A UNIT OF STUDY FOR GRADES 4–8

The Liberty Bell 7

Schaefer Planetarium and Object Theater

CHILDREN'S MUSEUM INDIANAPOLIS

Acknowledgments

The Liberty Bell 7
Schaefer Planetarium and Object Theater
The Children's Museum of Indianapolis
A Unit of Study for Grades 4–8

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The Children's Museum of Indianapolis is a nonprofit institution dedicated to creating extraordinary learning experiences across the arts, sciences, and humanities that have the power to transform the lives of children and families. It is the largest children's museum in the world and serves more than 1 million people across Indiana as well as visitors from other states and nations.

VISIT THE MUSEUM

The museum provides special programs and experiences for students as well as teaching materials and professional development opportunities for teachers. To plan a visit or learn more about educational programs and resources, visit the Teacher section of the museum's website at **childrensmuseum.org**.

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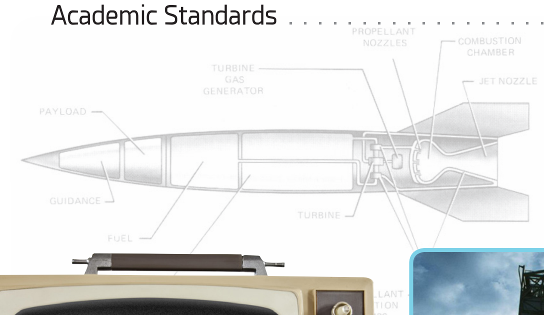

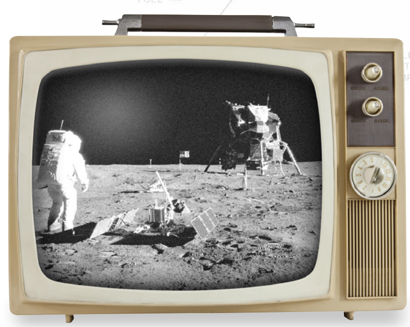


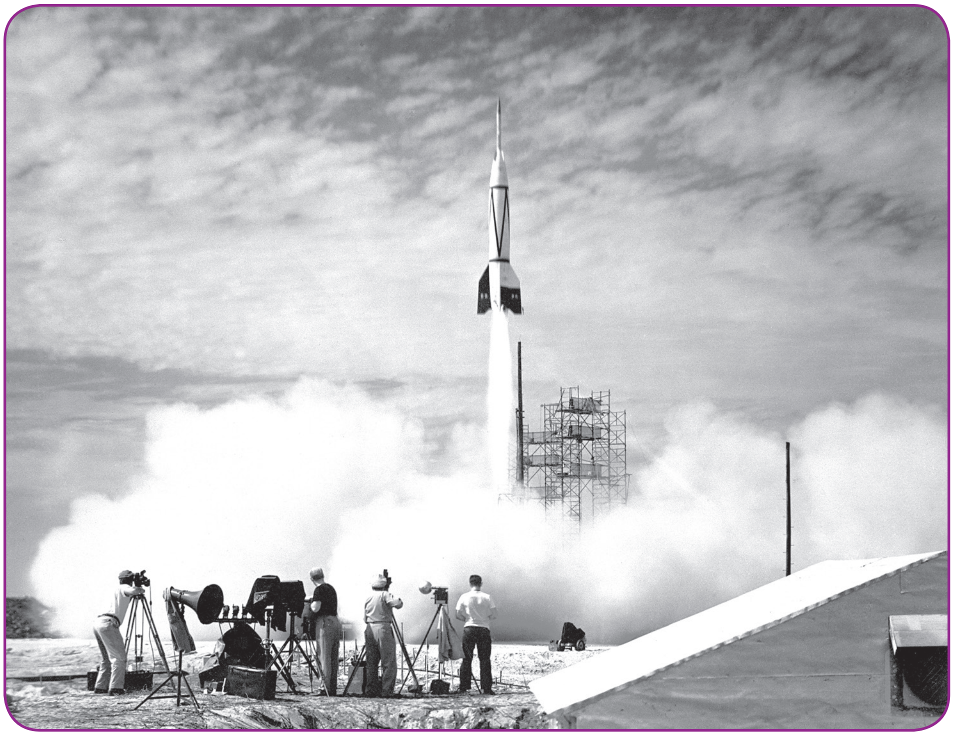

Introduction

Human beings have always been fascinated by the sky and dreamed of traveling beyond the atmosphere that surrounds Earth to the moon, planets, and stars. The history of this quest begins with early attempts to build flying machines and rockets, which led to the invention of modern rockets capable of launching spacecraft and astronauts into Earth orbit and beyond. An important step in this journey was the development and testing of the first space capsules, such as the *Liberty Bell 7*, which could carry astronauts into orbit and return them safely to Earth.

Above: A new chapter in space flight began in July 1950 with the launch of the first rocket from Cape Canaveral, Florida: the Bumper 2, an ambitious two-stage rocket program that topped a V-2 missile base with a Corporal rocket. The upper stage was able to reach then-record altitudes of almost 250 miles, higher than the present-day International Space Station's orbit. PHOTO CREDIT: NASA

Enduring Idea

Early space flights and spacecraft were designed to test the abilities of piloted machines to leave Earth's surface. The first astronauts, such as Gus Grissom, were trained pilots with experience guiding specialized, high-flying aircraft. Rockets were used to propel these early astronauts and their spacecraft into orbit in the upper levels of our planet's atmosphere. Over time, rockets and spacecraft have become more complex and the role of astronauts has become increasingly diverse.

Top right: After the hatch of *Liberty Bell 7* opened prematurely, gallons of seawater entered the spacecraft. A helicopter recovery team attempted to empty the water, as seen in this photo. Seconds after this picture was taken, the Marine helicopter dropped the spacecraft because it was too heavy to continue lifting, and the capsule sank. The *Liberty Bell 7* was eventually recovered from 15,000 feet (4,600 m) below the surface of the Atlantic Ocean in 1999.
PHOTO CREDIT: NASA

The Exhibit

The Schaefer Planetarium and Space Object Theater opened in 2016 at The Children's Museum of Indianapolis. The goal of this unique planetarium is to engage visitors with the past, present, and future of space exploration through objects, multimedia presentations, and first-person interpretation. The first object on display is the *Liberty Bell 7*, a spacecraft flown by Gus Grissom on the second piloted U.S. space flight. *Liberty Bell 7* was launched atop a Mercury-Redstone rocket on July 21, 1961. The flight lasted 15 minutes 30 seconds and reached an altitude of 108 nautical miles above Earth. *Liberty Bell 7* splashed down in the Atlantic Ocean after a successful mission but, before Gus Grissom was ready to exit the spacecraft, the hatch blew open and the capsule began to fill with water. Rescue teams were able to save Gus, but *Liberty Bell 7* was too heavy for helicopters to lift from the water and it sank to the bottom of the ocean. After a 14-year search that began in 1986, *Liberty Bell 7* was located on the floor of the Atlantic and recovered on July 20, 1999. The Kansas Cosmosphere and Space Center dismantled, cleaned, and restored the space capsule and put it on display. In 2016, *Liberty Bell 7* was loaned to The Children's Museum of Indianapolis, where it is featured in the museum's newest exhibit, **Beyond Spaceship Earth**.

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The Unit of Study

In this set of learning experiences students discover how scientists, engineers, and astronauts worked together to solve design and retrieval problems related to using rockets to launch the first space capsules and their astronauts.

Above: John Houbolt, as photographed in 1962, showing his Lunar Orbit Rendezvous (LOR) concept for landing on the moon.

PHOTO CREDIT: NASA

Vocabulary

- air
- air resistance
- astronaut
- atmosphere
- drag
- friction
- gravity
- kinetic energy
- lift
- matter
- orbit
- payload
- physical forces
- potential energy
- rocket
- space capsule
- spacecraft
- suborbital
- thrust
- weight

Liberty Bell 7

Astronaut Gus Grissom climbs into his *Liberty Bell 7* spacecraft on July 21, 1961. The Mercury-Redstone 4 rocket successfully launched the *Liberty Bell 7* at 7:20 a.m. that morning. This was the second in a series of successful U.S. manned suborbital flights.

PHOTO CREDIT: NASA

Objectives

Students will

- investigate the engineering and physical science concepts involved in sending spacecrafts into orbit
- test air-powered rockets to understand basic rocketry and solve engineering challenges
- develop and test models designed to slow down a cargo-carrying spacecraft and land it safely
- work in teams to test models, record data, and compare results with other teams
- use physical science concepts and vocabulary to explain results
- research, plan, and build a scale model for Rocket Park, a space flight history park commemorating early astronauts and spacecrafts

Focus Questions

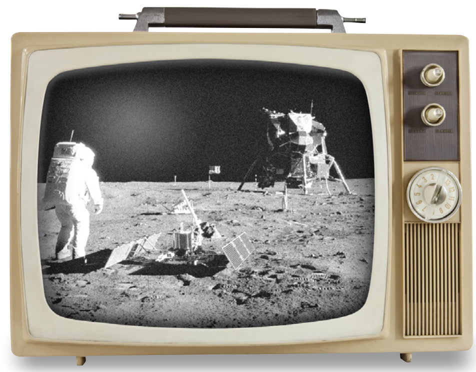
- How did scientists work to overcome gravity to launch rockets?
- What are some ways to create thrust and lift to get an object off the ground?
- What is weight? How does weight affect the way an object moves through the air?
- What causes an object to leave orbit and fall to Earth?
- How does friction affect an object moving through the atmosphere?
- How do scientists engineer spacecraft to help keep astronauts safe?
- What is the significance of the name of the *Liberty Bell 7*?
- How did Gus Grissom and other space-capsule astronauts contribute to the space program?

Introductory Experience: Galactic Glossary

In this experience students examine their prior knowledge about how humans have learned to travel from Earth into space. Students begin to develop a scientific vocabulary related to the early exploration of space.

Above: Scientist and mathematician Jeanette A. Scissum joined NASA's Marshall Space Flight Center in 1964 after earning bachelor's and master's degrees in mathematics from Alabama A&M University. Scissum published a NASA report in 1967, "Survey of Solar Cycle Prediction Models," which put forward techniques for improved forecasting of the sunspot cycle. PHOTO CREDIT: NASA

On May 25, 1961, President John F. Kennedy announced before a special joint session of Congress that the United States would commit to a lunar landing by 1970. PHOTO CREDIT: NASA



On July 20, 1969, America's Apollo 11 Lunar Module pilot Buzz Aldrin and mission commander Neil Armstrong were the first humans to set foot on the moon. PHOTO CREDIT: NASA

Procedures

- Tell students they will be identifying problems space scientists had to overcome for early space flights. This includes how to get **astronauts** into space.
- To introduce the unit and activate prior knowledge, have students work in pairs to complete a quick brainstorming activity.
- Explain to students that they will have a set length of time to brainstorm as many words as they can that relate to human space flight. As this is a quick brainstorm, provide students with only 1 or 2 minutes to complete their lists.
- At the conclusion of the brainstorm time, ask each pair of students to provide one word or phrase from their list that will be added to a class list. Encourage students to compare lists with their classmates and share words that aren't on everyone's list.
- Rotate through each pair and record their words on a class chart. Use a piece of chart paper or other material that can be displayed in the classroom. If you have a smartboard, use the interactive whiteboard feature to record student ideas. Save the document for future use.
- Ask students if any pair still has a word on their list that has not yet been included. Continue collecting responses from students until all of their words are on the chart.
- After you have completed the class list of words, ask students to read through it and sort words into categories, such as parts of a **rocket** or how a **spacecraft** moves.
- Explain to students that they will be reviewing this list as a class throughout the unit and will add to it after each lesson.
- As unit vocabulary words are introduced, add them to the chart to support students' use of science terminology.

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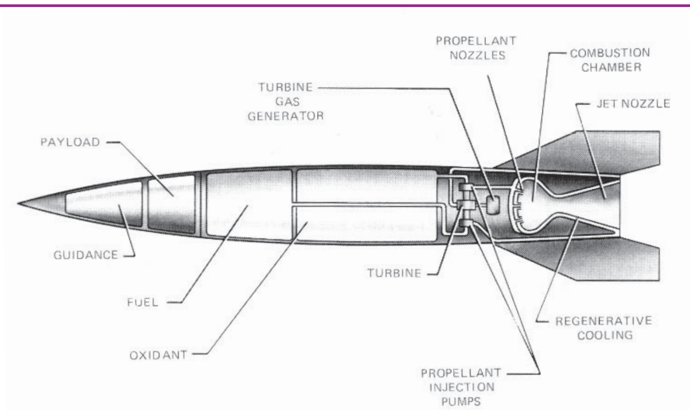
Lesson 1: To Space and Back

The History of Rocketry

The concept of the rocket developed when explosive materials, such as gunpowder, were employed to launch weapons. The first recorded use of this technology took place in 1232, when the Chinese used rocket-propelled arrows in a battle with the Mongols. The Chinese also used small rockets to launch fireworks into the sky during celebrations, just as people do today. In 1687, Isaac Newton published his three laws of motion, which established the scientific foundation for the modern study of rocketry.

Although people in the late 19th and early 20th centuries theorized about space travel, research continued to focus on the use of rockets as weapons. During World War II, Wernher von Braun and a team of German scientists invented the V-2 rocket, a ballistic missile that the Nazi military intended to use against England and the United States. This type of rocket used liquid fuel and was strong enough to reach space. Von Braun and many members of his team defected to the United States and were able to continue their research. Eventually, von Braun was able to pursue his dream of developing rockets for travel into outer space. This led to the beginning of the United States' space exploration program.



Liquid Propellant Rockets may offer better performance, but the storage and handling of their fuels is a little difficult. This is why U.S. space boosters use solid propellant rockets instead of liquid propellant rockets. CREDIT: NASA

Academic Standards

Indiana Academic Standards
4.PS.1; 4.PS.2; 6.PS.2, 6.PS.3; 7.PS.4

National Standards
Next Generation Science Standards
4-PS3-1, 4-PS3-4; 5-PS2-1; 3-5-ETS1-1, 3-5-ETS1-2, 3-5-ETS1-3; MS-PS2-2; MS-ETS1-1, MS-ETS1-3, MS-ETS1-4

You will need

Experience 1: Rocketry Basics

- ❑ Piece of paper
- ❑ Paper ball
- ❑ Small ball
- ❑ Large ball

Experience 2: Getting Off the Ground

- ❑ Web video of a rocket launch
- ❑ Paper
- ❑ Aluminum foil

Equipment per team:

- Balloons of varying sizes (round balloons work best for this activity)
- Ruler and bookends to measure balloon diameter
- String
- Masking tape
- Large plastic drinking straw
- Binder clips
- Pennies

Experience 3: Safe Landing

- ❑ Recyclable boxes, cups, egg cartons, etc.
- ❑ String
- ❑ Napkins or tissue paper
- ❑ Tape
- ❑ Glue
- ❑ Pringles-style potato chips
- ❑ Large plastic tablecloth

Experience 1: Rocketry Basics

Students carry out a series of demonstrations to explore the effect of gravity and friction on objects of different shapes, sizes, and weights. They construct arguments to explain why objects behaved in specific ways and back up arguments with data from their demonstrations. They work in pairs to record their observations and consider why rocket designers must consider the need to overcome effect of air pushing against an object and the force of gravity pulling it down.

Above: John Glenn's *Friendship 7* spacecraft launches on a Mercury-Atlas rocket on Feb. 20, 1962.
PHOTO CREDIT: NASA

Procedures

- To introduce the experience, complete a demonstration with students.
- Hold up a sheet of paper, a large ball (such as a soccer ball or beach ball), a small item (such as a rubber bouncy ball or wooden block), and a small ball of paper.
- In their notebooks or on scrap paper, have students record which items they think will fall to the ground first if all of the items are dropped at the same time.
- Invite a few students to the front of the classroom to complete the demonstration. Ask the students to create pairings such as the beach ball versus the paper ball. Assign 1 student to be the dropper, and 1 or 2 students to be the official observers. Have dropper students hold their hands at the same height and release the items at the same time. The observer(s) should watch to see which item hits the ground first.
- Repeat the tests, allowing several students the opportunity to observe and drop. For each test, have all of the students record the pairing and which item landed first.
- After the class has completed several trials, have students pair with another student for a think-pair-share. Ask students to individually review their data and record 1 or 2 statements about what they observed. Students should begin to notice that all of the objects landed at the same time, with the exception of the flat piece of paper. Have the student pairs share their statements and construct an argument for why they believe some items landed at different times. Remind students that they should back up their arguments with evidence collected from the demonstrations.
- Ask the pairs to share their arguments and the observations that support their ideas. As students share, reinforce their use of words such as **gravity**, **friction,** or **air**. Guide the discussion to highlight the role of gravity and air in how the objects fell.
- Close the lesson by explaining that students will use their observations of gravity as a constant force pulling down on objects and the effect of air pushing on an object in designing rockets, the next experience in the lesson.

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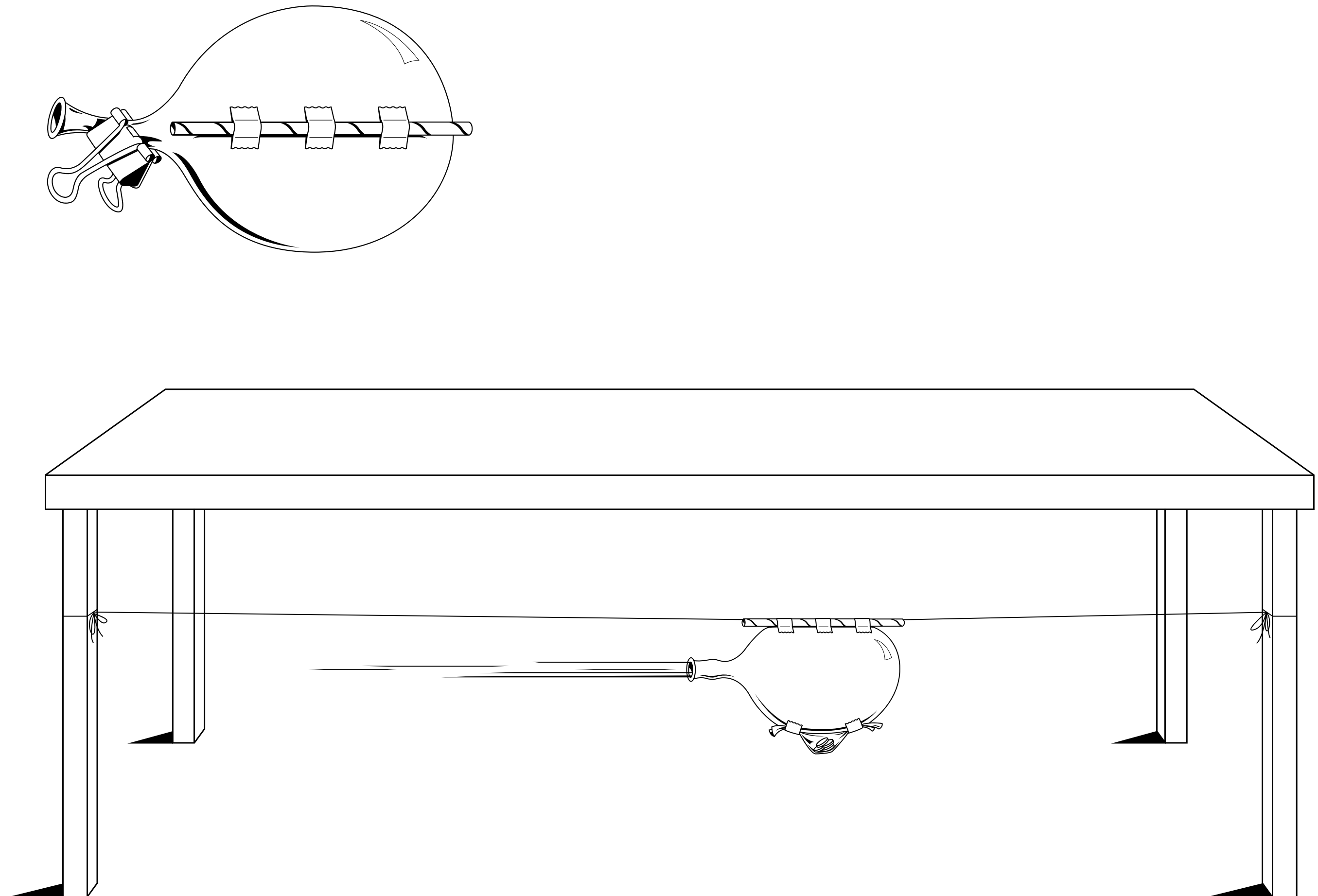
Experience 2: Getting Off the Ground

Students investigate the challenges of launching an object into orbit. They construct and launch air-powered rockets to examine the physical forces, such as thrust and drag, that influence the way an object moves through the air. Students build balloon rockets that travel along a horizontal string and test balloons of different sizes to lift cargo.

Above: A stage of the uprated Saturn 1 launch vehicle unloaded from NASA barge *Promise* after arrival at Cape Kennedy. This was the launch vehicle for the Apollo/Saturn 204 mission, 1966.
PHOTO CREDIT: NASA

Procedures

- Prior to the start of the class, create a **rocket** testing station for students. Because rockets will be launched horizontally, choose a space in the classroom or multi purpose room that is at least 10 feet across. Thread a string through a straw prior to securing both ends of the string to the attachment points for the track. Attach each end of the string to a chair or table, making sure the string is tight. Construct one station for every two or three student groups, keeping the conditions in the rocket launch as similar as possible.
- Begin the experience by showing students a short video of the *Liberty Bell 7* rocket launch. Encourage students to watch for challenges the rocket design had to overcome to **orbit** Earth. https://www.youtube.com/watch?v=WmpNh8JqnS8
- Ask students to share their observations of the rocket launch. Point to the vocabulary generated from the brainstorm in **Experience 1** and encourage students to use them in their observations.
- Introduce the experience to students by inviting them to become rocket engineers. Explain that their task is to design a rocket that will move the farthest distance possible. For older students, add the challenge of increasing the weight the rocket must carry.
- Share with students that engineers developing the first spacecraft had to carefully record specifics of the rocket as well as its performance. Ask students to think about the rocket launch they observed and suggest the types of data they may need to collect during their tests.
- Provide each student with the **Engineering Project Report** handout on page 11 and review the types of data they will need to collect. While reviewing the handout, ask students why they think the report asks them to record the diameter of the balloon. Share with students that air inside the balloon will be the rocket fuel and the size of balloon will help them determine which rockets had the most air.



Balloon Rocket Testing Station

- Before students build a rocket, show them the test stations. Demonstrate to students that they should inflate the balloons and close them with binder clips instead of tying them off. Explain to students they should attach the balloons to the straw with a piece of masking tape. Provide students enough time to build and test a rocket.

- Remind students to record their data as they test their rockets. Data will be needed to complete the engineering project report.

- After older students have been able to test their rockets, provide them with the additional challenge of increasing the **payload**, or **weight** the rocket carries, with a small package of pennies. Students will need to use the data they collected to create a rocket that can carry 5 pennies and that will travel 10 feet.

  As part of the engineering challenge, students should be allowed to decide how they will package the pennies in foil and attach the package to the rocket.

- When students have completed all of the tests, provide them with time to create their reports. This portion of the lesson could be completed in a writer's workshop period or during a second class period.

- After groups have finished their reports, ask them to identify two or three discoveries or observations they made while working on the rockets. Lead a science discussion with students, having each group share their observations while you record them on the board. If you have a smartboard, use it to capture the students' discoveries.

- To extend the science discussion after all students have shared their observations, ask the entire class to identify discoveries that are similar among all of the groups. Highlight these similarities, which may include statements such as: More air was needed to move the balloon carrying pennies; a balloon that is a certain size in diameter can carry only a certain number of pennies; or air provided the "fuel" for the balloon rocket.

- Pose the following questions to students and provide them with time to respond in writing before taking a whole group response.

  - What material did you use to power your rocket?
  - What forces, such as **thrust**, **lift**, or **drag**, did your rocket have to address in order to carry the pennies?

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STUDENT HANDOUT

Engineering Project Report: Getting Off the Ground

Team Members:

____

Engineering Goal: Design and test a balloon rocket that will carry the greatest amount of weight.

Project Constraints: You will have _________ minutes or _________ class periods to test your rocket design. The rocket must include a balloon and travel along one of the launch areas.
Your final rocket design must carry a bag of pennies for the duration of its flight.

STUDENT RECORD SHEET

Investigation 1
ROCKET FUEL

TRIAL	BALLOON DIAMETER	DISTANCE TRAVELED

Investigation 2
PAYLOAD

TRIAL	BALLOON DIAMETER	NUMBER OF PENNIES	DISTANCE TRAVELED

Reflection Questions:

- What did you learn from your first set of flights that helped design new flights with increased payload? _______________
____
____
- How is your balloon rocket similar to the *Liberty Bell 7* launch? ____
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____
- Based on your experience, what challenges do you believe NASA engineers face when designing rockets for space? _______
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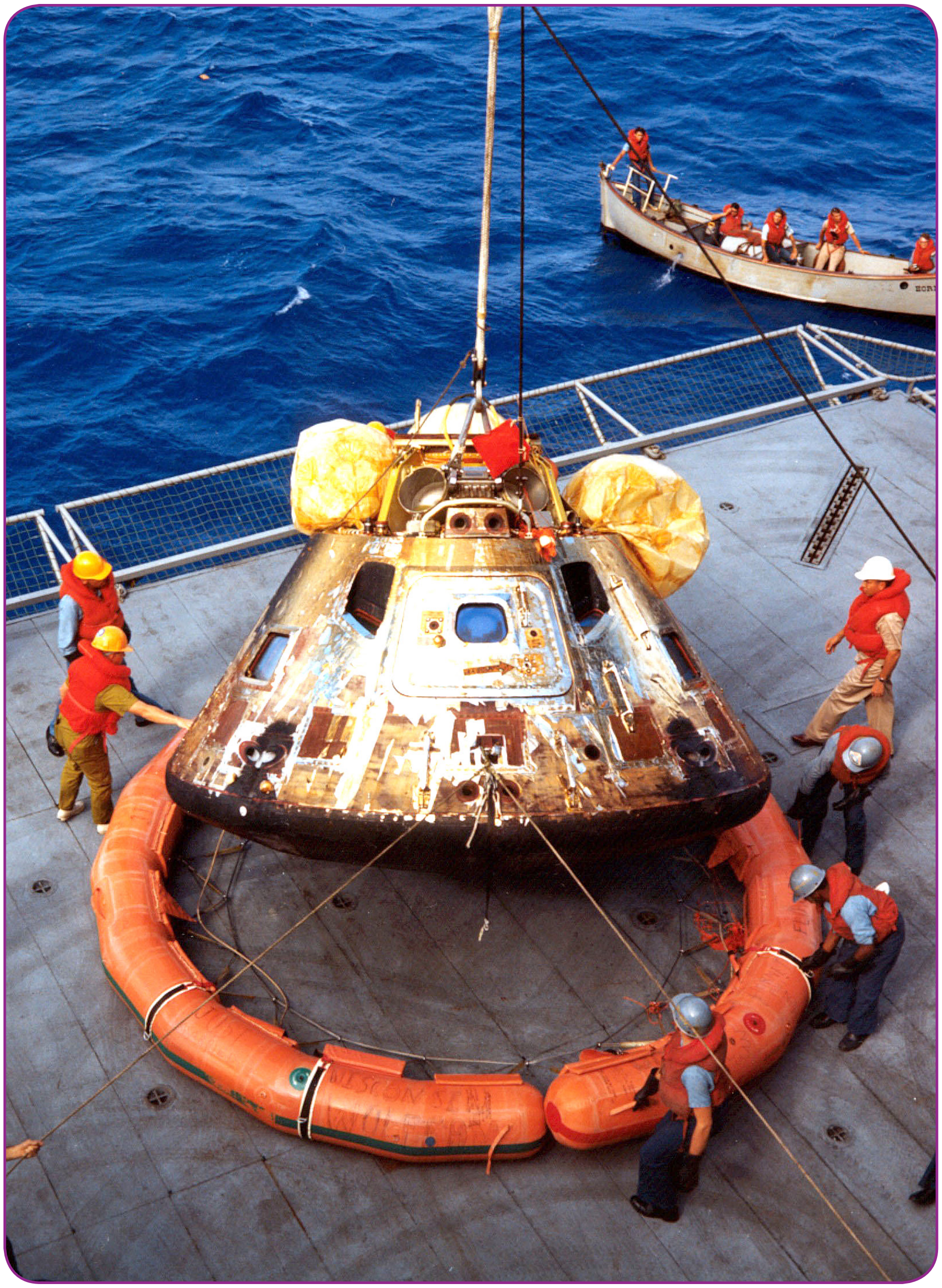

Experience 3: Safe Landing

Students consider the major engineering problems in returning an orbiting space capsule safely. They learn about the dangers of reentry into Earth's atmosphere as gravity pulls an object toward Earth's surface, and how the friction created when an object moves rapidly through the air produces heat that can destroy the object even before it reaches Earth. They use what they have learned about push and pull forces, such as lift and gravity, to build and test different capsule models to see which one can safely land fragile cargo.

Above: The Apollo 11 spacecraft command module, after being lifted from the ocean, is lowered to the deck of the USS Hornet, the main recovery ship for the historic lunar landing mission in 1969.
PHOTO CREDIT: NASA/KIM SHIFLETT

Earth's Atmosphere

Earth's atmosphere is made up of a combination of gases that protect the planet by reflecting and absorbing harmful radiation. The atmosphere retains heat that warms the Earth's surface and reduces temperature extremes. Oxygen, nitrogen, and argon are the three major elements that make up the atmosphere. There are also traces of carbon dioxide, methane, nitrous oxide, and ozone, along with natural and human-made pollutants and natural substances such as pollen. The atmosphere is held in place by Earth's gravity.

Earth has four major layers of atmosphere. The **troposphere** is closest to Earth's surface and can extend up to about 9 miles. This is where human activity and most weather take place. The next layer, the **stratosphere**, extends 10 to 31 miles above the troposphere and includes the ozone layer, which absorbs dangerous ultraviolet light from the sun. The third atmospheric layer is the **mesosphere**, 31 to 53 miles above Earth. This is where meteors that enter the atmosphere usually burn up. Above the mesosphere is the **thermosphere**, 53 to 372 miles above the planet's surface. Many satellites are launched into orbit in the thermosphere. The International Space Station orbits Earth in the upper part of this layer. Overlapping the mesosphere and thermosphere from about 30 miles to as many as 600 miles above Earth's surface is a belt of ionized atomic oxygen and nitrogen called the **ionosphere**. It reflects radio waves back to Earth, making long-range communication possible. Above that is the **exosphere**, which extends to 6,200 miles from Earth's surface and into outer space. It is made up of low densities of hydrogen, helium, oxygen, nitrogen, and carbon dioxide. The molecules of these gases are so far apart from each other that they constantly exit into space.

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Procedures

- Explain to students that a challenge early space flight engineers had to overcome was how to return an astronaut to safety.
- Ask students to consider the most important engineering question in spacecraft design: How can astronauts return safely to Earth? Ask students why it is so difficult to reenter Earth's **atmosphere** and return to the surface. What **physical forces** are involved?

Spacecraft Basics

There are two major forces that engineers must overcome in order to return a spacecraft safely to Earth. The particles that make up Earth's atmosphere hit and pass around a falling object, causing **friction**. This slows the object but also causes it to heat up. An unprotected object moving through the atmosphere can burn and completely disintegrate. Spacecraft must be designed with shields made of heat-resistant materials to protect them as they encounter aerodynamic heating. **Gravity** also pulls down on an object, causing it to fall at high speed and generate even more heat. For this reason, engineers work to control the path and speed of spacecraft as they reenter the atmosphere and design them to withstand both heat and impact. Safety equipment and suits also are designed to protect astronauts from the dangers of reentry.

- Share with students that their next task as engineers is to design a way to land a spacecraft safely on Earth. Younger students will land their spacecraft on land. Give older students the option of landing their spacecraft in the water.
- Demonstrate for students the project goal of safely landing an astronaut on Earth. Show how an astronaut will be represented by a potato chip (due to their uniformly curved shape, Pringles-style chips work best) and the spacecraft will be dropped from a height of 10 feet.
- Assign students to teams to complete this design test.
- Provide students with the design handout. Before students build their spacecraft, instruct them to complete a draft of their design. Instruct students to complete new sketches of their design after each test, making sure to include any modifications they made in the design.
- For the spacecraft build, provide students with a variety of recyclable materials. This could include cracker or cereal boxes, string, egg cartons, cups, packing materials, and paper napkins. You may also choose to let students bring in materials based on their brainstorming sessions.
- Emphasize to students that they have a limited amount of time to build their spacecraft before the first engineering test. Explain to students that this is part of the design process.
- When students are ready to test the spacecraft, set up a testing zone. This should be a large area free of obstacles such as chairs or desks. Spread a large plastic trash bag or tablecloth on the floor to make cleanup easier.
- Provide each team with an opportunity to test their spacecraft. Determine if students or a teacher will complete the drop. To achieve the height of 10 feet, you may need to use a ladder or stand on a desk.
- If your school has the technology available, encourage each group to identify a team member who could film the drop and landing. Students can use either regular video mode or the slow-motion feature. Video evidence may be useful to students as they evaluate their designs.
- Once teams drop their chip, ask them to open up their craft to test how well their chip survived. Provide students with the opportunity to modify their designs if the chip broke. For students with a successful test, allow them to drop from a greater height, or add a second astronaut (chip).
- At the conclusion of the tests, ask students to complete the Spacecraft Discoveries section of their handout.
- Once students have completed their chip-drop reflections, host a science talk with all of the students. Students should have their design handout in front of them for reference.
- Ask students to share observations of the devices that protected the astronauts. Encourage students to explain why they believe those features protected the chips.
- Introduce the words and phrases air resistance, gravity, potential energy, and kinetic energy by writing them on the board. Use the following definitions with students:
  - **kinetic energy** – the energy of motion
  - **potential energy** – the opportunity for energy to be released
  - **air resistance** – the property of air, because it is **matter**, to interact with moving objects
  - **gravity** – the force that attracts an object toward Earth
- Ask students to identify examples of each vocabulary term in their chip drop. Record the examples on the board. You may wish to have students draw a bubble diagram in their notebooks to help record ideas.
- As an extension, show students video evidence of various spacecraft—such as Apollo, Space Shuttle, or Soyuz—landing back on Earth. Ask students to explain how their landings were similar and different.

STUDENT HANDOUT

Safe Landing Engineering

Team Members: ____

Engineering Objective: To safely land an astronaut from a height of 10 feet. The astronaut must stay intact and inside the spacecraft.

Spacecraft Brainstorm: List the features and materials you will include in your first spacecraft design. You may include sketches or drawing.

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Spacecraft Design #1: Sketch your spacecraft design before its test. Label spacecraft features and materials used.

Condition of astronaut: Following the first test, describe the condition of your astronaut.

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What design modifications do you plan to make for a second test?

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STUDENT HANDOUT

Safe Landing Engineering, continued

Spacecraft Design #2: Sketch your spacecraft design after its modifications. Label spacecraft features and materials used in this new design.

Condition of astronaut: Following the second test, describe the condition of your astronaut.

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What design modifications would you make for additional tests?

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Space Craft Discoveries: Describe the features your group believes worked the best to protect your astronaut.

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Lesson 2: People and Places in Space Exploration

Above: NASA astronaut Michael Hopkins, Expedition 37/38 flight engineer, makes final touches on a training version of his Extravehicular Mobility Unit (EMU) spacesuit in preparation for a spacewalk training session in the waters of the Neutral Buoyancy Laboratory, August 2012. PHOTO CREDIT: NASA

Experience 1: Outstanding Astronauts

Students learn about Indiana astronaut Gus Grissom, his flight on the *Liberty Bell 7*, and his important contributions to the space program. As they carry out the astronaut trading card project they learn about other astronauts and use their close-reading skills to identify both major ideas and details.

Academic Standards

Indiana Science Standards, 2016

6-8LST1.1, 6-8LST1.2, 6-8LST3.2

Indiana Mathematics Standards

5.AT.1, 5.M.1; 6.GM.1; 7.C.6, 7.GM.3

Indiana English/Language Arts Standards

4.RN.1, 4.RN.3.1, 4.RN.4.2, 4.RV.1, 4.W.5; 5.RN.1, 5.RN.3.1, 5.RN.4.2, 5.RV.1, 5.W.5; 6.RN.1, 6.RV.1, 6.RV.3.2, 6.W.1; 7.RN.1, 7.RV.1, 7.RV.3.2, 7.W.1, 7.W.5

National Standards

Next Generation Science Standards

MS-ETS1-4

Student Project— Astronaut Trading Cards

- Introduce the experience by asking students what they know about astronauts. Questions could include: What types of training and experience do astronauts need to work in space? What types of jobs do astronauts complete in space?
- Explain to students that they are going to explore the job of an astronaut by using research skills to create astronaut trading cards.
- Show students examples of sports trading cards (digital images may be used). Ask students to identify key facts of an athlete's history included on the trading card. Possible answers include date of birth, hometown, team affiliation(s), and performance statistics.
- Ask students to think about the work of astronauts. Ask: What key facts might be important to include on an astronaut trading card? What facts would be different from those on a sports trading card? Answers may include spacecraft, space missions, or number of days in flight.
- Discuss the question: What special skills do individual astronauts have? Answers may include engineering, math, computers, or biology.
- Explain to students that they will be researching astronauts and creating trading cards about them. You may want to provide specific astronauts for younger students to research. Possible suggestions are:
  - Astronauts with a connection to your state
  - Astronauts from countries other than the United States
  - Astronaut firsts, such as first woman or first African American in space
- Provide students with the **Astronaut Trading Card Research Guide** on page 18 and have them use it as a research template to help understand the amount of information they need to include. Remind students that for a trading card, they will need to create bullet points rather than a narrative.
- To practice selecting and summarizing information, provide students with the biography on page 18 of Gus Grissom, pilot of the *Liberty Bell 7*. Give them time to read the brief biography and use the Research Guide to create bullet points for a Gus Grissom trading card.

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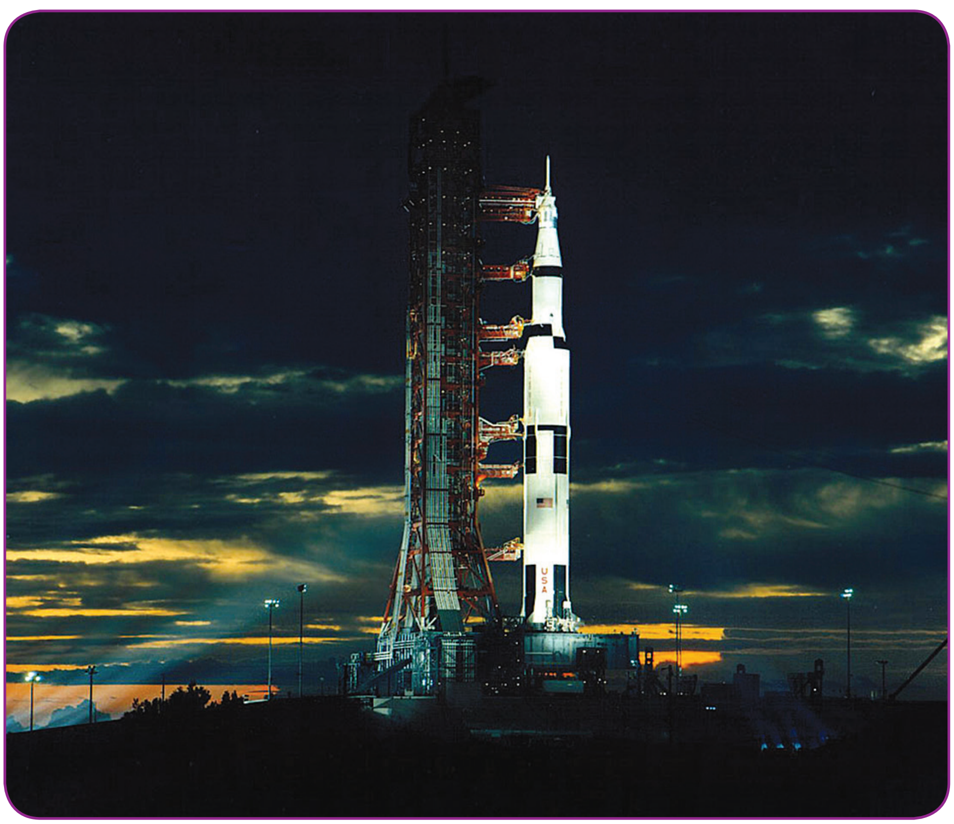
In preparation for their April 16, 1972 launch, Apollo 16 astronauts Charles Duke and John Young simulate navigating the lunar surface at a training area located at Kennedy Space Center. PHOTO CREDIT: NASA



- When students have completed their practice cards on Gus Grissom, have them use the Astronaut Trading Card Research Guide to begin study of another astronaut. Review with students what types of resources they should use in their research.
- If students will be researching at school, allow time for them to research online to identify and collect information about the astronauts they have chosen.
- Once students have completed their research, allow time for them to create the trading cards. You may choose to have students create trading cards out of construction paper or cardboard, using the Research Guide. Students may also create digital trading cards using PowerPoint or graphic design software.
- For digital trading cards, encourage students to use NASA websites to find images of the astronaut and his or her spacecraft or video of the astronaut's mission. Additional NASA facts could be linked from the trading card.
- Students' trading cards should be evaluated for the completeness of the information, the inclusion of a visual image, and grammar appropriate for the students' grade level.

Left: The Saturn V rocket and Apollo 17 space-craft await the December 1972 night launch. The Saturn V is the same rocket that was used to carry the Apollo 16 astronauts to the moon.
PHOTO CREDIT: NASA

STUDENT HANDOUT

Astronaut Trading Card Research Guide

Student Name: ____

Astronaut Name:

____

Space Missions:

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Important Dates:

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Special STEM Skills and Training:

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Interesting Facts:

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STUDENT HANDOUT

Gus Grissom

Virgil "Gus" Grissom was born in Mitchell, a small town in southern Indiana, on April 3, 1926. He was the oldest child in his family, with a younger sister and two brothers. Although he was very smart, he didn't do particularly well in school. He was good at math but didn't put a lot of effort into his other subjects. To earn money he did odd jobs, including delivering newspapers and picking fruit at nearby orchards. He was too short to play on the basketball or football teams at school, but he joined the local Boy Scouts troop and became a member of the honor guard.

Project Mercury Astronaut Virgil I. Grissom, primary pilot for the Mercury-Redstone 4 manned space flight known as *Liberty Bell 7*, gets an assist from suit specialist Joe W. Schmidt as he prepares for spaceflight. PHOTO CREDIT: NASA

Grissom didn't seem to know what he wanted to do with his life until World War II caused him to consider a military career. He decided he wanted to be a combat pilot and enlisted as an Air Force aviation cadet during his senior year of high school. However, the war ended before he could receive his training, so Gus left the military. He worked for a while at a bus factory in Mitchell before deciding to go to college to earn a degree in mechanical engineering. After graduating from Purdue University in 1950, he reenlisted in the Air Force. This time, he received his training and his pilot's wings. He flew 100 missions during the Korean War and was awarded several medals. After the war, he earned a degree in aeromechanics and became a test pilot for the Air Force.

On March 23, 1965, astronauts Gus Grissom and John W. Young participated in the first crewed Gemini flight, Gemini III. PHOTO CREDIT: NASA

In 1958, Grissom received an official message instructing him to report to an unfamiliar address. He was told to wear civilian clothes instead of his military uniform. It was all very mysterious. Once there, he learned he was one of 110 military test pilots chosen to learn about the new space program, Project Mercury, but only seven would be chosen to participate. After many tests and interviews, Grissom was chosen as one of the seven Project Mercury astronauts!

On July 21, 1961, Grissom piloted the second Project Mercury mission, a **suborbital** flight that lasted 15 minutes and 37 seconds. Grissom nicknamed the spacecraft the *Liberty Bell 7*. Although the flight was a success, there were problems upon landing. The capsule splashed down in the ocean as intended, but the hatch blew open early, before the capsule could be retrieved. Water rushed in, sinking the *Liberty Bell 7*. Fortunately, Grissom was able to escape and was rescued. There were many questions surrounding the incident, but Grissom was cleared of wrongdoing and the sinking was declared an accident. *Liberty Bell 7* remained at the bottom of the ocean for almost 40 years before being recovered in 1999.

Next, Grissom worked on Project Gemini and became the first NASA astronaut to fly in space twice. The first three Gemini spacecraft were designed around Grissom before officials realized Grissom was much shorter than most of the other astronauts. So much shorter, in fact, that 14 of the 16 other astronauts could not fit inside the cockpit. Later Gemini spacecraft were modified to fit larger astronauts.

Grissom's final assignment for NASA was as command pilot for Apollo 1. It would be his last mission. During a preflight launch test, the command module caught fire, killing Grissom and two other astronauts, Ed White and Roger Chaffee. Their fellow scientists and astronauts were deeply saddened by the accident but knew the best way to honor their fallen friends was to complete the project. NASA scientists learned a great deal from the tragedy and were able to make later spacecraft much safer. The Apollo program eventually went on to land the first man on the moon. Gus Grissom's contributions to the space program helped to make this historic step in space exploration possible. He will always be remembered for his courageous work as one of America's first astronauts.

A Marine helicopter attempted to lift the *Liberty Bell 7* out of the water, but dropped the spacecraft because it was too heavy. The capsule sank to the ocean floor. It was eventually recovered from 15,000 feet below the surface of the Atlantic on July 20, 1999. PHOTO CREDIT: NASA

Extending Experience: The Liberty Bell 7 and Gus Grissom

Gus Grissom's flight on the *Liberty Bell 7* made history in many ways. It was only the second piloted flight in the U.S. space program, and tested the program's ability to return a human being safely to Earth. The plan to recover the **space capsule** using U.S. Navy ships and helicopters had been well developed and practiced, but even the best plans can encounter the unexpected. When the hatch of the space capsule blew open prematurely, Gus Grissom's life was at stake. Rescue teams and helicopter crews had to act fast and make split-second decisions.

Use primary sources, such as historic photos, news footage, newspaper articles, illustrations, or books retelling the dramatic story of Grissom's rescue, to inspire student writing. Prompt students to put themselves in the historic moment and develop their own first-person narrative of the event as witnessed by a helicopter pilot, a medic, a ship's captain, or a scientist at mission control.

Top: Gus Grissom's dramactic rescue from the sea. PHOTO CREDIT: NASA

Lower right: Grissom's work in the **Apollo** program helped lead to the first moon landing in 1969. PHOTO CREDIT: NASA

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Experience 2: Famous Flights

Students research and construct a timeline for space flight in the past and add information about future missions.

Above: The Space Shuttle *Discovery*, along with its External Tank and Solid Rocket Boosters, begins the long roll toward Launch Pad 39B at NASA's Kennedy Space Center. The Return to Flight mission, STS-114, launched on July 26, 2005. Discovery's seven crew members flew to the International Space Station, testing out new safety procedures and resupplying the orbital outpost. PHOTO CREDIT: NASA/KSC

Procedures

- Prior to introducing the project, decide on a timeline format you would like to use with students. Suggestions include a digital timeline using programs such as PowerPoint or a physical timeline. If you choose a physical timeline, provide a long piece of paper or sentence strips, or use string to which students can attach event cards. If multiple classes will be completing the physical timeline, consider attaching cards to the timeline with clothespins or binder clips so the timeline can be reset for each class.
- Introduce the lesson by showing students a short video of the International Space Station. NASA offers many videos of the ISS at https://www.nasa.gov/mission_pages/station/videos/index.html
- Ask students to notice as they watch the video what types of innovation they see that may help people living and working in space. Afterward, ask: How has space travel changed since the days of the *Liberty Bell 7* and other early space flights?
- Explain to students that space programs have been an ongoing pursuit by NASA and other countries for many years. Tell students they will explore key events in space history through a space history timeline.
- Place students in small groups for their research. Assign each group a set of years for their research. Suggested ranges are 1900–1949, 1950–1959, 1960–1969, 1970–1979, 1980–1989, 1990–1999, 2000–2009, and 2010–present. For a more in-depth timeline, you may want to encourage students to include both piloted and unpiloted missions to space.
- Encourage students to find 8 to 10 items they believe would be key events to add to the timeline. You may wish to have a discussion with students about what might be considered a key event. For some decades, there will be numerous events.
- Have student use NASA and/or web resources to identify their timeline events. Remind students that when they create their timeline entries, they need to include a description of the event in their own words. Also included in the timeline entry should be a phrase about why this event might be useful for future missions to space.
- If possible, encourage students to include visuals on their timeline entries. Remind students that they should include an image credit for each photo source.
- Once students have created all of their entries, provide an opportunity for them to display or present their timelines.
- After students have had time to examine the timelines created by the class, have students complete a writing assessment. You can either assign a writing task, or allow students to choose one of these:
  - Write a persuasive essay describing what you believe are the top three most important events in the history of space travel.
  - Write a news article about current space travel as though you are a reporter working 20 years from now.

Culminating Experience: Building a Rocket Park

In this culminating experience, students use their historical research and put their math skills to work as they create a model rocket park.

Above: NASA Rocket Park. PHOTO CREDIT: NASA/KSC

- Introduce the culminating experience by explaining to students that rockets were required to take people to space. As bigger and more powerful rockets were developed, people were able to reach new milestones in space travel.
- Assign students to small groups, and assign each group a type of rocket used in space exploration. For examples, see https://spaceflightsystems.grc.nasa.gov/education/rocket/gallery.html and http://www.nasa.gov/sites/default/files/images/125306main_rocket_chart.jpg
- Allow time to research basic age-appropriate information on rocket design. Use the investigation sheet on page 23 to support research and to help with scale drawing.
- Decide on the format for the scale models. Students can construct 2D or 3D models on paper or computer. For a more realistic effect, use large poster paper if completing a 2D model.
- Have students who create digital models place models of other famous objects of different heights beside the rocket models to compare the size of different rockets.
- Introduce the idea of scale to students using a state or local map or a globe. Walk students through the process of finding the map scale. Ask: Why is a map scale useful?
- Explain to students that rockets used in space travel are very large and don't fit in most buildings. In fact, NASA had to build new facilities to assemble rockets because they were so big.
- Tell students they will be creating a model of a rocket park with NASA rockets used to take humans into space.
- Discuss with students the format they will be using, either physical or virtual models. On the board or a computer, show students the dimensions of the Saturn V rocket. Ask students to suggest what might be an appropriate unit to use for a scale model of the rocket. Suggestions might include 1 foot = 1 inch. For a more complex set of calculations, student's models could be 10 feet = 1 inch.
- Assign each group of students a model rocket they should research. Possible rockets include:
  - PGM-11 Redstone
  - Atlas-Agena
  - Titan II
  - Saturn I
  - Saturn IB
  - Saturn V
  - Space Shuttle solid rocket boosters
  - Space Launch System
- Provide students time to create a scale model of their particular rocket. If students are constructing a physical 3D model, provide them with materials such as cardboard, paper, and glue.
- After students have completed their rocket models, explain the purpose of a museum display label. Help students create a label to place next to their rocket when it is displayed. The label should include rocket name, years used in space, and important missions.
- For a rocket celebration, create a space museum using the students' timelines and astronaut trading cards. Group displays together by programs such Mercury or Apollo, or by decades. Invite other classes or parents to view the museum. Students can serve as docents, explaining what they learned about the history of the space program.

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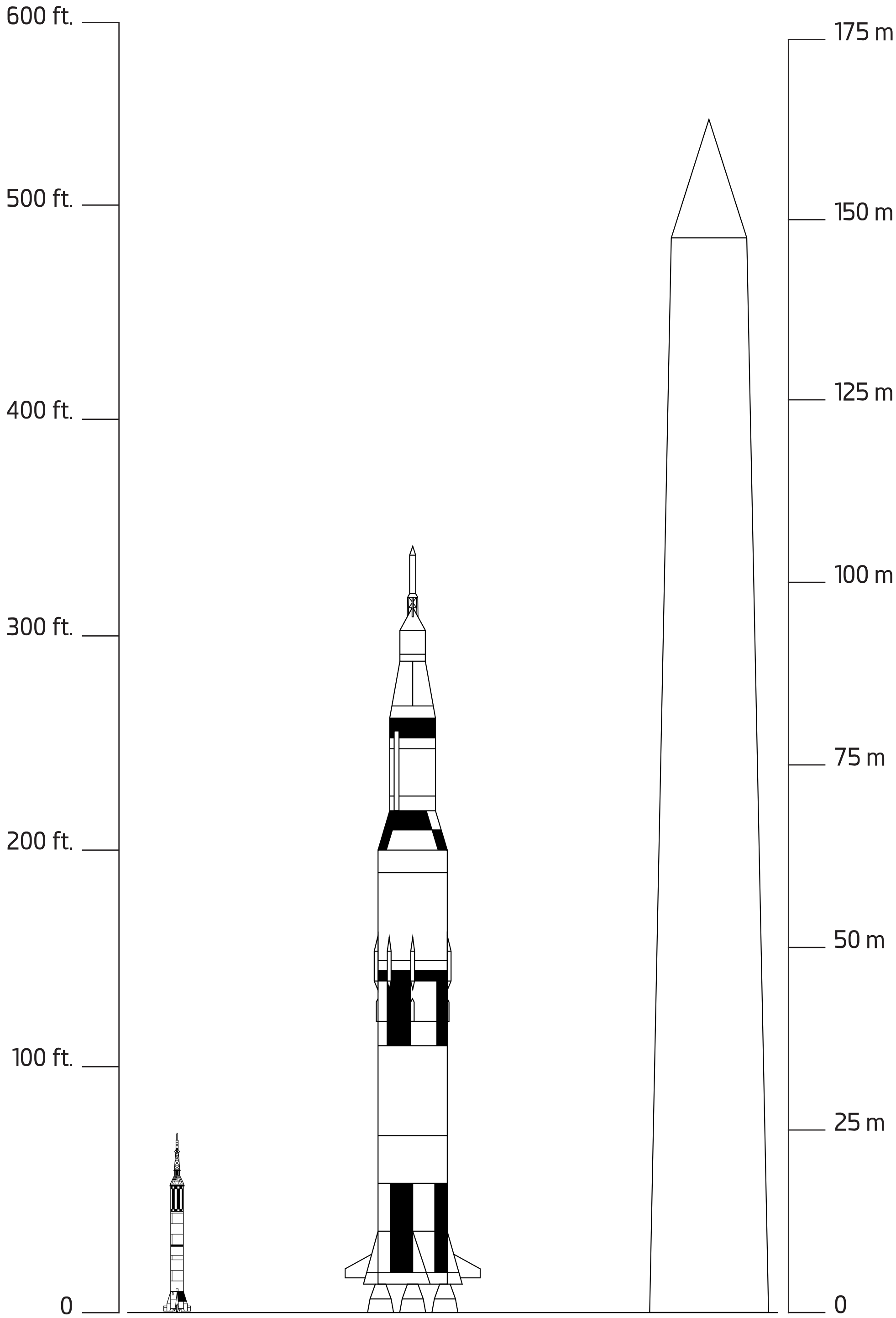
STUDENT HANDOUT



How big is a Mercury-Redstone rocket? Height: 25.41 m (83.38 ft.) Diameter: 1.78 m (5.83 ft.)

How big is a Saturn V rocket? Height: 110 m (363 ft.) Diameter: 10.1 m (33 ft.)

How big is the Washington Monument? Height: 169 m (555 ft.) Obelisk: 16.8 m² (55.5 ft.²) wide at base.

Fun Fact: If you laid a Saturn V rocket on its side, it would be as long as a football field.

Glossary

air: The invisible gaseous matter surrounding Earth, composed primarily of oxygen and nitrogen.

air resistance: The frictional force air exerts against a moving object. The faster an object moves, the greater the air resistance against it.

astronaut: A person trained to travel beyond Earth's atmosphere in a spacecraft.

atmosphere: The blanket of gases extending from the surface of a planet.

drag: The aerodynamic force that opposes a solid object's motion through the air. Drag is generated by every part of a spacecraft.

friction: The resistance to motion of objects or fluids moving against each other.

gravity: The force that attracts an object toward Earth.

kinetic energy: The energy an object possesses because of its motion.

lift: The force that directly opposes the weight of an object in motion and holds the object in the air.

matter: Anything that has mass and takes up space.

orbit: The curved path of a celestial object or spacecraft around a planet, star, or moon.

payload: The load, or weight, carried by a vehicle exclusive of what is necessary for its operation. A rocket's payload may be a space probe or satellite, or a spacecraft carrying humans or other cargo.

physical forces: Push or pull on an object, such as friction or gravity, as a result of its interaction with another object.

potential energy: The energy an object possesses because of its position.

rocket: A self-propelled cylindrical projectile that can be propelled to a great height or distance by the combustion of its contents. NASA rockets are used to carry spacecraft.

space capsule: A small spacecraft (or part of a larger one) that contains the instruments and crew.

spacecraft: A vehicle designed for travel to and/or operation in space beyond Earth's atmosphere or in orbit around Earth.

suborbital: A flight trajectory that does not include a full orbit of Earth or another celestial body.

thrust: The force that moves an object through the air. Thrust overcomes drag.

weight: An object's relative mass, or the quantity of matter contained by an object, resulting in downward force.

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NONFICTION BOOKS FOR STUDENTS

Becker, Helaine, and Brendan Mullan. *Everything Space.* Washington, DC: National Geographic Kids, 2015.

This fun book launches readers from the space they're familiar with on Earth into outer space and among its planets, stars, and more. More than 250 fascinating facts about space and space explorers are illustrated with photos and info-graphics. Suitable for Grades 3 through 7.

Berne, Emma Carlson. *Totally Wacky Facts about Exploring Space.* North Mankato, MN: Capstone, 2015.

How much does a spacesuit weigh? Which astronaut played golf on the moon? Where do astronauts put their dirty underwear? A colorful, contemporary design pulls even the most reluctant readers into this book to learn surprising facts about life in space. Suitable for Grades 3 through 8.

Blobaum, Cindy, and Bryan Stone. *Explore Gravity!* White River Junction, VT: Nomad, 2013.

Students in Grades 3 through 5 will enjoy the 25 easy projects included here that reinforce gravity vocabulary words and provide hands-on STEM activities that use everyday objects to build a deeper understanding of weight, matter, attraction, and gravitational pull.

Brake, Mark. *How to Be a Space Explorer: Your Out-of-This-World Adventure.* Oakland, CA: Lonely Planet, 2014.

For the aspiring astronauts in your classroom, this book presents every-thing they need to know about travel in space: how to navigate the solar system, how to live in microgravity, and how to go to the bathroom while wearing a spacesuit! The astonishing true stories and hundreds of amazing photos are recommended for Grades 3 through 8.

Buckley, James. *Space Heroes: Amazing Astronauts.* New York, NY: DK, 2004.

For students in Grades 3 through 5, this book presents the history of space exploration and the brave astronauts from the United States and Russia who made the first space flights.

Hayden, Kate, and Peter Dennis. *Astronaut: Living in Space.* New York, NY: DK, 2012.

Try this reader with younger students who are still learning to read alone. It's a solid introduction to space travel and working in space, and it's told from a female astronaut's point of view. Photos and information boxes throughout introduce new vocabulary.

Mooney, Carla. *Rocketry: Investigate the Science and Technology of Rockets and Ballistics.* White River Junction, VT: Nomad, 2014.

Students in Grades 3 through 6 will enjoy projects that dive into the science behind rocketry. In addition to 25 hands-on experiments, the book includes back-ground information on the history of rocketry and how rockets are used in the space program.

Wilkinson, Philip. *Spacebusters: The Race to the Moon.* New York, NY: DK, 2012.

For students in Grades 3 through 5 who are learning to read alone, this is a highly engaging story of the United States' race to be the first to send a man to the moon in the 1960s. As with all DK Readers, this book is heavily illustrated and also includes new vocabulary and complex sentences to build literacy skills.

WEBSITES

For Kids – Explore Deep Space. The Coalition for Deep Space Exploration offers a variety of videos, activities, quizzes, images, and links for students in Grades 3 through 8. http://exploredeep-space.com/for-kids/

NASA Knows: History. Students in Grades 5 through 8 can access informational pages on NASA mission programs such as Mercury and Apollo. https://www.nasa.gov/audience/forstudents/5-8/features/nasa-knows/history/index.html

NASA Knows: What Is a Rocket? Developed for students in Grades 5 through 8, this site provides students with basic background on how rockets work. https://www.nasa.gov/audience/forstudents/5-8/features/nasa-knows/what-is-a-rocket-58.html

NASA Astronauts. Find out all about your favorite current and former astro-nauts on this comprehensive site. Each biography includes education, research, and work background. https://www.nasa.gov/astronauts

NASA Project Mercury Page. These web pages describe the United States' first program (1958–1963) to orbit manned spacecraft around Earth, which included Liberty Bell 7. https://www.nasa.gov/mission_pages/mercury/index.html

BOOKS FOR TEACHERS

Boomhower, Ray. *Gus Grissom: The Lost Astronaut.* Indianapolis, IN: Indiana Historical Society Press, 2004.

Part of the Indiana Biography series published by the Indiana Historical Society, this book explores the life of Virgil "Gus" Grissom from his childhood in Mitchell, Indiana, to his career as one of the first men in space.

Carpenter, M. Scott et al. *We Seven.* New York, NY: Simon and Schuster, 1962.

Writing by the original seven Mercury astronauts, this book includes firsthand accounts of the early years of the U.S. space program.

Shetterly, Margot Lee. *Hidden Figures.* New York, NY: William Morrow, 2016.

During the first space launches, NASA relied on gifted female mathematicians to complete complex calculations needed to launch rockets into space. This book follows the stories of several African American "human computers" and explores their role in the U.S. space program.

Leopold, George. *Calculated Risk: The Supersonic Life and Times of Gus Grissom.* West Lafayette, IN: Purdue University Press, 2016

This biography uses extensive interviews with families and fellow astronauts to explore the life of astronaut Gus Grissom. The book begins with Gus's early years in Mitchell, Indiana, and follows him to Purdue and eventually the U.S. space program.

Indiana Standards

Science

Process Standards for the Nature of Science (Grades 4–8) include:

- Constructing and performing investigations
- Analyzing and interpreting data
- Constructing explanations and designing solutions
- Engaging in argument from evidence
- Obtaining, evaluating, and communicating information

Science and Engineering Process Standards

- SEPS.1 Posing questions (for science) and defining problems (for engineering)
- SEPS.2 Developing and using models and tools
- SEPS.3 Constructing and performing investigations
- SEPS.4 Analyzing and interpreting data
- SEPS.6 Constructing explanations (for science) and designing solutions (for engineering)
- SEPS.8 Obtaining, evaluating, and communicating information

Physical Science

4.PS.1 Investigate transportation systems and devices that operate on or in land, water, air and space and recognize the forces (lift, drag, friction, thrust and gravity) that affect their motion.

4.PS.2 Investigate the relationship of the speed of an object to the energy of that object.

6.PS.2 Describe the motion of an object graphically showing the relationship between time and position.

6.PS.3 Describe how potential and kinetic energy can be transferred from one form to another.

7.PS.4 Investigate Newton's first law of motion (Law of Inertia) and how different forces (gravity, friction, push and pull) affect the velocity of an object.

Literacy in Science/Technical Subjects

6-8LST1.1 Read and comprehend science and technical texts within a range of complexity appropriate for Grades 6–8 independently and proficiently by the end of Grade 8.

6-8LST1.2 Determine the central ideas or conclusions of a text; provide an accurate, objective summary of the text.

6-8.LST.3.1 Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to Grades 6–8 texts and topics.

6-8LST3.2 Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks.

Mathematics

5.AT.1 Solve real-world problems involving multiplication and division of whole numbers (e.g., by using equations to represent the problem). In division problems that involve a remainder, explain how the remainder affects the solution to the problem.

5.M.1 Convert among different-sized standard measurement units within a given measurement system, and use these conversions in solving multi-step real-world problems.

6.GM.1 Convert between measurement systems (English to metric and metric to English) given conversion factors, and use these conversions in solving real-world problems.

7.C.6 Use proportional relationships to solve ratio and percent problems with multiple operations, such as the following: simple interest, tax, markups, markdowns, gratuities, commissions, fees, conversions within and across measurement systems, percent increase and decrease, and percent error.

7.GM.3 Solve real-world and other mathematical problems involving scale drawings of geometric figures, including computing actual lengths and areas from a scale drawing. Create a scale drawing by using proportional reasoning.

English Language Arts

Reading: Nonfiction

4.RN.1 Read and comprehend a variety of nonfiction within a range of complexity appropriate for Grades 4 and 5. By the end of Grade 4, students interact with texts proficiently and independently at the low end of the range and with scaffolding as needed at the high end.

4.RN.3.1 Apply knowledge of text features to locate information and gain meaning from a text (e.g., *charts, tables, graphs, headings, subheadings, font/format*).

4.RN.4.2 Combine information from two texts on the same topic in order to demonstrate knowledge about the subject.

5.RN.1 Read and comprehend a variety of nonfiction within a range of complexity appropriate for Grades 4 and 5. By the end of Grade 5, students interact with texts proficiently and independently.

5.RN.3.1 Apply knowledge of text features in multiple print and digital sources to locate information, gain meaning from a text, or solve a problem.

5.RN.4.2 Combine information from several texts or digital sources on the same topic in order to demonstrate knowledge about the subject.

6.RN.1 Read a variety of nonfiction within a range of complexity appropriate for Grades 6–8. By the end of

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Grade 6, students interact with texts proficiently and independently at the low end of the range and with scaffolding as needed at the high end of the range.

7.RN.1 Read a variety of nonfiction within a range of complexity appropriate for Grades 6–8. By the end of Grade 7, students interact with texts proficiently and independently at the middle of the range and with scaffolding as needed for texts at the high end of the range.

Reading: Vocabulary

4.RV.1 Build and use accurately general academic and content-specific words and phrases.

5.RV.1 Build and use accurately general academic and content-specific words and phrases.

6.RV.1 Acquire and use accurately grade-level appropriate general academic and content-specific words and phrases; gather vocabulary knowledge when considering a word or phrase important to comprehension or expression.

6.RV.3.2 Determine the meaning of words and phrases as they are used in a nonfiction text, including figurative, connotative, and technical meanings.

7.RV.1 Acquire and use accurately grade-appropriate general academic and content-specific words and phrases; gather vocabulary knowledge when considering a word or phrase important to comprehension or expression.

7.RV.3.2 Determine the meaning of words and phrases as they are used in a nonfiction text, including figurative, connotative, and technical meanings; analyze the impact of a specific word choice on meaning and tone.

Writing

4.W.5 Conduct short research on a topic.

5.W.5 Conduct short research assignments and tasks on a topic.

6.W.1 Write routinely over a variety of time frames for a range of tasks, purposes, and audiences; apply reading standards to support analysis, reflection, and research by drawing evidence from literature and nonfiction texts.

7.W.1 Write routinely over a variety of time frames for a range of tasks, purposes, and audiences; apply reading standards to support analysis, reflection, and research by drawing evidence from literature and nonfiction texts.

7.W.5 Conduct short research assignments and tasks to build knowledge about the research process and the topic under study.

National Standards

Next Generation Science Standards

4-PS3-1 Use evidence to construct an explanation relating the speed of an object to the energy of that object.

4-PS3-4 Apply scientific ideas to design, test, and refine a device that converts energy from one form to another.

5-PS2-1 Support an argument that the gravitational force exerted by Earth on objects is directed down.

3-5-ETS1-1 Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.

3-5-ETS1-2 Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.

3-5-ETS1-3 Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.

MS-PS2-1 Apply Newton's Third Law to design a solution to a problem involving the motion of two colliding objects.

MS-PS2-2 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-PS3-1 Construct and interpret graphical displays of data to describe the relationships of kinetic energy to the mass of an object and to the speed of an object.

MS-PS3-5 Construct, use, and present arguments to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object.

MS-ETS1-1 Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant principles and potential impacts on people and the natural environment that may limit possible solutions.

MS-ETS1-2 Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

MS-ETS1-3 Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

MS-ETS1-4 Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.