
</tr>
<tr>
<td>Our team was able to explain our design, gather feedback, and explain how we solved the challenge.</td>
<td>Difficult issues were explained and their solutions described.</td>
<td>Difficult issues were explained with no solutions offered.</td>
<td>Discussion of difficult issues was unclear and no solutions were presented.</td>
<td>No discussion of difficult issues was included.</td>
</tr>
<tr>
<td>Our team made design improvements after testing the prototype.</td>
<td>All improvements to the prototype were described.</td>
<td>Two improvements to the prototype were described.</td>
<td>One improvement to the prototype was described.</td>
<td>No improvements to the prototype were described.</td>
</tr>
<tr>
<td>Our team followed the presentation process to communicate our team design.</td>
<td>All the presentation requirements and procedures were met.</td>
<td>Three or more of the presentation requirements and procedures were met.</td>
<td>One or two of the presentation requirements and procedures were met.</td>
<td>The presentation requirements and procedures were not met.</td>
</tr>
</tbody>
</table>
Vocabulary List

**Aerodynamics.** The qualities of an object that affect how easily it is able to move through the air

**Capsule.** A pressurized modular compartment of an aircraft or spacecraft, designed to accommodate a crew or to be ejected

**Cargo.** Freight carried by an aircraft or other transportation vehicle

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

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

**Dependent variable.** A value that is determined based on the values of other traits

**Descent.** The downward incline or passage of an object

**Dimension.** A physical property of a mass, length, or time, or a combination of any or all

**Exploration.** The act of systemically investigating an objective for the purpose of discovery

**Fragile.** Easily broken or damaged

**Gravity.** The force that attracts a body toward the center of the Earth or toward any other physical body having mass

**Hatch.** An opening for entering and exiting a spacecraft, commonly called the door

**Independent variable.** A value that is determined without support by other traits

**Inferring.** To conclude from evidence rather than from definitive statement of fact

**Internal.** On the inside

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

**Landing pad.** A site for landing an aircraft

**Launcher.** A device for firing rockets

**Mass.** A unified body of matter without any specific shape

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

**Observation.** The act of noting and recording something with an instrument

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

Online Resources

To learn more about NASA’s Orion Spacecraft:
http://www.nasa.gov/exploration/systems/orion

To learn more about NASA’s Space Launch System:
http://www.nasa.gov/exploration/systems/sls

To watch an exciting NASA video about Orion’s development:
https://www.youtube.com/watch?v=KyZqSWWkmHQ

To learn more about NASA’s historic Voyager missions:
http://voyager.jpl.nasa.gov/

To learn more about NASA’s New Horizons Spacecraft exploration of Pluto:
http://pluto.jhuapl.edu/
Back cover: Orion splashdown tests soak up data to keep astronauts safe. (NASA)