Activity Four: Safe Landing on the Lunar Surface

Educator Notes

Learning Objectives

Students will use the engineering design process to

- Identify the challenges of landing a lunar lander on the surface of a body without an atmosphere.
- Design, build, and improve a model of a lunar lander that can slow its descent using the downward thrust of a balloon.
- Graph the speed with respect to elevation of a model lunar lander.

Challenge Overview

In this challenge, students will work in teams to design and build a model of a lunar lander that will use the thrust of balloons to slow its rate of descent. The goal of the challenge is to slow the lander's rate of descent as much as possible to simulate a soft landing on the lunar surface. Students will drop their landers from a height of 2 meters both with and without the use of propulsion, and they will use stopwatches, slow-motion video, and/or video analysis software to measure the effects of propulsion on their landers' rates of descent.

Suggested Pacing

120 to 180 minutes

National STEM Standards

Science and Engineering (NGSS)	
Disciplinary Core Ideas • MS-PS2-2 Motion and Stability: Forces and Interactions: Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object. • MS-PS2-4 Motion and Stability: Forces and Interactions: Construct and present arguments using evidence to support the claim that gravitational interactions are attractive and depend on the masses of interacting objects. • MS-ETS1-3 Engineering Design: 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. *Crosscutting Concepts* • Stability and Change: Explanations of stability and change in natural or designed systems can be constructed by examining the changes over time and forces at different scales.	*Crosscutting Concepts (continued)* • Systems and System Models: Models can be used to represent systems and their interactions—such as inputs, processes and outputs—and energy and matter flows within systems. *Science and Engineering Practices* • Planning and Carrying Out Investigations: Planning and carrying out investigations to answer questions or test solutions to problems in 6–8 builds on K–5 experiences and progresses to include investigations that use multiple variables and provide evidence to support explanations or design solutions. • Engaging in Argument From Evidence: Engaging in argument from evidence in 6–8 builds from K–5 experiences and progresses to constructing a convincing argument that supports or refutes claims for either explanations or solutions about the natural and designed world. • Analyzing and Interpreting Data: Analyzing data in 6–8 builds on K–5 experiences and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis.
Technology (ISTE)	
Standards for Students • Innovative Designer 4c: Students develop, test, and refine prototypes as part of a cyclical design process.	*Standards for Students (continued)* • Computational Thinker 5b: Students collect data or identify relevant data sets, use digital tools to analyze them, and represent data in various ways to facilitate problem solving and decision making.
Mathematics (CCSS)	
Mathematical Practices • CCSS.MATH.CONTENT.8.EE.B.5: Graph proportional relationships, interpreting the unit rate as the slope of the graph. Compare two different proportional relationships represented in different ways. For example, compare a distance–time graph to a distance–time equation to determine which of two moving objects has greater speed.	

Activity Preparation

The educator should

- Read the introduction and background information, the Educator Notes, and the Student Handout to become familiar with the challenge.
- Print the Student Handout for each team.
- Select the method students will use to measure the motion of their landers (e.g., stopwatches, slow-motion video, or video analysis software).

  - Consider the ability range of students and whether most students will have access to smartphones.
  - If using video analysis software, several free or inexpensive sources are available online that can be used for this activity (e.g., Tracker, Logger Pro, and Video Physics).
- Gather and prepare materials for student designs.
- Prepare the drop zone.
  - On a wall, mark a starting point 2 meters from the floor and ensure there is a clear path to the floor.
  - If using a smartphone for slow-motion measurements, place clear reference marks at 20-centimeter intervals from the 2-meter mark, all the way down to the floor.
  - If students have already completed the NASA activity "Sculpting Lunar Geology," which is also contained in this guide, consider allowing students to use their replica landing sites as a target for the drop test.

Materials

- Tape
- Scissors
- Balloons of various size
- Variety of lightweight materials (e.g., foam cups or plates, soda straws, index cards, etc.)
- Small, heavy items for ballast (e.g., washers, coins, marbles, etc.)
- Clothespins or binder clips
- Meterstick or measuring tape
- Stopwatch or smartphone with slow-motion video camera application
- Video camera and computer if using video analysis software

Safety

- Ensure that students are practicing safe cutting techniques when building their landers.
- Ensure that students do not stand on any unstable surfaces, such tables or chairs, when performing their drop tests.
- Ensure that students' model landers do not contain sharp or pointed surfaces that could present a hazard during the drop tests.
- Ensure that the drop zone is clear of students and items that may be in the path of falling landers.
- Use a balloon pump or designate a single person to inflate each balloon to minimize the risk of spreading germs.
- Use caution and wear eye protection when inflating, handling, and releasing landers during drop tests. If a balloon pops, loose debris may be propelled and present an eye hazard.

Introduce the Challenge

- Provide context for this activity using the introduction and background information in this guide. Discuss how a spacecraft's engines can provide downward thrust to counteract the force of gravity not only at launch, but also during a landing to slow its descent. Discuss the difficulties in landing a lander on the surface of a terrestrial body that does not have an atmosphere (no atmospheric braking, no use of parachutes, and no aerodynamic control surfaces).
- Explain the role of engineers in designing technology to solve problems. Share the NASA for Kids video "Intro to Engineering." https://www.youtube.com/watch?app=desktop&v=wE-z_TJyzil
- Group students into teams of three to five. Consider assigning roles and tasks to individual students within the team. See the Teamwork section at the beginning of the guide for suggestions.
- Distribute the Student Handout and scratch paper.
- Explain the challenge to students:
  - Each team will use the available materials to build a model lunar lander.
  - The lander must incorporate one or more inflated balloons into its design.

  - The lander must be sturdy enough that it can be dropped from a height of 2 meters without being damaged.
  - Each team will record the time the lander took to fall from a height of 2 meters both with and without the use of a balloon to provide thrust.
  - The goal is to use the thrust of the balloon to slow the rate of descent as much as possible.
- Explain procedures for retrieving materials.

Criteria	Constraints
Lander must use at least one inflated balloon.	May only use everyday, readily available supplies.
Design must incorporate landing legs that result in a stable, upright landing position after drop tests.	May not use parachutes or other items designed to create drag.
Lander must survive drop tests from a height of 2 meters.	

Facilitate the Challenge

Ask

Engage students with the following discussion questions:

- Why doesn't NASA use parachutes for its lunar lander?
  - Possible answer: Parachutes slow an object's descent using drag in the atmosphere. Because the Moon has very little atmosphere, a parachute would not work on a lunar lander.
- What factors could make your lander unstable as it descends?
  - Possible answers:
    - Lander is top-heavy or unbalanced and wants to flip.
    - Thrust from balloon is not directed straight downward.
- What other problems do you anticipate encountering during the challenge?
  - Possible answers:
    - Building the lander strong enough to survive the fall intact.
    - Being accurate enough with the stopwatch to collect good data.
- Does your team have any other questions about the challenge before you begin?

Imagine

- Before allowing students to see the supplies, have them imagine how they would design a lander that could safely land on the lunar surface.
- Ask students to individually sketch an initial design.
- Allow students time to observe the available materials and work in their teams to brainstorm how the materials could be used to create a model lander.

Plan

- Have teams sketch a second design for their lander that incorporates the materials available to them.
- Ensure that teams label each major part along with its purpose and what materials it will be made from.
- Each design must incorporate at least one design idea from each team member.

Share With Students

Brain Booster

NASA has selected three companies (Blue Origin-led team, Dynetics, and SpaceX) to develop human landers for the Artemis missions to the Moon. Each is developing its own unique designs. Be sure to follow their progress.

Learn more: https://www.nasa.gov/content/humans-on-the-moon-0

On Location

Named for NASA astronaut Neil Armstrong and located within Edwards Air Force Base in western California's Mojave Desert, Armstrong Flight Research Center (AFRC) serves as a prime location for NASA's flight research and test projects. This includes the Lunar Landing Research Vehicle (LLRV) that was used to train Apollo astronauts in piloting their lunar landers to the surface of the Moon.

For more information on Armstrong Flight Research Center and the LLRV, visit https://www.nasa.gov/centers/armstrong/Features/armstrong_recalls_first_moon_landing.html

Create

- Have teams construct their landers.
- Ensure that an inflated balloon is incorporated into the build, as it may be difficult to attach once the lander is complete. The balloon's nozzle should NOT be tied. It should be rolled and held shut with a binder clip or clothespin.
- The teams' landers should be sturdy enough to be dropped from a height of 2 meters without damage.

Tip: If students' landers are unstable, encourage them to place most of the weight of their lander below the balloon. Also have them add mass where needed to balance it out. The thrust of the balloon can be directed more downward by securing the balloon to the lander near the nozzle.

Test

To conduct the drop test, one student will operate the data collection device (stopwatch or slow-motion camera) while another releases the model lander in the drop zone from a height of 2 meters. For the first test, the binder clip or clothespin will remain in place, keeping the balloon's nozzle closed. For the second test, before releasing the lander, the binder clip or clothespin must be removed from the nozzle of the balloon. To ensure a smooth drop test, the nozzle of the balloon should be pinched closed while the binder clip or clothespin is removed, and then released at the same time the lander is released for the test.

Have students follow the drop test procedure for the testing method you have chosen (stopwatches, slow-motion video, or video analysis software).

1. If using a stopwatch:
   - With the balloon still sealed, have students record the time it takes for their lander to fall from a height of 2 meters.
   - Have students repeat the drop test with the nozzle of the balloon opened, again having students record the time of descent.
   - Have students calculate and record the average speed for each drop.
   - Using their data from both trials, have each team create a bar graph that shows the average speed of their lander both with and without the use of thrust from the balloon to slow its descent.
2. If using a slow-motion camera, such as a smartphone application:
   - With the balloon still sealed, have students record the time it takes for their lander to fall from a height of 2 meters in 20-centimeter increments. This can be accomplished by measuring the time elapsed as the lander passes each of the 20-centimeter reference marks on the wall.
   - Have students repeat the drop test with the nozzle of the balloon opened, again having students record the time it takes for the lander to fall in 20-centimeter increments.
   - Have students calculate and record the average speed of their lander at each of the 20-centimeter intervals.
   - Using their data from both trials, have each team create a line graph that shows their lander's speed at 20-centimeter intervals as it makes its descent both with and without the use of thrust from the balloon to slow its descent.
3. If using video analysis software:
   - Have students record two videos of their drop test, one with the balloon still sealed and another with the nozzle opened.
   - Have students upload their videos into the software for analysis.
   - Have students use the software to measure the acceleration of their lander both with the nozzle sealed and with the nozzle opened.
   - Using the modeling capabilities of the video analysis software, have students graph the acceleration of their lander in both of their trial videos.

If students are not familiar with calculating the speed of objects, share the following information:

To find the speed of the lander at any distance interval, or to find its average speed during its entire descent, use the speed formula: $s = d/t$. The speed (s) of the lander is equal to the distance (d) it has traveled (distance fallen), divided by the time (t) it took to travel that distance. Using metric units, measure the distance in meters (m) and the time in seconds (s). This will result in the speed being in meters per second (m/s).

Improve

- Have each team identify at least two areas in which their lander design can be improved. Remind students that the force of gravity pulling on their lander is dependent on the mass of their lander. This force is called weight. If their landers have less mass, they will also have less weight and will be pulled down with less force. The thrust from their balloons is the force that opposes the weight of the landers and causes the net downward force on the landers to decrease. Increasing the thrust will also cause the landers to fall more slowly. Balancing the thrust and weight will cause the landers to hover, and having too much thrust will overcome the weight of the landers and cause them to increase in altitude.
- Allow each team additional time and materials to incorporate these changes into their landers.
- Have students repeat their drop tests and determine if their design changes improved the performance of their landers.

Share

Engage students with the following discussion questions:

- What were some difficulties your team faced during the initial design and build process, and how did you overcome them?
- Were you surprised by the performance of your lander? Explain.
- How were you able to improve your lander during the redesign phase? What design changes did you make, and how did they improve your lander's performance?
- On a scale of 1 to 10, rate how your lander performed. Rate the landers of other teams as well. Were there any designs or features from other teams' landers that impressed you?
- If you could create a lander with additional materials you did not have available today, what materials would you use, and how would they improve the performance of the lander?

Students could also present their findings by creating a poster presentation, a computer graphical presentation, an oral report, or a written log or journal of their team's experimentation and results.

Optional: Share student results on social media using #NextGenSTEM. Be sure to include the module and activity name.

Extensions

- Have students make a two-stage lunar lander. A smaller upper stage with its own sealed balloon can be added to their current lander. After the lander has touched down on the surface, the upper stage can be disconnected from the lower stage and its balloon released. The upper stage will launch upward off the lunar surface. This is similar to how the Apollo Lunar Lander used both a descent stage and an ascent stage for landing on the Moon and returning to lunar orbit.
- Have students create a NASA Docking Adapter from the "Model a Spacecraft Docking System" activity in the Crew Transportation With Orion guide (https://www.nasa.gov/sites/default/files/atoms/files/np-2020-02-2805-hq.pdf) and attach it to their landers. They can then create models of the Orion crew module that can rendezvous and dock with their landers in lunar orbit.

Additional Resources

- This activity is written as an engineering design challenge in which students build and construct objects using common, everyday items. In the Materials ISS Experiment–X (MISSE–X) activity, students can explore how NASA tests different materials for their suitability for use in the construction of NASA hardware: https://www.nasa.gov/stem-ed-resources/best-technology-demonstration.html
- These NASA blog posts describe liquid rocket engines and provide video links: https://blogs.nasa.gov/J2X/tag/marshall-space-flight-center/
- The Tensegrity Planetary Lander, also called the Super Ball Bot, is a project that utilizes a radically different approach to landing and maneuvering a robotic craft on a planetary surface: https://www.nasa.gov/content/super-ball-bot

Activity Four: Safe Landing on the Lunar Surface

Student Handout

Your Challenge

You will work in teams to design and build a model of a lunar lander that will use the thrust of balloons to slow its rate of descent as much as possible to simulate a soft landing on the lunar surface. You will then drop your landers from a height of 2 meters in a series of trials, both with and without the use of propulsion, and collect and graph data of your lander's descent. Finally, you will make design changes and implement them into your lander to improve its performance.

Criteria	Constraints
Lander must use at least one inflated balloon.	May only use everyday, readily available supplies.
Design must incorporate landing legs that result in a stable, upright landing position after drop tests.	May not use parachutes or other items designed to create drag.
Lander must survive drop tests from a height of 2 meters.	

Ask

Discuss the following questions with your team and be prepared to share your answers aloud:

- Why doesn't NASA use parachutes for its lunar lander?
- What factors could make your lander unstable as it descends?
- What problems do you anticipate encountering?
- Does your team have any other questions about the challenge before you begin?

Imagine

- How would you design a craft that could safely land on the lunar surface?
- Sketch your own design of a lunar lander.
- Observe the building materials that are available for your team to use. Brainstorm with your team how they can be used in your model lander.

Plan

- As a team, sketch a design for your lander that incorporates the supplies available to you.
- Label each major part along with its purpose and what materials it will be made from.
- Your sketch must include at least one design idea from each team member.

Create

- Begin constructing your lander following the plans in your sketch. Be sure to use an inflated balloon in your design during the construction process, as it may be difficult to attach once your lander is completed. The balloon's nozzles should NOT be tied. They should be sealed by rolling the nozzle and pinching it shut with a binder clip or clothespin. This will ensure that the balloon is easy to release.

Fun Fact

How do you reliably start a rocket engine in space? Hypergolic fuels ignite spontaneously when mixed without the need of a spark or heat. They are, however, highly toxic. Researchers are developing nontoxic "green" propellants that are less harmful to the environment, increase fuel efficiency, and are less hazardous to work with.

Learn more: https://www.nasa.gov/content/gpim-spacecraft-to-validate-use-of-green-propellant

Career Corner

Enjoy designing and building spacecraft? Have a passion for solving problems and innovation? NASA employs over 20 types of engineers. Come explore the diverse career paths available and prepare to become part of the NASA team.

Learn more: https://www.nasa.gov/careers/engineering

- After completing your lander, practice dropping it, with the balloon still sealed, from a height of 2 meters. Your lander must be sturdy enough to survive multiple 2-meter drops without damage.
- Now practice releasing the nozzle of your balloon as you drop your lander. The thrust of the balloon should be directed downward, and the lander should descend without traveling sideways. If you are having trouble keeping your lander stable, ask the instructor for advice, and then work on your design.

Test

- Your team will be making two official drops with your lander, first with the balloon's nozzle sealed, and then with the nozzle released.
- To conduct the drop test, one student will operate the data collection device (stopwatch or slow-motion camera) while another releases the model lander in the drop zone from a height of 2 meters. For the first test, the binder clip or clothespin will remain in place, keeping the balloon's nozzle closed. For the second test, before releasing the lander, the binder clip or clothespin must be removed from the nozzle of the balloon. To ensure a smooth drop test, the nozzle of the balloon should be pinched closed while the binder clip or clothespin is removed and then released at the same time the lander is released for the test.
- Carefully follow instructions on how to collect data for your tests and how to calculate the speed of your lander during its descent.
- Graph your results as directed and determine if the thrust from the balloon slowed the descent of your lander.

Improve

- As a team, identify at least two ways in which you can improve upon the design of your lander. Sketch them out, detailing what changes you will make to your design.
- Gather the necessary materials and incorporate your changes into your lander model.
- Repeat the drop tests, collecting data as you did before.
- Graph your new results and compare them to those of the previous drop tests to determine if the changes in your design improved the performance of your lander.

Share

- What were some difficulties your team faced during the initial design and build process, and how did you overcome them?
- Were you surprised by the performance of your lander? Explain.
- How were you able to improve your lander during the redesign phase? What design changes did you make, and how did they improve your lander's performance?
- On a scale of 1 to 10, rate how your lander performed, and then rate the other teams' landers. Were there any designs or features from other teams' landers that impressed you?
- If you could create a lander with additional materials that you did not have available today, what materials would you use, and how would they improve the performance of the lander?