Science and Innovation

A Boeing/Teaching Channel Partnership

MISSION TO MARS

Teacher Handbook

Teaching Channel

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The Boeing Company and Teaching Channel teamed in 2014 to create problem-based curricula inspired by science and engineering innovations at Boeing and informed by globally competitive science, math, and literacy standards. This two-week curriculum module and the companion video series are designed to help teachers in grades 4–8 integrate the engineering design process, aligned to science standards, into their classrooms. The collection of Teaching Channel curricula is one part of a collection of K–12 education resources intended to mark Boeing's centennial anniversary and prepare the next generation of innovators.

The materials created by this collaboration were taught by the authoring teachers in Puget Sound and Houston, and in 2015, a second group of teachers taught the lessons and provided feedback to improve the modules. As part of a second iteration of the modules, the senior science editor at Teaching Channel worked with Achieve to integrate the teachers' feedback while more closely aligning the modules to The Next Generation Science Standards (NGSS) call for significant shifts in the way science is taught and learned. In 2016, a panel of science experts from around the country convened for a two-day training with Achieve to learn how to incorporate the Educators Evaluating the Quality of Instructional Products (EQuIP) Rubric for Science. As part of the iterative process of improvement, the expert reviewers then completed an EQuIP Rubric for each module. Teaching Channel's senior science editor combined the reviewers input to create a third iteration of the modules that promotes a close alignment to standards while honoring the original expertise of the authoring teachers and engineers.

Partners at both the University of Washington's Institute for Science and Math as well as Educate Texas were instrumental in teacher recruitment for this project. Teachers and engineers in the project received training from learning scientists at the University of Washington's Institute for Science and Math Education, led by Dr. Philip Bell. He and his team also created a design template to support curricula development to promote alignment to standards and research on science learning and teaching.

Please note that the resource links provided in these lessons are intended as helpful illustrations to teachers adapting the unit for their classrooms and are not an endorsement of specific products or organizations.

Mission to Mars

Background and Overview

In this module, students simulate a launch sequence for a manned mission to Mars. In preparation for the mission, students engage with several small missions (design problems) related to Earth and the solar system, interdependent relationships in ecosystems, energy transfer, and forces. Mission to Mars features a final mission to simulate a rocket launch from Earth and a landing on Mars. Students design, build, and launch a bottle rocket, testing and documenting variables in its flight. They design and test a nose cone for payload and crew so it will detach and safely deliver a lander device to the planet surface.

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Module Overview

In Mission to Mars, students plan a manned voyage to Mars with four main mission elements. Each mission element incorporates a different middle school science idea. The culminating design problem helps students grow in their understanding of forces.

Mission 1: This mission needs to travel the 33+ million miles it will take to reach Mars when the two planets are at their closest. Students construct a basic model of the solar system to determine the distance from Earth to Mars. Students build solar sails, which will be used to span the distance. Along the way, they learn about scale properties of objects in our solar system.

Mission 2: Astronauts, like all living things, have basic needs for survival. The students take these needs into account as they design a habitat module for a multi-month stay on Mars. They design either a habitat for life in zero gravity as they travel to Mars, or a habitat to suit the astronaut's life on Mars' surface. As part of the design process, students learn about interdependent relationships in ecosystems.

Mission 3: On the mission to Mars, astronauts may experience extreme temperatures. To stay alive, astronauts must have ways to control their body temperature and the temperature of their habitat. Students design a temperature control system for space suits. Along the way, students learn about energy transfer.

Final Mission: To get to Mars, students need to design a rocket capable of making the journey. Once the mission arrives at Mars, the astronauts and their equipment need to land safely on the planet. Students construct a rocket with a payload section that detaches, as well as a device to help the cargo or crew to land safely on the red planet. Students design, build, test, and remodel their devices using the data they gather from their launches and landings.

Mission to Mars

Background and Overview

Engineering Design in the Module

The curriculum features a combination of three small design problems and one large design problem. In the final mission, students simulate a rocket launch from Earth and a landing on Mars. Students design, build, and launch a bottle rocket, documenting and testing variables in its flight. This includes designing and testing a nose cone that can accommodate both payload and crew. The design for the nose cone must be constructed so that it detaches and safely delivers a lander device to the planet surface.

Sequencing

Mission to Mars is intended as a middle school module that can be used at various points throughout the development of MS-ESS1-3 (Earth and the Solar System), MS-LS2-1 (Interdependent Relationships in Ecosystems), MS-PS3-3 (Energy Transfer), MS-PS2-2 (Forces and Interactions), MS-ETS1-1, MS-ETS1-3, and MS-ETS1-4. The small design problems included on Days 2 through 4 are designed to enhance student work with MS-ESS1-3, MS-LS2-1, and MS-PS3-3. The large design problem on Days 1 and 5 through 10 is designed to help students make progress on MS-PS2-2, MS-ETS1-1, MS-ETS1-3, and MS-ETS1-3.

One option is to place this module after the development of MS-ESS1-3, MS-LS2-1, and MS-PS3-3, but before students have made significant progress on MS-PS2-2. A second option is to use the module at various points throughout the year as students work on each performance expectation. For instance, Day 3 could be used as students work with MS-LS2-1 and Day 4 could be used several weeks later as students work with MS-PS3-3.

For Days 1 and 5 through 10, Students should have already mastered the *performance expectations*, *disciplinary core ideas*, *science and engineering practices*, ***and*** *crosscutting concepts* included in 5th-grade Physical Science and Engineering Design.

- Students should have mastered 3-PS2-1 and 3-PS2-2, which address the effects of balanced and unbalanced forces on the motion of an object. Students should already have made significant progress with MS-PS2-4 and figured out that gravitational interactions are attractive and depend on the masses of interacting objects.
- Beyond the aforementioned performance expectations, students should have already demonstrated deep conceptual understanding for all of the 3-5 Engineering Design performance expectations and associated science and engineering practices, disciplinary core ideas, and crosscutting concepts.
- Students should have made grade-appropriate progress on the following science and engineering practices: Asking Questions and Defining Problems, Developing and Using Models, Analyzing and Interpreting Data, and Constructing Explanations and Designing Solutions.
- Students should also have made grade-appropriate progress on the following crosscutting concepts: Influence of Engineering, Technology, and Science on Society and the Natural World, Scale, Proportion, and Quantity, Energy and Matter, and Cause and Effect.

Performance Expectations

MS-ETS1-1. 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.

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.

MS-ESS1-3. Analyze and interpret data to determine scale properties of objects in the solar system.

MS-LS2-1. Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem.

MS-PS3-3. Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.

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.

Mission to Mars

Connecting to the Next Generation Science Standards

The lessons and activities outlined in this module are one step in the learning progression toward reaching the performance expectations listed below. Additional supporting lessons and activities will be required.

Specific connections between the performance expectations, three dimensions, and classroom activities are articulated at the beginning of every lesson.

Important Note

The grade level and associated performance expectations, disciplinary core ideas, science and engineering practices, and crosscutting concepts identified throughout the module were selected to align with the Next Generation Science Standards. In classrooms using local or state standards, this module may fall within a different grade band and may address different standards. Teachers should adapt this module to meet local and state needs.

Furthermore, teachers should adapt the module to extend student learning to additional grade levels, performance expectations, disciplinary core ideas, science and engineering practices, and crosscutting concepts to meet student needs.

Helpful Tip

The small design problems included in Days 2 through 4 are designed to enhance student work with MS-ESS1-3, MS-LS2-1, and MS-PS3-3. The large design problem on Days 1 and 5 through 10 is designed to help students make progress on MS-PS2-2, MS-ETS1-3, and MS-ETS1-3.

This module can be placed after the development of MS-ESS1-3, MS-LS2-1, and MS-PS3-3 but before students have made significant progress on MS-PS2-2. Alternatively, the learning experiences in this module could be used at various points throughout the year as students work on each performance expectation. For instance, Day 3 could be used as students work with MS-LS2-1, and Day 4 could be used several weeks later as students work with MS-PS3-3.

Performance Expectations

The lessons and activities in this module contribute toward building understanding of the following *engineering* performance expectations:

MS-ETS1-1. 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.

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.

Days 2 through 4 can be used to enhance the development of the following *life science* and *earth and space science* performance expectations:

MS-ESS1-3. Analyze and interpret data to determine scale properties of objects in the solar system.

MS-LS2-1. Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem.

MS-PS3-3. Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.

Days 5 through 10 contribute toward building understanding of the following *physical science* performance expectations:

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.

Dimension	NGSS Element
Science and Engineering Practices	**Asking Questions and Defining Problems** • Define a design problem that can be solved through the development of an object, tool, process, or system and includes multiple criteria and constraints, including scientific knowledge that may limit possible solutions. **Developing and Using Models** • Develop a model to generate data to test ideas about designed systems, including those representing inputs and outputs. • Use and/or develop a model of simple systems with uncertain and less predictable factors. **Analyzing and Interpreting Data** • Analyze and interpret data to determine similarities and differences in findings. **Constructing Explanations and Designing Solutions** • Apply scientific ideas or principles to design, construct, and test a design of an object, tool, process, or system.
Disciplinary Core Ideas	**ETS1.A: Defining and Delimiting Engineering Problems** • The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge likely to limit possible solutions. **ETS1.B: Developing Possible Solutions** • A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. • Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. • Models of all kinds are important for testing solutions. **ETS1.C: Optimizing the Design Solution** • Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design. • The iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution. **PS2.A: Force and Motion** • The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion. ***ESS1.B: Earth and the Solar System**

	• The solar system consists of the Sun and a collection of objects, including planets, their moons, and asteroids that are held in orbit around the Sun by its gravitational pull on them. ***LS2.A: Interdependent Relationships in Ecosystems** • Organisms, and populations of organisms, are dependent on their environmental interactions both with other living things and with nonliving factors. ***PS3.B: Conservation of Energy and Energy Transfer** • Energy is spontaneously transferred out of hotter regions or objects and into colder ones.
Crosscutting Concepts	**Influence of Science, Engineering, and Technology on Society and the Natural World** • The use of technologies and limitations on their use are driven by individual and societal needs, desires, and values; by the findings of scientific research; and by differences in such factors as climate, natural resources, and economic conditions. ***Scale, Proportion, and Quantity** • Time, space, and energy phenomena can be observed at various scales using models to study systems that are too large or too small. ***Cause and Effect** • Cause and effect relationships may be used to predict phenomena in natural or designed systems. ***Energy and Matter** • The transfer of energy can be tracked as energy flow through a designed or natural system.

** Addressed in Lessons 2 through 4.*

Connections to the Common Core State Standards

In addition to connecting to the *Next Generation Science Standards*, this module can support student growth in multiple *Common Core State Standards.* This module can be easily adapted to support growth in the following standards:

English Language Arts

- CCSS.ELA-Literacy.W.8.1: Write arguments to support claims with clear reasons and relevant evidence.
- CCSS.ELA-Literacy.SL.8.3: Delineate a speaker's argument and specific claims, evaluating the soundness of the reasoning and relevance and sufficiency of the evidence and identifying when irrelevant evidence is introduced.
- CCSS.ELA-Literacy.SL.8.4: Present claims and findings, emphasizing salient points in a focused, coherent manner with relevant evidence, sound valid reasoning, and well-chosen details; use appropriate eye contact, adequate volume, and clear pronunciation.

Mathematics

- CCSS.Math.Content.6.SP.A.2: Understand that a set of data collected to answer a statistical question has a distribution which can be described by its center, spread, and overall shape.
- CCSS.Math.Content.6.SP.A.3: Recognize that a measure of center for a numerical data set summarizes all of its values with a single number, while a measure of variation describes how its values vary with a single number.

Mission to Mars

Module Storyline

This module is designed as a coherent set of learning experiences that motivate a progressive building of understanding of disciplinary core ideas, science and engineering practices, and crosscutting concepts. The following storyline demonstrates how ideas are built across the lessons. You may find it helpful to continually reference the storyline to help frame lessons.

Driving Question:
How can we plan a mission to Mars?

Question/Problem	What Students Are Doing	What Students Figure Out
How can we design a spacecraft capable of making the journey to Mars?	Students use a solar system model to determine the distance to Mars. Students design solar sails to be used during the journey.	The trip to Mars should be made when Earth and Mars are closest. Solar sails can be used but must take into account the distance between Mars and the Sun.
How can we design a habitat for astronauts to live on Mars?	Students design a habitat of living and nonliving factors for astronauts on Mars.	Habitats must incorporate multiple living and nonliving components necessary for human survival.
How can we design a system to help with temperature control on Mars?	Students design and justify a temperature-control device to use in space suits.	Energy can be transferred in systems. Energy transfer can be used to keep astronauts cool.
How can we design a rocket to leave Earth and land on Mars?	Students design, test, and revise models for rockets.	A rocket's motion depends on the sum of the forces acting on it.

Mission to Mars

Day 1: Introduction to the Mission to Mars

Grade Level	Middle School
Lesson Length	One 50-minute session

Lesson Overview

In this introductory lesson, students explore and study a brief history of space travel and some of the engineering challenges that have emerged over time. They learn that the next frontier for space travel is a manned mission to Mars. Students are presented with the design challenge and the mission elements. Students brainstorm initial ideas regarding each mission element. Students write a letter to NASA explaining their current understanding and thinking related to the design problems involved in sending a manned Mission to Mars.

Connecting to the Next Generation Science Standards

On Day 1, students make progress toward developing understanding across the following three dimensions:

- Science and Engineering Practices: Asking Questions and Defining Problems
- Disciplinary Core Ideas: ETS1.A Defining and Delimiting Engineering Problems
- Crosscutting Concepts: Influence of Science, Engineering, and Technology on Society and the Natural World

In the following table, the specific components addressed in this lesson are underlined and italicized. The specific connections to classroom activity are stated.

Performance Expectations		
This lesson contributes toward building understanding of the following *engineering* performance expectation: MS-ETS1-1. *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.		
Specific Connections to Classroom Activity In this lesson, students are introduced to a design problem. They brainstorm criteria and constraints for different elements of the design problem. Students write a letter to NASA to explain what they believe a successful solution would entail. At this point, students have yet to incorporate relevant scientific principles into the criteria and constraints, but they should consider potential impacts on people and the natural environment.		
Dimension	**NGSS Element**	**Connections to Classroom Activity**
Science and Engineering Practices	Asking Questions and Defining Problems • *Define a design problem that can be solved through the development of an object, tool, process, or system and includes multiple*	After being given the overall design problem, students define the criteria, constraints, and possible solutions. In future lessons, students incorporate

	criteria and constraints, including scientific knowledge that may limit possible solutions.	science ideas to further define and solve the design problem.
Disciplinary Core Ideas	**ETS1.A: Defining and Delimiting Engineering Problems** • *The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful.* Specification of constraints includes consideration of scientific principles and other relevant knowledge likely to limit possible solutions.	Students work to precisely define a design task for different elements of a mission to Mars. Students consider the criteria and constraints, but don't yet incorporate the science ideas related to the design problem.
Crosscutting Concepts	**Influence of Science, Engineering, and Technology on Society and the Natural World** • *The use of technologies and limitations on their use are driven by individual and societal needs, desires, and values*; by the findings of scientific research; and by differences in such factors as climate, natural resources, and economic conditions.	After exploring the history of space travel, students consider the reasons why space travel to Mars may be desirable by individuals and society.

Basic Teacher Preparation

To prepare for this lesson, pre-read a brief history of spaceflight. Be ready to summarize it for students and translate its events to a timeline. The same information can be displayed with a projector, or students can view the pages on laptops or tablet computers.

Required Preparation	Links/Additional Information
❑ Gather or purchase the required materials for the lesson	Refer to the Materials List below
❑ Ensure technology is available to project information from the recommended websites, or print and copy relevant information for students to place in their notebooks	Refer to the Suggested Teacher Resources at the end of this lesson
❑ Review suggested teacher preparation resources to prepare for the history of space flight mini-lesson and the introduction of different engineering fields	Refer to the Suggested Teacher Resources at the end of this lesson

Materials List

Item	Description/Additional Information	Quantity	Where to Locate/Buy
Computer (or computers) with Internet access and a projector		1 per class for projecting to entire class, or access to a computer lab	Available in most schools
Roll of butcher paper		1 per class	Available in most schools

Day 1: Introduction to the Mission to Mars

Introduction (5 minutes)

Kick off the module with a brief class discussion. Invite students to share times they have gone on a long trip. Ask:

- *What did you have to do to prepare for the trip?*
- *What did you take?*
- *How much money do you think it cost?*

Give students 5 minutes to answer this prompt in their science notebooks, *If you knew you were going to be away from home for 2 years, what would you do to prepare?*

Whole Group Discussion: History of Space Travel (10 minutes)

Prepare and share a brief history of space flight. One good way to help students understand such a continuum is to put the dates and activities you select on a long sheet of butcher paper, creating a timeline of the highlights of space travel for the front of the classroom. Refer to the milestones while you speak.

Ask students to note the year of their birth on the timeline. In later lessons, the birthdates of students' parents and grandparents can also be entered, bringing a sense of relevancy to this progression. Point out how much significant space exploration has happened in the past 100 years.

Web Resources

These websites can provide useful information about key dates and milestones to aid in preparation:

- Aerospace [Web Link]
- Space.com Timeline [Web Link]

Whole Group Discussion: Mission to Mars (15 minutes)

Show the Boeing film Let's Go Beyond Earth. Ask students to discuss in small groups the reasons for space exploration. Allow approximately 5 minutes for group discussion and a similar amount of time for class discussion. Follow the first video with the second Boeing film, The Path to Mars. Discuss with students the technology needed for the manned **Mission to Mars**.

Video Link

- Let's Go Beyond Earth [YouTube Link]
- The Path to Mars [YouTube Link]

Transition from this discussion to an introduction of the module design problem, *How can we plan a mission to Mars?* Tell students that they will be the engineers and scientists working on the first manned mission to Mars (reference The Path to Mars video). To prepare for the challenge,

students engage in a first draft Mission to Mars. In this module, students consider multiple aspects of the mission. Students develop a mission plan to present to NASA. The mission plan includes the following:

Mission Elements

- Leaving Earth (Rocket)
- Landing on Mars (Rocket)
- Traveling to Mars
- Living on Mars
- Temperature Control on Mars

As students plan the mission to Mars, they engage in the Engineering Design Process (Appendix A). Introduce students to the Engineering Design Process by reviewing key elements. Be sure to mention that the engineering design process is not a linear process. Rather, scientists and engineers engage in all of the steps, often jumping between steps.

NGSS Key Moment

Engineers often refer to the **engineering design process** when they discuss their work. In the NGSS, the Science & Engineering Practices are used in place of the engineering design process. Students should understand that the engineering design process is not linear in practice. Rather, engineers engage in all of the steps, often jumping between steps. Students may want to think of the engineering design process as a web of practices.

Design Work: Defining the Problem (15 minutes)

To design an effective solution, students must understand the elements of the design problem. For each design problem (leaving Earth, landing on Mars, traveling to Mars, living on Mars, and temperature control on Mars), have students brainstorm a list of criteria and constraints for the design problem. Prompt students by asking, *What would a successful design solution include?* Have students brainstorm a list of possible solutions.

Tell students their client, NASA, must know they understand the design problem. Have students write a letter to NASA explaining their understanding of the design problem. In the letter, students should start by explaining the individual and societal needs that drive the mission to Mars. Next, students should include criteria, constraints, and possible solutions for all of the mission elements. Finally, students should discuss what a successful design solution would entail to meet all of the Mission Elements.

NGSS Key Moment

The letter to NASA can be used to formatively assess student progress on MS-ETS1-1. In the letter, students should define the design problem, include criteria and constraints, and propose initial solution ideas. Be sure to emphasize the connection between space travel and individual or societal needs.

Lesson Close (5 minutes)

Have students share their letters with a classmate. As students share, they should provide kind, specific, and helpful feedback to their classmates. All feedback should relate to defining the problem, outlining criteria and constraints, and incorporating societal needs driving the manned mission to Mars.

Homework

Have students continue to work on their letters for homework. They should revise their letters based on their discussions with their classmates.

Assessment Opportunities

The letter to NASA explaining the criteria, constraints, individual and societal needs driving the mission, and possible solutions for the Mission Elements can be used to formatively assess students understanding of the design problem. Read the letters to determine whether concepts from Day 1 should be revisited or expanded on. Reference Appendix B for suggestions for meeting the needs of all learners.

Community Connections

Identify and investigate local firms that rely on engineering and engineers. Share some examples of familiar companies with students. Consider inviting an engineer to visit the class to share his or her experiences and to help with the design problems.

Suggested Teacher Resources

Engineering Design Process	Mission to Mars Teacher Handbook, Appendix A
Meeting the Needs of All Learners	Mission to Mars Teacher Handbook, Appendix B
Aerospace	[Web Link]
Space.com Timeline	[Web Link]
Let's Go Beyond Earth	[YouTube Link]
The Path to Mars	[YouTube Link]

Mission to Mars

Day 2: Mission #1—Travel to Mars

Grade Level	Middle School
Lesson Length	One 50-minute session

Lesson Overview

In this lesson, students study interplanetary distances and understand why getting to Mars takes a long time. They also learn about some basic properties of the Sun and explore how these properties might provide propulsion for spacecraft. Students manipulate a basic model of relative distances for the inner planets and make a simple model of a spacecraft with a solar sail.

Connecting to the Next Generation Science Standards

Day 2 can be used to *enhance* progress toward developing understanding across the following three dimensions:

- Science and Engineering Practices: Analyzing and Interpreting Data
- Disciplinary Core Ideas: ESS1.B: Earth and the Solar System
- Crosscutting Concepts: Scale, Proportion, and Quantity

Day 2 is best taught in tandem with other lessons relating to ESS1.B.

In the following table, the specific components addressed in this lesson are underlined and italicized. The specific connections to classroom activity are stated.

Performance Expectations		
This lesson can be used to enhance the development of the following *earth and space science* performance expectations: MS-ESS1-3. Analyze and *interpret data to determine scale properties of objects in the solar system*.		
Specific Connections to Classroom Activity In this lesson, students build a scale model of the solar system. Students use the scale model to figure out what the sun might look like from Mars. Students use this understanding in their construction of solar sails, a technology designed to help the crew travel from Earth to Mars.		
Dimension	**NGSS Element**	**Connections to Classroom Activity**
Science and Engineering Practices	**Analyzing and Interpreting Data** • Analyze and *interpret data to provide evidence for phenomena.*	Students use a solar system model calculator to determine scaled distances from the Sun to Earth and Mars. Students interpret the output from the calculator to provide evidence for the relative distances between the planets.
Disciplinary Core Ideas	**ESS1.B: Earth and the Solar System** • *The solar system consists of the Sun and a collection of objects, including planets, their*	Students construct a scale model of the solar system that includes the Sun and

	moons, and asteroids that are held in orbit around the Sun by its gravitational pull on them.	some of the planets. Students consider planetary orbits around the Sun.
Crosscutting Concepts	**Scale, Proportion, and Quantity** • *Time, space,* and energy *phenomena can be observed at various scales using models to study systems that are too large* or too small.	As students build a scale model of the solar system, they work with the idea of using various scales to observe space.

Basic Teacher Preparation

This is a good time to think about student groupings for design teams. Assign teams of 3 or 4 students per team. Plan to build a solar distance model ahead of time in order to assist students with their own. Additionally, precut the cardstock and Mylar, and glue the coffee stirrers for the solar sails model activity. Build one solar sails model as a class example.

Required Preparation	Links/Additional Information
❑ Gather or purchase the required materials for the lesson	Refer to the Materials List below
❑ Ensure that technology is available to project or allow students to access the recommended websites	Refer to the Suggested Teacher Resources at the end of this lesson
❑ Build a solar sails spacecraft model in advance	Refer to the Solar Sails Spacecraft Model section in this lesson
❑ Review suggested teacher preparation resources in advance	Refer to the Suggested Teacher Resources at the end of this lesson

Materials List

Item	Description/Additional Information	Quantity	Where to Locate/Buy
Computer (or computers) with Internet access and a projector		1 per class for projecting to entire class, or access to a computer lab	Available in most schools
Model of solar system distances	Each set includes: • Small Styrofoam ball • Tape measures • Thin string (not yarn) • 5 soda can tabs • 5 pony beads • Scissors • Bamboo skewer • Masking tape	1 set per student	Soda can tabs, string, masking tape, tape measures, scissors, and permanent markers available in most schools, or bring from home. Other materials available at craft stores or online: • Pony beads [Web Link]

	• Permanent marker		• Styrofoam balls [Web Link] • Bamboo skewers [Web Link]
Model of solar sails on spacecraft	Materials include: • Scissors • Water-based glue • Tape • Light cardstock, each sheet cut into 4 pieces • Gold or silver Mylar film cut into 15 sq. cm. • 2 coffee stirrers, hot-glued into an X shape	Enough per student or per team	Scissors, glue, tape, and cardstock available in most schools, or bring from home. Gold or silver Mylar, and coffee stirrers, are available at craft stores or online: • Mylar [Web Link] • Coffee stirrers [Web Link]

Day 2: Mission #1—Traveling to Mars

Introduction (5 minutes)

Engage students by asking them to think about the farthest distance that they have ever traveled from home. If desired, show several examples on a map, and have students explain how long it took to get to each place.

Have students contrast those distances with the actual distances from the Sun to the Earth (92,960,000 miles) and from the Sun to Mars (141,600,000 miles). Have students look up the actual distances on a site such as the Exploratorium's Build a Solar System page. Compare the scales of the different systems (on Earth and in the solar system).

Web Resource

- Exploratorium's Build a Solar System page [Web Link]

Investigation: How Far Away Is Mars? (20 minutes)

Ask students to think about the distance between Earth and Mars. Compare and contrast this distance with the distance between Earth and the Sun. Ask students, *Do you think the distance between Earth and Mars is always the same?*

Tell students that the goal of the next investigation is to figure out how far the four-person crew must travel to get from Earth to Mars.

To do so, students use the materials listed in Day 2's Materials List to make a model showing the relative distances in our solar system. The directions are as follows:

Important Note

Ideally, students should create their own models, but a demonstration model can be made ahead of time instead, if desired.

Relative Distance Model

1. Access the Build a Solar System page. In the Solar System Model table, enter 1 in the red or green cell, and locate the scaled orbit radius to find the scaled distance for each planet from the Sun to use in the model.
2. Engage students in a class discussion about scale and proportion related to the solar system model calculator. Have students explain how the calculator works to help the class build a solar system.
3. Assign a planet (only Mercury through Mars or Jupiter) to each team. Ask students if they know why they will not be cutting string for the other planets. Explain that the classroom is probably not large enough for the string lengths. Relate the discussion to the ideas of scale and proportion.
4. Give each team a spool of string and have them tie an end to their pony bead. Then, attach a piece of tape to the string, labeled with the planet's name.

5. Have each team use the website's table to determine the length of the piece of string to cut for their planet's distance from the Sun (scaled orbit radius). Add 1 extra centimeter to allow for tying off. Tie this end through the opening in the soda can tab.
6. Pierce the Styrofoam Sun model with a bamboo skewer, and then put the soda can tabs over the tip of the skewer where it exits through the top or bottom of the "Sun." Each planet should have one student handler.
7. Ask students to line up their planets, while you or a student holds the Sun. Explain that the planets really revolve around the equator of the Sun.
8. Demonstrate that if the planets were lined up, Earth and Mars are relatively close. Ask students to manipulate the model to show how far apart Earth and Mars could be at their farthest distance. Access The Planets Today website to demonstrate how far apart Earth and Mars are by showing students their relative positions in real time. This exercise helps students internalize relative distances in the solar system between and among planets.

Extension

As an optional extension, have students figure out the scaled size of each planet. Use clay rather than pony beads.

Extension

Consider discussing **revolution** and **rotation**, which can be difficult concepts for middle school students to understand.

Web Resources

- The Planets Today [Web Link]

To conclude the lesson, lead a discussion about when (with respect to planet orbits, as students may not know exact timing) they think the mission to Mars should take place. Students should provide evidence from the modeling demonstration to back up their claim.

Next, pose the question, *What do you think the Sun looks like from Mars?*

Instruct students to write an argument that includes a claim, evidence, and reasoning. Students should use evidence from the class investigation to back up their claim.

In addition, students should incorporate the ideas of scale and proportion. Understanding what the Sun might look like from Mars sets students up to understand the solar sails and habitat design challenges.

NGSS Key Moment

To make a claim about how the Sun looks from Mars, students must think about the planets using different scales (the classroom model and the actual size). In addition, students must incorporate ideas from the planet model. This activity sets students up for the next science investigation in which they consider the use of solar sails. Students begin to realize that even though it is possible to use solar sails, the spacecraft will move significantly further from the Sun than what students might expect.

When students are finished, you might show them images of the Sun from Mars. If you do, have students compare their claims to the pictures.

Web Resources

- Images of the Sun from Mars [Web Link]

Investigation: Space Fuels (10 minutes)

Rocket Fuels

Ask students to think about how a spacecraft moves itself though space. Explain how rocket fuel choices have changed over time. Fuel choices evolved from:

gunpowder → water steam → liquid oxygen + gasoline → liquid oxygen + alcohol → liquid oxygen + liquid hydrogen

Aerospace engineers are still developing new ways to fuel travel in space.

Space Fuels of the Future

Show the short video Astronomy Properties of the Sun. This video, which is part of a larger course, summarizes some of the Sun's most important characteristics. Ask students to take notes on one or two of the most interesting facts from the video, and ask for examples at the end during a popcorn share.

Video Links

- Astronomy Properties of the Sun [YouTube Link]
- Solar Sails [Web Link]

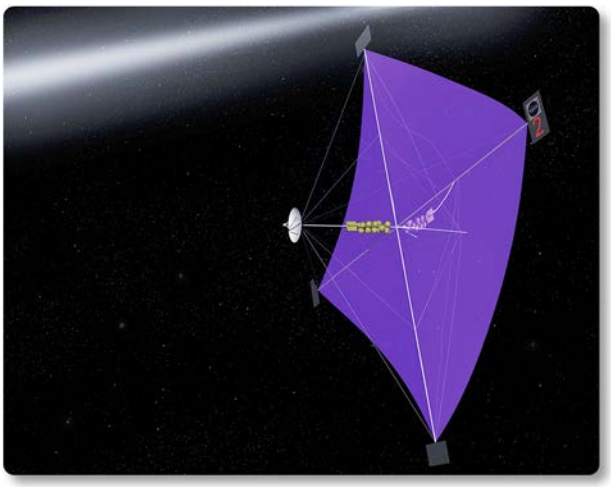
Let students know that some scientists are discussing (and planning to test) **solar wind** as a new kind of space fuel. The Sun's outer atmosphere, the super-hot corona, is the source of solar wind, which is a steady outpouring of charged particles from the Sun. Have students watch the short Solar Sails video to see a model of solar sails that can be launched in space via a satellite. Using solar sails could provide a new type of ongoing fuel to help us travel long distances in our solar system.

Design Work: Solar Sails (10 minutes)

Tell students that NASA would like to use solar sails for the mission to Mars. Lead a discussion about how the previous investigation (*What does the Sun look like from Mars?*) might inform the construction of the solar sails.

Show students the simple solar sails spacecraft model, which was assembled ahead of time. To build the model, a square of Mylar film, simulating the solar sail, should be glued to two coffee stirrers that were hot-glued together in the shape of an X. Then, a small cardstock paper tube should be glued to the middle of the X, simulating a spacecraft attached to the sail. Consider making small notches where the paper tube crosses the coffee stirrers.

Display the prepared materials for student teams to build their own solar sails. Show the entire class various images of solar sails. Allow each student (or student team) to review the images and decide how they want to create their model. Explain that they only have access to the materials in the classroom.



Source: https://commons.wikimedia.org/wiki/File:Solarsail_msfc.jpg

Have students determine which tools they need for model construction. Instruct students to submit a **materials requisition** (in their notebooks) before you distribute the materials. Discuss how this requisition relates to what engineers have to do when they build devices.

Help students construct their models, and facilitate communication among team members as they seek assistance from each other. For more information about solar sails, review the Web resources provided.

Web Resource

- Images of Solar Sails [Web Link]
- The Planets Today [Web Link]
- New Scientist: Maiden Voyage for First True Space Sail [Web Link]
- Discovery Channel: Solar Winds [Web Link]
- Exploratorium: Build a Solar System Model [Web Link]
- Planetary Society: Assembly Instructions for Your Cosmos-1 Solar Sail Spacecraft Scale Model [Web Link]
- Planetary Society: LightSail [Web Link]

Lesson Close (5 minutes)

Wrap up today's lesson by telling students that they just completed the first task of their mission. Tell students they have a device that will facilitate travel to Mars.

Instruct students to revisit the letter they wrote to NASA. Have students add a paragraph explaining how they solved the problem of "traveling to Mars." Instruct students to incorporate multiple ideas from the lesson. Have students discuss what was challenging, why they chose their design, and what they learned from the construction process. Students should conclude their paragraph by commenting on ways that they would further revise or improve their solar sail design.

NGSS Key Moment

By revisiting the design problem, students consider the ways that their design solution meets the criteria and constraints of the design problem. Students should incorporate science ideas related to the solar system and scale and proportion. Students should use these ideas to justify their design decisions.

Assessment Opportunities

Two assessment opportunities are embedded in this lesson:

- Students' written argument about how the Sun might appear from Mars can help you understand students' developing ideas about scale and the solar system.
- The revised letter to NASA can help you understand students' developing ideas about using science ideas to inform design solutions.

Provide additional supports or extension opportunities depending on student performance on these tasks.

Reference Appendix B for suggestions for meeting the needs of all learners.

Community Connections

Have students ask their parents or an adult at home if they have to create models in their work. If so, have them share this information with the class. Encourage the class to think about the ways models show scale or help us understand very large or very small systems.

Suggested Teacher Resources

Meeting the Needs of All Learners	Mission to Mars Teacher Handbook, Appendix B
Images of the Sun from Mars	[Web Link]
Astronomy: Properties of the Sun	[YouTube Link]
Solar Sails	[Web Link]
Images of Solar Sails	[Web Link]
The Planets Today	[Web Link]
New Scientist: Maiden Voyage for First True Space Sail	[Web Link]
Discovery Channel: Solar Winds	[Web Link]
Exploratorium: Build a Solar System Model	[Web Link]
Planetary Society: Assembly Instructions for Your Cosmos-1 Solar Sail Spacecraft Scale Model	[Web Link]
Planetary Society: LightSail	[Web Link]

Mission to Mars

Day 3: Mission #2—Living on Mars

Grade Level	Middle School
Lesson Length	One 50-minute session

Lesson Overview

On Day 3, students review the basic needs of all living things and determine how these needs apply to crew members in a spacecraft and on the surface of a foreign planet such as Mars. They also determine some of the constraints of space travel and determine their effect on living spaces. They then design a habitat for either a spacecraft to support travel trip to Mars or to reside on the surface of Mars.

Connecting to the Next Generation Science Standards

On Day 3, students make progress toward developing understanding across the following three dimensions:

- Science and Engineering Practices: Developing and Using Models
- Disciplinary Core Ideas: LS2.A Interdependent Relationships in Ecosystems
- Crosscutting Concepts: Cause and Effect

Day 3 is best taught in tandem with other lessons relating to LS2.A.

In the following table, the specific components addressed in this lesson are underlined and italicized. The specific connections to classroom activity are stated.

Performance Expectations		
This lesson can be used to enhance the development of the following *life science* performance expectations: MS-LS2-1. Analyze and interpret data to provide evidence for the *effects of resource availability on organisms and populations of organisms in an ecosystem.*		
Specific Connections to Classroom Activity In this lesson, students develop a model habitat for astronauts during their mission to Mars. Students take into account the availability of resources in the habitat and the effect the living and nonliving resources may have on the astronauts.		
Dimension	**NGSS Element**	**Connections to Classroom Activity**
Science and Engineering Practices	Developing and Using Models • *Use and/or develop a model of simple systems with uncertain and less predictable factors.*	Students develop a model of a proposed habitat for astronauts either on their journey to Mars or during their stay on Mars. The habitat is a simple system that has less predictable factors.

Disciplinary Core Ideas	LS2.A: Interdependent Relationships in Ecosystems • *Organisms,* and populations of organisms, *are dependent on their environmental interactions both with other living things and with nonliving factors.*	In the student model of a proposed habitat, students take into account the interactions between living things and nonliving factors. Students consider the effects of both on astronaut survival.
Crosscutting Concepts	Cause and Effect • *Cause and effect relationships may be used to predict phenomena in natural or designed systems.*	In developing their model habitat, students consider the cause and effect relationships between the living and nonliving factors and the astronauts' survival.

Basic Teacher Preparation

Continue with the student teams formed on Day 2. Alternatively, consider having students complete this lesson's activities individually. Make copies of the needed habitat photos, or locate them online.

Required Preparation	Links/Additional Information
❑ Gather or purchase the required materials for the lesson	Refer to the Materials List below
❑ Ensure technology is available to project or allow students to access the recommended websites	Refer to the Suggested Teacher Resources at the end of this lesson
❑ Review suggested teacher preparation resources in advance	Refer to the Suggested Teacher Resources at the end of this lesson

Materials List

Item	Description/Additional Information	Quantity	Where to Locate/Buy
Computer (or computers) with Internet access and a projector		1 per class for projecting to entire class, or access to a computer lab	Available in most schools
Photos of native plants and animals indigenous to various habitats	Can be shown from picture books or identified on the Internet and projected to the class	Several images to share with the class	Images of animals in their habitats [Web Link] Images of plants from various habitats [Web Link]
Drawing paper, or access to computers with drawing programs			Paper available in schools Drawing software, such as Sketchpad [Web Link]

Day 3: Mission #2—Living on Mars

Introduction (5 minutes)

Show students a picture of a familiar native plant, and ask them what this plant needs to survive. Discuss what would happen if the plant was picked up and moved to a different climate. *Would it survive? Why or why not?* Repeat this process with a picture of a plant from a very different environment.

Show a picture of familiar local animal, and then an animal from a completely different habitat. Discuss how the animals have adapted to survive where they live.

NGSS Key Moment

Beginning the lesson by engaging students in a discussion about what plants and animals need to survive draws out current student conceptions about interdependent relationships in ecosystems. Use student ideas to guide the amount support provided throughout the lesson.

Finally, show a picture of a person, and discuss basic needs to survive in different climates. *How do humans accommodate and adapt to live in various extremes?* Show a picture of an astronaut in a zero-gravity setting. Discuss how people are impacted as they try to survive in the unique setting of a spacecraft for several months as they travel to and from Mars. *Once they land on a planet that does not have an atmosphere, what problems will they face? How can those problems be addressed?*

Allow students 5 minutes to work in their teams to make lists of the problems that need to be addressed. Have students revisit their letter to NASA to add ideas to the criteria and constraints of living on Mars.

Design Work: Create a Habitat (30 minutes)

Bring students back together for a group discussion of the issues that have to be addressed. (Some examples include the need for oxygen, food, water, waste systems, mental stimulation, exercise, space, sleeping quarters, and so forth). If some of the categories shown here do not emerge, ask questions to elicit these responses from students. Be sure to emphasize the idea that humans depend on living and nonliving factors to survive. If critical needs are not met, the astronauts may be at risk.

NGSS Key Moment

As you introduce the design work, emphasize the idea that humans rely on living and nonliving factors. Reinforce the idea of cause and effect in natural and design systems. Help students understand that when certain living or nonliving factors are unavailable, it may have a negative effect on the astronauts.

After the class has created a group list of the most critical needs, discuss the constraints of cargo space on a spaceship. Tell students that their team (or each individual) has been contracted to come up with designs for living quarters for four Mars mission crew members. Students should design the crew's housing quarters on Mars keeping in mind that they will be on Mars for almost a year.

Allow students to work in their teams (or individually) on their designs. They may sketch on sheets of paper or use a computer drawing program. Encourage the use of labels and accurate dimensions as much as possible.

Students should label living and nonliving factors necessary for the astronaut's survival.

After designing the habitat, students should write a justification for their design decisions. Students should relate the design decisions to the living and nonliving factors needed for survival. Students should also comment on what might happen if elements of their proposed habitats may be missing. This, and a sketch of the habitat, should be incorporated into the letter to NASA.

Lesson Close (15 minutes)

Discuss the following questions as a group:

- *What challenges did they think about?*
- *What solutions did they identify?*
- *What accommodations will need to be made to ensure survival in space?*
- *What other needs still have to be addressed in their designs?*

After the discussion, ask students to think about which engineering teams would be involved in the design planning or construction (for example, launch team for weight considerations, environmental control team for the volume of area contained in their design, and so forth). Finally, show students interior shots of the first manned space capsules, the space shuttle, and the International Space Station.

Ask students to identify elements in their own designs that they see in the real-life images:

How do the spacecraft differ from each other and from the students' designs?

Use the Web Resources to show students photos of other crew quarter designs (including inflatable quarters) currently being designed and refined by the aerospace industry. Discuss which problems the new crew quarter designs solve. Ask students to identify the constraints of using inflatable quarters. Encourage students to continue their design process at home. Let students know they should plan to talk about Mars' surface conditions and engineering problems in the next lesson.

Web Resources

- Manned Space Capsules [Web Link]
- Space Shuttle [Web Link]
- International Space Station [Web Link]
- Inflatable Space Station [Web Link]
- Inflatable Mars Quarters [Web Link]
- Other Astronaut Living Quarters [Web Link]

Assessment Opportunities

Use the habitat models and justification paragraphs to inform your understanding of developing student conceptions related to LS2.A, Cause and Effect, and Developing and Using Models. Provide additional supports or extensions when necessary. Reference Appendix B for suggestions for meeting the needs of all learners.

Community Connections

If parents, guardians, or family members of any students work as architects, consider inviting them to visit the classroom to assist as a volunteer or to share their work experiences as designers of physical spaces intended to enhance human quality of life.

Suggested Teacher Resources

Meeting the Needs of All Learners	Mission to Mars Teacher Handbook, Appendix B
Manned Space Capsules (Gemini)	[Web Link]
Space Shuttle	[Web Link]
International Space Station	[Web Link]
Inflatable Space Station	[Web Link]
Inflatable Mars Quarters	[Web Link]
Other Astronaut Living Quarters	[Web Link]

Mission to Mars

Day 4: Mission #3—Temperature Control

Grade Level	Middle School
Lesson Length	One 50-minute session

Lesson Overview

Students learn how knowledge about simple physics (energy transfer) can help provide for human needs on Mars. They build a simple device to demonstrate how spacesuits help keep astronauts alive at temperatures and in environments that are not suitable for humans. As an optional extension, students build and demonstrate a simple gas collection device for propellant and oxygen.

Connecting to the Next Generation Science Standards

On Day 4, students make progress toward developing understanding across the following three dimensions:

- Science and Engineering Practices: Constructing Explanations and Designing Solutions
- Disciplinary Core Ideas: PS3.B Conservation of Energy and Energy Transfer
- Crosscutting Concepts: Energy and Matter

Day 4 is best taught in tandem with other lessons relating to PS3.B.

In the following table, the specific components addressed in this lesson are underlined and italicized. The specific connections to classroom activity are stated.

Performance Expectations		
This can be used to enhance the development of the following *physical science* performance expectation: MS-PS3-3. *Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.*		
Specific Connections to Classroom Activity In this lesson, students use their understanding of how energy can be spontaneously transferred from hot regions to cold regions to design a cooling device for space suits. Students consider the transfer of energy in the designed system.		
Dimension	**NGSS Element**	**Connections to Classroom Activity**
Science and Engineering Practices	**Constructing Explanations and Designing Solutions** • *Apply scientific ideas or principles to design, construct, and test a design of an object, tool, process, or system.*	Students use their knowledge of energy transfer to design a device to keep astronauts cool. Students justify their design using science ideas.
Disciplinary Core Ideas	**PS3.B: Conservation of Energy and Energy Transfer**	In other lessons relating to PS3.B, students should have already developed the idea that energy can be transferred from hotter

	• *Energy is spontaneously transferred out of hotter regions or objects and into colder ones.*	regions into cooler regions. In this lesson, students use this science idea to design a device to keep astronauts cool.
Crosscutting Concepts	Energy and Matter • *The transfer of energy can be tracked as energy flow through a designed or natural system.*	As students design a device to cool astronauts, they consider the idea that energy can be transferred from humans to the designed cooling device in the space suit.

Basic Teacher Preparation

Make copies of the needed photos, or locate and share them with the class online. Be sure to familiarize yourself with the passive gas collection process beforehand if you choose to do the optional Oxygen on Mars activity. If you are going to acquire and use dry ice in this lesson, familiarize yourself with safety procedures.

The Heating and Cooling activity can be very messy. Prepare appropriate measures to help students pour water into tubes or to collect any spilled water. Practice the Heating and Cooling activity prior to engaging in the activity with students.

Required Preparation	Links/Additional Information
❑ Gather or purchase the required materials for the lesson	Refer to the Materials List below
❑ Ensure technology is available to project or allow students to access the recommended websites	Refer to the Suggested Teacher Resources at the end of this lesson
❑ Familiarize yourself with the processes for the heating/cooling device and the optional gas collection device	Refer to the Heating/Cooling Device and the Gas Property sections in this lesson
❑ Review suggested teacher preparation resources in advance	Refer to the Suggested Teacher Resources at the end of this lesson

Materials List

Item	Description/Additional Information	Quantity	Where to Locate/Buy
Computer (or computers) with Internet access and a projector		1 per class for projecting to entire class, or access to a computer lab	Available in most schools
Heating/cooling device	Each set includes: • 2 buckets • Hot and cold water • Funnel	1 set per team	Items available at most hardware or aquarium/pet stores, or online: • Buckets [Web Link]

	• 4–6 feet of flexible aquarium tubing (.25–.5 inches in diameter) • Thermometer		• Funnel [Web Link] • Flexible aquarium tubing [Web Link] • Thermometer [Web Link]
Gas collection device (Optional)	Each set includes: • 2 buckets • Cold and very warm water • Clean and empty 2-liter soda bottle • Large balloon • Dry ice (if available) • Tongs and gloves (if using dry ice)	1 set per team	Items available at most hardware stores, at home, or online: • Buckets [Web Link] • Large balloons Web Link] • Dry ice [Web Link]

Day 4: Mission #3 - Temperature Control

Introduction (15 minutes)

Ask students to explain how they dress differently in summer and winter. *What else do people do to stay comfortable in different types of weather?* Discuss the different heating and air conditioning methods currently in use. *Why do people use these inventions?*

Ask students which locations on Earth require special equipment for people to live there. Some examples include life in submarines, polar regions, deserts, underwater, and at extremely high altitudes. Discuss how the special equipment used in these extreme environments on Earth might relate to life on Mars.

Let students use Space.com to look up the most extreme temperatures on Earth. Discuss whether people live in these places and, if so, what they need to survive there. Then, have students look up the temperature ranges on Mars at NASA Quest. Discuss what people need to do to survive there.

Humans can live comfortably in temperature ranges of approximately 10–30° Celsius. Ask students if this temperature range is found on Mars. Give students a few minutes to talk to their teams about how they might protect astronauts from extreme temperatures.

Web Resources

- Space.com: What Is the Temperature of Earth [Web Link]
- NASA Quest Mars Facts [Web Link]

NGSS Key Moment

Listening to student discussions about keeping astronauts protected from extreme temperatures will help inform you of current student conceptions of PS3.B. Use student ideas to guide the amount support provided throughout the lesson.

Design Work: Heating and Cooling on Mars (30 minutes)

Give each team a length of tubing, a bucket of cold water, and an empty bucket. Challenge them to use the materials to devise a method of cooling astronauts while they work in sunlight on Mars.

If after a few minutes students have not come up with a method, show them how to wrap tubing around their arm, and pour cold water in the upper end with a bucket and a funnel, collecting it at the lower end with the empty bucket. Give them a few minutes so they can all experience the results.

Give students the warm water to try warming themselves with the device. Discuss the

Important Note

This activity can be messy. To minimize the mess, help students carefully pour the water into the tubing. Provide buckets or baby pools to catch spilled water.

advantages and disadvantages of a water cooling system in the spacesuits. Access Space.com to show the class a diagram of how space suits work, pointing out the heating/cooling system.

Revisit student letters to NASA. Have students add their ideas about temperature control to their letters. Students should include a justification for *how* and *why* the design helps to keep astronauts cool (or warm).

Students should build on ideas from previous lessons (not included in this module).

Students should comment on energy transfer in the system.

Students should recognize that energy is spontaneously transferred from warm areas to cold areas.

Web Resource

- Space.com: How NASA Spacesuits Work (infographic) [Web Link]

NGSS Key Moment

This activity can be used as a formative assessment of a student's ability to design a system that maximizes thermal energy transfer. Simply *doing* the activity, however, is not enough. Students must justify their ideas about *how* and *why* the design worked.

Whole Group Discussion: Oxygen on Mars (Optional) (10 minutes)

Remind students that astronauts also need to breathe on Mars. Ask students what they think they will need to fill the Mars habitat with oxygen.

Where will this oxygen come from? Are there any resources on Mars that might provide astronauts with oxygen?

Introduce the term **in situ**. Access the Phoenix Mars Mission website. Discuss the gas composition of Earth's atmosphere and Mars' atmosphere.

Review with students the contraction and expansion properties of matter, including gases. Tell them that Mars' gases can be collected passively though the heating and cooling cycles of the planet's surface. Review how the heating and cooling cycles happen on Earth in the day/night cycle, which also helps account for weather events.

Web Resource

- Phoenix Mars Mission [Web Link]

Helpful Tip

If you are short on time, consider showing students the videos included in this activity rather than completing the entire activity.

Show the Gas Property Demonstration video created by one of the module's engineer contributors. This video and the activity demonstrates expansion and contraction of gases. Emphasize the idea that warmer molecules move faster, thus increasing the volume of their container (if the material of the container is flexible). Allow students to try this in their teams with the warm and cold water.

If desired, demonstrate this process in front of the class, using the dry ice (frozen carbon dioxide) to achieve greater temperature differences and greater inflation rates for the balloon. Dry ice safety information can be found at Safe Handling of Dry Ice.

Video Link

- Gas Property Demonstration [YouTube Link]

Web Resources

- Safe Handling of Dry Ice [Web Link]

Discuss why space pioneers (or humans on Earth) might want to use a passive system using in situ resources over a mechanized system to meet their needs for warmth, fuel, and so forth. *What are the advantages and disadvantages of this type of passive system?*

Lesson Close (5 minutes)

End the class with a review of the properties of heat, reminding students that knowing about these properties helps to determine how resources are used in space. As an exit ticket, ask students to identify one new fact they learned today and to think of one question they have about the lesson's experiences. Have them record this information in their science notebooks.

Assessment Opportunities

Use student justifications for the heating and cooling device to gather data regarding student progress on MS-PS3-3. Provide appropriate supports or extensions as needed. Reference Appendix B for suggestions for meeting the needs of all learners.

Community Connections

Many new companies—particularly solar-oriented firms—now use passive heating and cooling technologies. Identify and research a few companies in your region to share with students.

Suggested Teacher Resources

Meeting the Needs of All Learners	Mission to Mars Teacher Handbook, Appendix B
Space.com: What Is the Temperature of Earth	[Web Link]
NASA Quest Mars Facts	[Web Link]
Space.com: How NASA Spacesuits Work (infographic)	[Web Link]
Phoenix Mars Mission	[Web Link]
In situ (definition)	[Web Link]
Gas Property Demonstration	[YouTube Link]
Safe Handling of Dry Ice	[Web Link]

Mission to Mars

Days 5 through 7: Final Mission—Leaving Earth

Grade Level	Middle School
Lesson Length	Three 50-minute sessions

Lesson Overview

On Days 5 through 7, students learn how to use pressurized gas to launch a soda bottle rocket. They then construct and launch a simple rocket. In the process, students identify variables, troubleshoot problems, identify design improvements, and record rocket performance data.

Connecting to the Next Generation Science Standards

On Days 5 through 7, students make progress toward developing understanding across the following three dimensions:

- Science and Engineering Practices: Developing and Using Models, Analyzing and Interpreting Data, Constructing Explanations and Designing Solutions
- Disciplinary Core Ideas: ETS1.B Developing Possible Solutions, ETS1.C Optimizing the Design Solution, PS2.A Force and Motion
- Crosscutting Concepts: Cause and Effect

In the following table, the specific components addressed in this lesson are underlined and italicized. The specific connections to classroom activity are stated.

Performance Expectations
This lesson can be used to contribute toward building understanding of the following *engineering* performance expectations:
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.*
This lesson can be used to contribute toward building understanding of the following *physical science* performance expectations:
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.
Specific Connections to Classroom Activity
In this lesson, students plan, build, and test a rocket designed for the mission to Mars. Students plan an initial model rocket based on their knowledge of forces acting on the rocket (pressurized water and gravity). Students test their rockets, revise their designs, and justify their design decisions using knowledge of the forces acting on the rocket. During tests, students record and analyze data to support changes in design decisions. Students continue to revise, test, and justify their rocket designs until they develop a final rocket design. Students combine the best ideas from each test to arrive at an optimal design solution.

Dimension	NGSS Element	Connections to Classroom Activity
Science and Engineering Practices	**Developing and Using Models** • *Develop a model to generate data to test ideas about designed systems,* including those representing inputs and outputs. **Analyzing and Interpreting Data** • *Analyze and interpret data to determine similarities and differences in findings.* **Constructing Explanations and Designing Solutions** • *Apply scientific ideas or principles to design, construct, and test a design of an object, tool, process, or system.*	Students develop a model rocket to test the structures that help it fly. Students use the model to generate data to inform design decisions. Students collect and analyze data from rocket launches to inform changes in design decisions. Students use their knowledge of forces acting on an object to construct rockets.
Disciplinary Core Ideas	**ETS1.B: Developing Possible Solutions** • *A solution needs to be tested, and then modified on the basis of the test results, in order to improve it.* • *Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors.* • *Models of all kinds are important for testing solutions.* **ETS1.C: Optimizing the Design Solution** • Although one design may not perform the best across all tests, *identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process-that is, some of those characteristics may be incorporated into the new design.* • *The iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution.* **PS2.A: Force and Motion** • *The motion of an object is determined by the sum of the forces acting on it;* if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion.	Students design rockets to test and then modify on the basis of the tests. Students use ideas from different solutions to create a solution that combines multiple elements. The rocket serves as a model for the potential rocket used for the mission to Mars. For ETS1.C, through an iterative process, students test, refine, and retest their design solutions. Students test their solutions under a variety of different conditions (angle launched, and so forth). For PS2.A, students predict how the forces acting on a rocket will change the rockets motion. Students modify their predictions according to data from tests.
Crosscutting Concepts	**Cause and Effect** • *Cause and effect relationships may be used to predict phenomena in natural or designed systems.*	Students consider the idea that if they change certain features of the rocket, it will make it fly differently.

Basic Teacher Preparation

To prepare for this lesson, carefully review safety procedures for the rocket launch. For the rocket launcher system, pre-drill a hole in each rubber stopper, from top to bottom. Alternatively, you can buy the stoppers with the holes pre-drilled. Finally, determine where the rockets can be launched, how to transport water to the launch site, and where to store the rockets between the three class sessions. Practice launching rockets prior to completing rocket launches with students.

Required Preparation	Links/Additional Information
❑ Gather or purchase the required materials for the lesson	Refer to the Materials List below
❑ Ensure that technology is available to project the identified video	Refer to the Suggested Teacher Resources at the end of this lesson
❑ Review suggested teacher preparation resources in advance	Refer to the Suggested Teacher Resources at the end of this lesson
❑ Pre-drill holes in stoppers	Refer to the Materials List below
❑ Set up and test the rocket launcher	Refer to the Materials List below

Materials List

Item	Description/Additional Information	Quantity	Where to Locate/Buy
Computer (or computers) with Internet access and a projector		1 per class for projecting to entire class, or access to a computer lab	Available in most schools
Launch device	Each set includes: • Tire pump • Rubber stopper (size 3 or 4) • Tire inflation needle • 2–3 foot metal rod that easily fits inside PVC pipe • .5-inch PVC pipe, 2–3 feet in length	2 or 3 sets per class	Bring from home, or buy online: • Tire pump [Web Link] • Rubber stopper [Web Link] or pre-drilled [Web Link] • Tire inflation needle [Web Link] • Metal rod [Web Link] • .5-inch PVC pipe [Web Link]
Safety glasses		1 per student	[Web Link]
Rocket assembly	Each set includes: • Soda bottles • .5-inch PVC pipe, 2–3 feet in length	1 set per team	Soda bottles can be collected and brought from home.

	• Duct tape • Scissors		Scissors are available in most schools. Other items can be purchased online: • .5-inch PVC pipe [Web Link] • Duct tape [Web Link]
Altimeter		1 per class	[Web Link 1] [Web Link 2]
Rocket modification supplies	Materials include: • Duct tape • Cardboard • Extra soda bottles • Styrofoam trays • Scissors	1 set per team	Extra soda bottles can be collected and brought from home. Scissors and cardboard are available at most schools. Other items can be purchased online: • Duct tape [Web Link] • Styrofoam trays [Web Link]
Balloons		Assortment for the class	Available at most local stores
Stopwatch		1 per class	Bring from home or buy online [Web Link]
Drill with 1/16-inch bit	The teacher should drill the holes in the rubber stoppers.	1 per class	Bring from home or buy at hardware store or online: • Drill [Web Link] • Drill bits [Web Link]
Launch materials	Materials to include: • Bucket • Water • Funnel • Mallet	1 set per class 1–5 gallons of water, depending on the number of launches	Bring from home, or buy online: • Bucket [Web Link] • Funnel [Web Link] • Mallet [Web Link]

Day 5: Final Mission—Leaving Earth

Introduction (10 minutes)

In front of the class, blow up a balloon, and hold the neck of the balloon with the opening pinched shut. Ask students what will happen if you let it go.

After a few guesses, let go of the balloon. Have students describe what happened. Encourage them to use specific information, such as the distance and length of time the balloon flew, and the cardinal direction. Ask:

- *What causes the balloon to fly?*
- *What forces are acting on the air escaping from the balloon?*
- *If I do this again, will the flight be exactly the same? Why not?*
- *What are the variables?*

If you did the optional lesson, remind students that in the last lesson, they saw how pressurized gas might be collected on Mars. *How can that pressurized gas help the astronauts trying to leave Mars?*

Show students the Rocket Project Part 1: Water Bottle Rocket Simple Launcher video. Afterwards, ask students to explain what caused the rocket model to fly.

Have students develop an initial model of the forces acting on the rocket. In this model, students should include the force of gravity (MS-PS2-4: Developed in previous lessons not included in this module) and the force of the pressurized water.

NGSS Key Moment

Listening to student discussions about the balloon will help inform you of current student conceptions of PS2.A. Use student ideas to guide the amount of support provided throughout the lesson.

Video Link

- Rocket Project Part 1: Water Bottle Rocket Simple Launcher [YouTube Link]

Important Note

This is a great opportunity to discuss forces. Draw student attention to the force of lift off from water pressure, the force of gravity pulling down towards Earth, and the force of air friction slowing the balloon.

Design Work: Rocket Build (20 minutes)

Distribute materials for the basic rocket assembly and let students assemble the rockets as teams. Discuss safety procedures as students work with the materials and prepare to launch their rockets.

Students should document and justify their design decisions using their model of forces acting on the rocket.

NGSS Key Moment

To make progress on PS2-2, students must first make predictions about the forces acting on their rockets. Students test these predictions during the launch.

Design Work: Rocket Testing (20 minutes)

Outside, in an area free from obstruction (a large playground or park is ideal), go through safety procedures with students and show them how to launch their rockets.

Show students the altimeter and use it to record the altitude of each flight. Review the information about altimeters in the Notes About Altimeter Use section at the end of this lesson.)

Important Note

Show students how to avoid standing over their rockets after pressurization begins.

Optionally, review how to use a stopwatch to document flight time. Show students how to set up a table in their notebooks to record the flight testing results. A simple T chart for at least two trials per team is recommended. The second trial takes place on the following day. Students can also record data from other teams for comparison. A sample data table is shown.

TEAM: _____

Trial #	Altitude	Duration	Notes

After students set up their data tables, instruct the teams to take turns launching their rockets. Have students document their first flight in their notebooks. After testing their rockets, students should revise their model of forces acting on their rocket. Students should show where their predictions were accurate and where they might need to make modifications. Students should consider the following questions:

- *What went well?*
- *What problems arose?*
- *What differences did students observe in the flights?*

Let students know that they will be modifying their rockets and testing them again on the following day. Have students label their rockets before storing them in the predetermined location.

Notes about Altimeter Use

An altimeter can be used in many ways. Some are attached to a vehicle and directly measure the height a vehicle flies. You can drop payloads and count the time to fall to Earth. There are also ground-based ways to measure height.

To see examples of vehicle-mounted altimeters, see this Altimeters page. Some of these even include the acceleration and velocity measurements. Altimeters can be found for $30 at some big box retailers. This is a high-tech solution for measurement.

Web Resources

- Altimeters [Web Link]
- How to Measure Model Rocket Altitude [Web Link]

Another method to strongly consider (although it requires greater understanding) is to use an angle finder and trigonometry to determine the height. This How to Measure Model Rocket Altitude website describes the process in detail. At this site, three methods are explained. Method 1 involves the electrical altimeter mentioned above. Method 2 involves the use of a streamer. Method 3 requires some simple trigonometry. The advantage of Method 3 is that everything can be made at home with very cheap supplies, and the trigonometry calculations can reinforce math applications. This third method works with any rocket.

Day 6: Final Mission—Leaving Earth

Introduction (5 minutes)

Discuss the variables identified after the Day 5 flights. Ask students what they can do differently during today's rocket testing. Have students predict the effects that the changes might have during the second round of testing.

Design Work: Rocket Testing (35 minutes)

Give students the materials they need to modify their rockets. Allow students time to modify their rockets. Students must justify all design decisions by developing a model to show the forces acting on the rocket.

Head outside to conduct another test launch. If possible, bring materials outside so students can make more modifications while they are waiting for other launches. Again, use an altimeter to document their flight height and a stopwatch to record flight duration. If time permits, have teams conduct 2 or 3 trials. Make sure teams record today's new data.

After each launch, students should revise their models and justification. The emphasis should be on understanding *how* and *why* the rocket flies as it does, rather than just randomly improving the rocket.

Important Note

Be sure to use safety goggles and remind students not to lean over the rocket while it is pressurized. The metal rod can also be dangerous, so students should stand several feet back from the launcher.

NGSS Key Moment

As students engage in the iterative modeling process, they begin to see that the forces involved in the rocket launch are not as simple as just water pressure and gravity. Students see that wind or direction might impact the rocket. Students should incorporate their new ideas about forces acting on rockets to inform revision decisions.

Lesson Close (10 minutes)

After today's rocket testing, discuss the results as well as the causes and effects of their modifications. Ask students what new questions they have.

Day 7: Final Mission—Leaving Earth

Design Work: Rocket Testing (35 minutes)

During this final day of rocket testing, think of mini-experiments that the teams can try as they launch their rockets. For example, they can change the following variables:

- Amount of air they pump in
- Amount of water inside
- Direction of the dowel
- Length of dowel

Have students document their rocket's results in the data tables in their notebooks. As before, have students model the forces acting on their rockets during each test. Students should justify design decisions by articulating changes in forces acting on the rocket.

NGSS Key Moment

Designing mini-experiments helps students test their ideas about other forces acting on the rocket. Have students defend their ideas for a mini-experiment with their ideas about forces acting on the rocket.

Lesson Close (15 minutes)

After today's testing trials are completed, ask students to write their observations about the experiments. Have them summarize their observations and data trends in their science notebooks. Have students come up with a final summary for *how* and *why* their rocket flew as it did. Students should incorporate the forces acting on the rocket into their final summary. Students should add their final design and justification to their letters to NASA.

Briefly introduce the next lesson by letting students know that their rocket designs need to be modified to accommodate cargo and crew.

Assessment Opportunities

Two assessment opportunities are embedded in this lesson. First, use students' models to determine their developing understanding of the forces acting on the rockets. Second, use students' final design decision and justification to assess how student experimentation informed students' ideas of the forces acting on the rocket.

Reference Appendix B for suggestions for meeting the needs of all learners.

Community Connections

These three days present opportunities for parent engineers or engineers from the community to assist and comment as students test and modify rockets. If additional adults are available, consider setting up two or three launchers so teams can conduct multiple trials.

Suggested Teacher Resources

Meeting the Needs of All Learners	Mission to Mars Teacher Handbook, Appendix B
Rocket Project Part 1: Water Bottle Rocket Simple Launcher	[YouTube Link]
Altimeters	[Web Link]
How to Measure Model Rocket Altitude	[Web Link]

Mission to Mars

Days 8 and 9: Final Mission—Landing on Mars

Grade Level	Middle School
Lesson Length	Two 50-minute sessions

Lesson Overview

During Days 8 and 9, students design and build a cargo module for their soda bottle rocket. In the process, students identify variables, troubleshoot problems, identify design improvements, and record rocket performance data.

Connecting to the Next Generation Science Standards

On Days 8 and 9, students make progress toward developing understanding across the following three dimensions:

- Science and Engineering Practices: Developing and Using Models, Constructing Explanations and Designing Solutions
- Disciplinary Core Ideas: ETS1.B Developing Possible Solutions, ETS1.C Optimizing the Design Solution, PS2.A Force and Motion
- Crosscutting Concepts: Cause and Effect

In the following table, the specific components addressed in this lesson are underlined and italicized. The specific connections to classroom activity are stated.

Performance Expectations		
This lesson can be used to contribute toward building understanding of the following *engineering* performance expectations: 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.* **This lesson can be used to contribute toward building understanding of the following *physical science* performance expectations:** 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.*		
Specific Connections to Classroom Activity In this lesson, students develop and test a model for a cargo module in the soda bottle rocket. Students consider all of the forces acting on the rocket. Students revise their cargo module designs based on observations from tests.		
Dimension	**NGSS Element**	**Connections to Classroom Activity**
Science and Engineering Practices	Developing and Using Models • *Develop a model to generate data to test ideas about designed systems, including those representing inputs and outputs.*	Students develop a model cargo module to test the structures that protect the crew. Students use the model to generate data to inform design decisions.

	Constructing Explanations and Designing Solutions • *Apply scientific ideas or principles to design, construct, and test a design of an object, tool, process, or system.*	Students use their knowledge of forces acting on an object to construct cargo modules for rockets.
Disciplinary Core Ideas	**ETS1.B: Developing Possible Solutions** • *A solution needs to be tested, and then modified on the basis of the test results, in order to improve it.* • *Sometimes, parts of different solutions can be combined to create a solution that is better than any of its predecessors.* • *Models of all kinds are important for testing solutions.* **ETS1.C: Optimizing the Design Solution** • *Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design.* • *The iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution.* **PS2.A: Force and Motion** • *The motion of an object is determined by the sum of the forces acting on it;* if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion.	Students design cargo modules for rockets to test and then modify on the basis of the tests. Students use ideas from different solutions to create a solution that combines multiple elements. For ETS1.C, through an iterative process, students test, refine, and retest their design solutions. As a final task, students develop a model showing all of the forces acting on the rocket and the cargo module.
Crosscutting Concepts	**Cause and Effect** • *Cause and effect relationships may be used to predict phenomena in natural or designed systems.*	Students consider the idea that if they change certain features of the rocket and the cargo module, the rocket will fly or land differently.

Basic Teacher Preparation

Make the parachute (or a couple of them) ahead of time. Students can also make their own parachutes if time permits.

Required Preparation	Links/Additional Information
❑ Gather or purchase the required materials for the lesson	Refer to the Materials List below

❑ Ensure technology is available to project the identified videos	Refer to the Suggested Teacher Resources at the end of this lesson
❑ If desired, prepare the parachute ahead of time	Refer to the Materials List below
❑ Review suggested teacher preparation resources in advance	Refer to the Suggested Teacher Resources section at the end of this lesson

Materials List

Item	Description/Additional Information	Quantity	Where to Locate/Buy
Rocket building and testing materials	All soda-bottle rocket and rocket testing materials should be available in these lessons	As needed	See Materials Lists for Days 5 through 7
Parachute	Each set includes: • Large clear plastic sheet from a dry-cleaning bag, or another large plastic bag • String • Tape	1 parachute minimum, extras better	Materials can be brought from home, or found in most schools
Payload/crew assembly	Each set includes: • Balloon • Water (for filling balloons) • Egg • Large plastic bubble wrap bags • String • Scale • Extra balloons and eggs for breakage	1 set per team	Most items can be brought from home or found in schools. The following items can be bought online: • Balloons [Web Link] • Plastic bubble wrap bags [Web Link]

Day 8: Final Mission—Landing on Mars

Introduction (5 minutes)

In front of the class, hold up the parachute. Ask students what it is and explain how it works. Demonstrate to confirm their predictions.

Next, tape an egg to the parachute, and ask students what would happen if you threw it into the air. *Would the egg break when it lands on the ground? Why or why not?* Ask students to explain how this egg and parachute demonstration relates to astronauts landing on Mars. Explain that space capsules need to have sufficient safety equipment and slow enough speed to protect the people who are landing.

If time allows and you have the necessary cleaning supplies, throw the toy into the air again with the egg attached. Have students explain why the egg broke even though the parachute filled with air. Relate what happened with the parachute to what students know about the properties of gases.

Show students another egg, and ask them to compare it to a person and expensive equipment that have to be delivered safely to Mars (and back to Earth). Ask them how they might protect the egg if it is launched with their soda bottle rocket.

NGSS Key Moment

To further extricate ideas related to the sum of the forces acting on the egg, have students draw a force diagram showing the different forces acting on the egg and explaining why the egg broke.

Whole Group Discussion: Landing on Mars (15 minutes)

To develop the concepts and understandings required for today's engineering challenge, show students the Rocket Project Part 2: Water Bottle Rocket Flight Tests and Rocket Project Part 3: Recovery Development and Test videos. After students watch the videos, present the design criteria and constraints for the next engineering challenge, in which students design an addition to their rocket.

Video Links

- Rocket Project Part 2: Water Bottle Rocket Flight Tests [YouTube Link]
- Rocket Project Part 3: Recovery Development and Test [YouTube Link]

Design Criteria and Constraints

- The rocket must be capable of withstanding launch stress without falling apart.
- The rocket must hold an egg and its deceleration device (parachute, air bag, or another device). A water balloon will be used instead of an egg until the last test flight.
- The water balloon/egg and its device must separate from the bottle rocket.
- The water balloon/egg must land without breaking.
- The time limit for design, build, and test is one class period. (Students will be given another class period to modify and retest.)

Design Work: Team Build (15 minutes)

Show students the materials for their crew and cargo capsules. Let the teams start building.

Design Work: Testing (15 minutes)

Take students outside to test their devices. Have students document their flight and landing data in their notebooks. Discuss what went well and what problems arose. Also, have students identify any observed differences in the flights. Let them know that they will be modifying their devices and testing them again in the next class session.

Helpful Tip

When students go outside, consider taking a trash bag to discard any broken water balloons. Also take extra water balloons and tape in case any are dropped on the way to the launch site.

Day 9: Final Mission—Landing on Mars

Introduction (5 minutes)

Discuss the variables students observed during the Day 8 flights. Discuss how students can change their designs to ensure that the balloon does not break. Have students explain the effect these changes might have on the rocket performance and the crew and cargo landing.

Design Work: Rebuild and Test (30 minutes)

Give students the materials they need to modify their rockets. Head outside to conduct another test launch. If possible, bring materials outside so students can make additional modifications while they wait for other launches. Use an altimeter to document the flight height or a stopwatch to record flight duration. Make sure the teams record today's new flight data. Have students write brief summaries of their modifications and the effects.

Lesson Close (15 minutes)

Using their final designs, have students develop models showing all the forces acting on their rocket and cone during the launch. The model should show several points in time. Students should incorporate their final designs, the model of forces acting on their rocket, and justifications for the design into their NASA letters.

Assessment Opportunities

Final student models showing the forces acting on the rocket can be used to assess student progress on PS2.A. Reference Appendix B for suggestions for meeting the needs of all learners.

Community Connections

These three days present opportunities for parent engineers or engineers from the community to assist and comment as students test and modify rockets. If additional adults are available, consider setting up two or three launchers so teams can conduct multiple trials.

Suggested Teacher Resources

Meeting the Needs of All Learners	Mission to Mars Teacher Handbook, Appendix B
Rocket Project Part 2: Water Bottle Rocket Flight Tests	[YouTube Link]
Rocket Project Part 3: Recovery Development and Test	[YouTube Link]

Mission to Mars

Day 10: Selling It to NASA

Grade Level	Middle School
Lesson Length	One 50-minute session

Lesson Overview

In this final lesson of the module, students prepare and give oral presentations (with one visual). During these presentations, students share their optimal solutions and evaluate solutions from other teams. Students understand how communicating with peers about proposed solutions is critical at all stages of the design process, and how shared ideas can lead to improved designs.

Connecting to the Next Generation Science Standards

On Day 10, students demonstrate understanding of the performance expectations and three dimensions developed throughout the entire module. These lessons serve as a performance assessment in which all of the performance expectations and dimensions are addressed in the final presentation. Reference the performance expectations, disciplinary core ideas, science and engineering practices, and crosscutting concepts referenced in the front matter of this module.

Basic Teacher Preparation

Students use all of the data they collected as well as their testing experiences to create their summative presentations. Make copies of the Presentation Rubric for each student or team and review it at some point in the lesson.

Required Preparation	Links/Additional Information
❑ Gather or purchase the required materials for the lesson	Refer to the Materials List below
❑ Ensure technology is available for students to show the identified product commercials, and if desired, for students to prepare their presentations	Refer to the Suggested Teacher Resources at the end of this lesson
❑ Conduct online search to identify one or two brief commercials for a product or a toy	
❑ Download and copy the Presentation Rubric for distribution	Mission to Mars Teacher Handbook, Appendix C

Materials List

Item	Description/Additional Information	Quantity	Where to Locate/Buy
Presentation Rubric		2 copies per team: 1 for the team, and 1 for the teacher to score	Mission to Mars Teacher Handbook, Appendix C
Computer (or computers) with drawing software		Enough computers in classroom for teams to share, or access to a computer lab	Available in most schools Options for drawing software include: • Sketchpad [Web Link] • Chogger [Web Link]
Paper, rulers, and markers for diagrams		Enough items for each team	Available in most schools

Day 10: Selling it to NASA

Introduction (10 minutes)

Show students one or two identified commercials for a product or toy. Ask students why the commercial was made. *To whom is the commercial targeted? What claims or evidence does the advertisement present?*

Talk to students about the last step of the design process. When engineers are working on projects, they must frequently give presentations. As their work progresses, they give presentations to their departments for feedback in a Technical Interchange Meeting (TIM).

Presentations that have already been reviewed and are ready for the finishing touches are subject to Preliminary Design Reviews (PDR), which is when engineers get feedback and editing ideas from their coworkers.

When engineers present to their clients during Critical Design Reviews, they must "sell" their design to the client and prove that it meets the established criteria. If the client approves the design, then the project moves through the budgeting and fabrication stages.

Tell students they are to prepare a Critical Design Review presentation for NASA based on their work during this module. Encourage students to make work assignments in their team. The presentation must include:

- Diagram of the optimized rocket design—with verbal commentary
- Cost analysis based on the recommended materials and an explanation of why those materials should be used
- Verbal explanation of the design features, why they are optimal, and what the team learned during their testing trials; reference to collected data is ideal
- Final edited version of the letter to NASA including design solutions and justifications for all elements of the mission

Helpful Tip

Review the **Presentation Rubric** (**Appendix C**) with students before they begin to work on them.

Each presentation should last no more than 5 minutes.

Design Work: Presentation Preparation (20 minutes)

Give the student teams 20 minutes to put together their presentations. Depending on time constraints, students can either give their presentations to other engineering teams or to the whole class. Presentations should be scored using the Presentation Rubric (Appendix C) provided.

Helpful Tip

If more time is needed, add another day for students to prepare and give presentations.

Whole Group Discussion: Final Presentations (15 minutes)

Student teams give their final presentations to their classmates.

Lesson Close (5 minutes)

After presentations are finished, have students address the following questions as they complete their reflections in their science notebooks:

- *Did you enjoy this module? Why or why not?*
- *What did you learn?*
- *What surprised you about the engineering design process?*
- *How does this experience relate to something in your daily lives or the products/machines you most like to use?*
- *After this, what would you like to study and learn next?*

Assessment Opportunities

Use the final presentation and NASA letter as a summative assessment for student progress on all identified performance expectations.

Reference Appendix B for suggestions for meeting the needs of all learners.

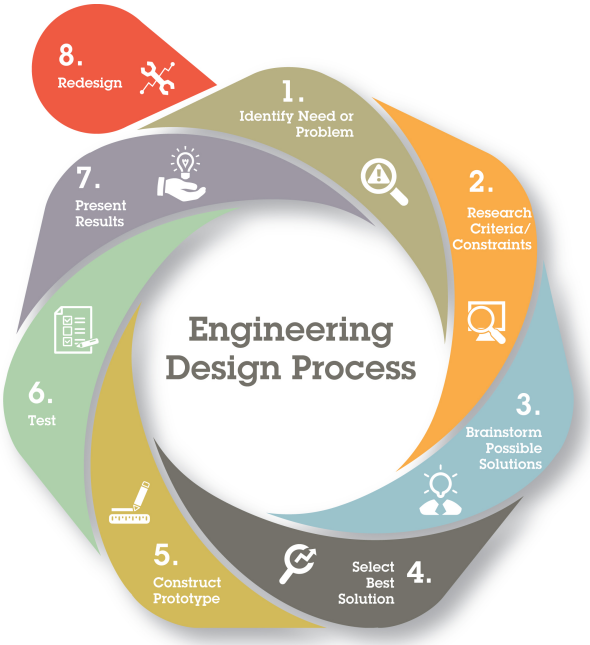
Community Connections

Consider a showcase design presentation from each team. Invite engineers, designers, and entrepreneurs to create a “shark tank” or “high stakes” environment.

Suggested Teacher Resources

Meeting the Needs of All Learners	Mission to Mars Teacher Handbook, Appendix B
Presentation Rubric	Mission to Mars Teacher Handbook, Appendix C

Appendix A
Engineering Design Process



Step 1 Identify the Need or Problem

Describe the engineering design challenge to be solved. Include the limits and constraints, customer description, and an explanation of why solving this challenge is important.

Step 2 Research Criteria and Constraints

Research how others have solved this or similar problems, and discover what materials have been used. Be sure to thoroughly research the limitations and design requirements for success.

Step 3 Brainstorm Possible Solutions

Use your knowledge and creativity to generate as many solutions as possible. During this brainstorming stage, do not reject any ideas.

Step 4 Select the Best Solution

Each team member presents their solution ideas to the team. Team members annotate how each solution does or does not meet each design requirement. The team then agrees on a solution, or combination of solutions, that best meets the design requirements.

Step 5 Construct a Prototype

Develop an operating version of the solution.

Step 6 Test

Test your solution. Annotate the results from each test to share with your team.

Step 7 Present Results

Present the results from each test to the team.

Step 8 Redesign

Determine a redesign to address failure points and/or design improvements. The design process involves multiple iterations and redesigns. Redesign is based on the data from your tests, your team discussions as to the next steps to improve the design, and the engineering design process Steps 1 through 7.

Once your team is confident of a prototype solution, you present the results to the client. The client may:

- Accept your solution as is, or
- Ask for additional constraints and criteria to be included in the solution. At this point, you and your team revisit the engineering design process and resume the iterative redesign cycle.

Appendix B

Meeting the Needs of All Learners

Every learner is unique. To meet the needs of all learners in your class, consider the following strategies:

- Provide students with sentence stems for models, arguments, and explanations (see below).
- Use a graphic organizer to help students organize their thinking prior to creating their final presentation (see below).
- Prior to each group discussion, engage students in individual or small group discussions to help them prepare to share their ideas in a larger group.
- Provide students with a vocabulary list using the Glossary.
- Offer additional extension problems or challenges in math or science.
- Provide students with additional time to formulate their ideas prior to sharing with the class.
- Offer opportunities for students to engage in additional investigations to extend learning. This may include additional readings, science investigations, or research.

Design Problem:
Science Ideas related to the Design Problem:
First Draft Design Solution: *Reflection/Modifications Needed:*
Second Draft Design Solution: *Reflection/Modifications Needed:*
Final Design Solution and Justification:

Sentence Stems

Contributed by Karl Muench, Collins Middle School, Salem, MA

Claim

You frame the question and answer it. This may take a sentence or a paragraph. Examples of claim sentences include the following.

- Analysis (breaking down the elements)
  - Our analysis looked at the parts and their function in …
  - We know from our data that … is comprised (made of) …, … and …
- Comparison (similarities and differences)
  - … (A) and … (B) are alike in that both …
  - However, while … (A) does this …, the other, … (B), does this …
- Evaluation (testing against a set of rules)
  - The … (subject of study) best matched the rule that …
  - In the situations involving …, the … (subject of study) showed …
- Problem/solution
  - … is a problem, and the best solution is …
  - Very often, … will have a problem with … The way to fix it is …
- Cause/Effect
  - … causes … to happen.
  - … is created when …
  - … if … then …

Give a preview of how you will prove your claim. Follow the above statements with the word ***because***.

Evidence

Include research and results of demonstrations or your own experimentation that support your claim. In science, you need to cite ALL available evidence, even some that may work against your claim. (You can deal with that issue by using reasoning.)

- Analysis
  - We conducted this experiment … The results are shown in the following table.
  - We graphed … over … and saw this pattern …
  - In most cases, we saw … Sometimes, however, … would happen.
  - We found the following analysis of this in our research … (direct quotes with sources)
- Comparison
  - We compiled the following T-chart showing where these things are alike and unalike.
  - In this Venn diagram, we can see where these things are similar and different.
  - In both cases, … is true. But only for ... is … true.
  - We have both things on this graph. You can see here … where they meet.
- Evaluation
  - We were looking for the following criteria … The following met those criteria … The following did not meet those criteria …
  - The rule … applies to the following … and does not work for …

  - Scientists say … (quotation with source). We found this applied to ...
- Problem/Solution
  - These sources … point to this issue …
  - We tested our prototypes by … These were the results …
  - Experts such as … (sources) say … is a common problem.
  - … (source) emphasizes that … is a problem, with this possible solution ...
- Cause/Effect
  - Every time … happened, … would happen.
  - Scientists believe that … is caused by … (quote with source)
  - The following graph shows how … influences …
  - This chart shows when … happens (or is present) and what happens next.
  - Statistics indicate that ...

Reasoning

You need to explain in your own words how your evidence supports your claim. In the case of evidence that contradicts your claim, you must explain why other evidence has more merit or reliability.

- Analysis
  - The evidence supports our claim because …
  - The graph shows that as … rises, … rises/falls at a (steady or increasing) rate. This allows us to predict …
  - Taking the evidence as a whole shows …
- Comparison
  - These things behave similarly when … but differently when …
  - Considering these similarities and differences indicates …
  - Looking at the chart of evidence, we see how … is similar to …, but different in ...
- Evaluation
  - If … is true, we should see … This is exactly what we see in the case(s) of …
  - Every time (or almost every time) we tried this …, this happened …
  - ... did not meet our criteria as well as …, eliminating it as an option.
- Problem/Solution
  - As you can see, our test (or research) indicates this solution will solve the problem because …
  - Our research and testing found … can best solve this problem by …
  - We were looking for this … and found it in ...
- Cause/Effect
  - The evidence shows that … causes … because …
  - Looking at the data, we see that … followed … every time.
  - Our research shows that scientists support that … causes … because ...
- Dealing with contrary evidence
  - By looking at all of this, we can see that these data … are outliers.
  - While some scientists say …, most scientists agree that …
  - Some of our results are less reliable because ...

Appendix C
Presentation Rubric

The Presentation Rubric is intended to be used as a guide for the development of the assessment for the final presentations. Teachers should tailor the rubric to fit the module's specific needs and design problem.

Science and Innovation
A Boeing and Teaching Channel Partnership
PRESENTATION RUBRIC

	No Evidence	Beginning	Developing	Advanced
Quality of Design Product NOTE: This section should be tailored to assess specific module and performance expectations.	Design product fails to address most aspects of the performance task. Design product shows no evidence of thoughtful problem solving. Design product shows evidence of low-quality craftsmanship.	Design product addresses some aspects of the performance task. Design product shows little evidence of thoughtful problem solving. Design product shows evidence of mediocre-quality craftsmanship.	Design product addresses most aspects of the performance task. Design product shows some evidence of thoughtful problem solving. Design product shows evidence of mostly high-quality craftsmanship.	Design product addresses all aspects of the performance task. Design product shows clear evidence of thoughtful problem solving, deliberation, and decision making. Design product shows clear evidence of high-quality craftsmanship.
Explanation of Science Ideas Science ideas include science and engineering practices, disciplinary core ideas, and crosscutting concepts. NOTE: This section should be tailored to assess specific module and performance expectations.	Relevant science ideas are not addressed. Evidence is not cited.	Most relevant science ideas are stated and partially described in relation to the design problem. Some evidence is cited. Evidence was gathered through science investigations or critical analysis of existing sources.	All relevant science ideas are stated and described in relation to the design problem. Several lines of evidence are cited. Evidence was gathered through science investigations or critical analysis of existing sources.	All relevant science ideas are clearly stated and described in detail in relation to the design problem. Multiple lines of evidence are cited. Evidence was gathered through science investigations or critical analysis of existing sources.
Organization	The presentation does not include all of the required components. The presentation does not have a main idea or presents ideas in an order that does not make sense.	The presentation includes most of the required components. The presentation moves from one idea to the next, but the main idea may not be clear or some ideas	The presentation includes all of the required components. The main idea is clearly stated. The presentation moves from one idea to the next in a logical order, emphasizing main	The presentation includes all of the required components and either provides additional information for each component or adds additional components relevant to the presentation.

		may be in the wrong order.	points in a focused, coherent manner.	The main idea is clearly stated. The presentation moves from one idea to the next in a logical order, emphasizing the main points in a focused, coherent manner. (CC 6-8. SL.4)
Presenting Skills	The presenter does not look at the audience and reads notes or slides. The presenter wears clothing inappropriate for the occasion. The presenter mumbles or speaks too quickly or slowly. The presenter speaks too softly to be understood.	The presenter makes infrequent eye contact and reads notes or slides most of the time. The presenter dresses professionally. The presenter speaks clearly most of the time, although sometimes too quickly or slowly. The presenter speaks loudly enough for most of the audience to hear, but may speak in a monotone.	The presenter keeps eye contact with audience most of the time and only glances at notes or slides. The presenter dresses professionally. The presenter speaks clearly and not too quickly or slowly. (CC 6-8.SL.4) The presenter speaks loudly enough for everyone to hear and changes tone to maintain interest. (CC 6-8.SL.4)	The presenter engages the audience by drawing their sustained attention. The presenter maintains eye contact with the audience most of the time and only glances at notes or slides. (CC 6-8.SL.4) The presenter dresses professionally. The presenter speaks clearly and not too quickly or slowly. (CC 6-8.SL.4) The presenter speaks loudly enough for everyone to hear and changes tone to maintain interest. (CC 6-8.SL.4)

Glossary

The key terms below are frequently used in the module. Students should develop a strong conceptual understanding of each term throughout the module. Definitions are from oxforddictionaries.com.

constraints	A limitation or restriction.
engineer	A person who designs, builds, or maintains engines, machines, or public works.
habitat	The natural home or environment of an animal, plant, or other organism.
in situ	In its original place.
interplanetary	Situated or traveling between planets.
launch	Send (a missile, satellite, or spacecraft) on its course or into orbit.
optimize	Make the best or most effective use of (a situation, opportunity, or resource).
pressurize	Produce or maintain raised pressure artificially in (a gas or its container).
rocket	A cylindrical projectile that can be propelled to a great height or distance by the combustion of its contents, used typically as a firework or signal.
satellite	An artificial body placed in orbit around the Earth, Moon, or another planet in order to collect information or for communication.
solar wind	The continuous flow of charged particles from the Sun that permeates the solar system.
space capsule	A small spacecraft, or the part of a larger one, that contains the instruments or crew.