



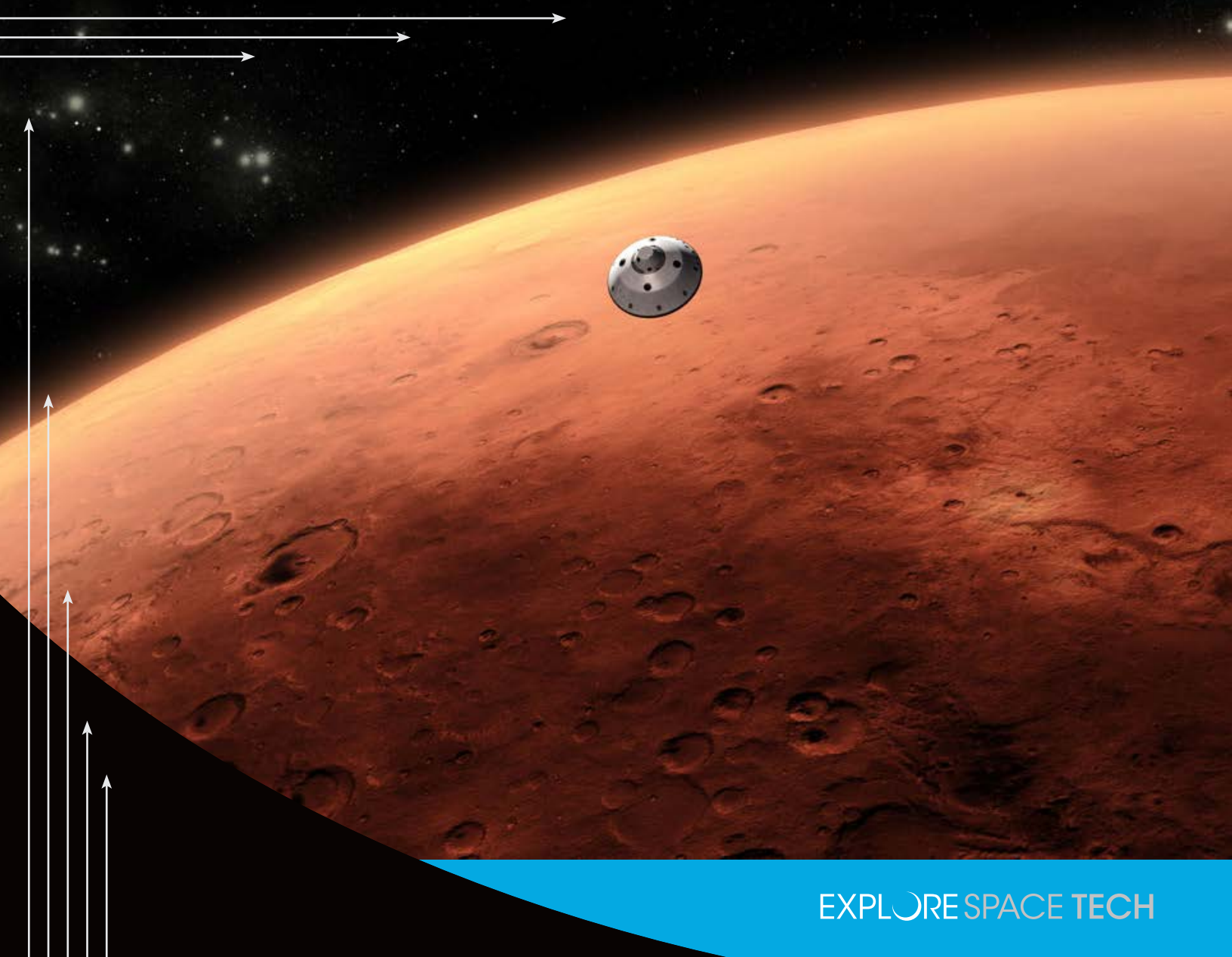
Tech Logic
LESSON SERIES

You Can't Take It All With You

Additive Construction with Mobile Emplacement (ACME)

GRADES 6–12

SECONDARY
EDUCATOR GUIDE



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INTRODUCTION

When early settlers first arrived in North America, and eventually moved west, they had to utilize local resources to build settlements and survive. Likewise, NASA's Additive Construction with Mobile Emplacement project (ACME) is exploring how local, or **in situ**, resources can be used to build habitats and structures on other planets. NASA engineers and scientists are developing ways to prepare for human settlement on other planetary bodies, like the Moon and Mars, while limiting the amount of materials

needed to be sent from Earth. One major challenge they face is determining the right combination of **regolith** and **binder** material needed to create structures that are ready and safe for astronauts. Furthermore, NASA is exploring the use of autonomous systems to prepare basic structures and settlement needs on other planetary bodies. A small number of astronaut technicians could oversee these systems until the foundational work is complete, reducing the manpower needed and the burden on astronauts.



Backpackers carry everything they need.



Many American settlers brought tools and supplies by covered wagon.



An artist's depiction of a settlement on Mars.

Overview

This lesson series includes activities designed to introduce students to NASA's ACME project and explores creating building materials for future Mars settlements. The first activity asks students to experiment with in situ resources (such as rocks and sand) and a binder (a glue) to develop building materials that can be used to construct a shelter. In the second activity, students utilize a 3D printer and 3D printing software to create a structure.

NOTE: *This guide uses inquiry-based instructional methods, providing students with the opportunity to work with the engineering design process. As with most inquiry-based activities, the role of the educator is to act as a guide instead of taking a more direct-instruction approach.*

Background

Throughout history, explorers and settlers traveling long distances or for long periods of time could not take everything they needed with them. Instead, they had to rely on local resources in addition to what they carried. Using local, or in situ, resources allows explorers to carry less with them, which reduces weight and costs. This also allows explorers to better adapt to their new surroundings. NASA is looking at ways to use in situ resources when humans travel into space.

Every kilogram of material sent into space requires lots of fuel, takes up valuable cargo space, and usually needs to be replaced by more materials created and prepared on Earth. Once materials arrive in space, astronauts need to unpack and manage these materials. This is why reusability is crucial on the International Space Station and any other off-Earth location. Currently, astronauts on the space station use many Earth-based resources that need to be continuously replenished. Once used, the waste generated from these materials is packaged into a nonreusable cargo vessel and jettisoned from the space station to burn up in the atmosphere.

The space station does have some capabilities to generate and recycle its own products. Water is collected and recycled using two different water recovery systems. In 2010, a Sabatier system was delivered to the space station, which

takes “waste” hydrogen and carbon dioxide and produces water. The **Sabatier process**, developed by French chemist Paul Sabatier in the early 1900s, had previously been used in commercial and military applications, but its use in space travel has further reduced astronauts' dependence on deliveries from Earth. This helps pave the way for farther space exploration as well as settlement on planets and moons that may not have a ready supply of water.

For missions to other planetary bodies, such as the Moon and Mars, NASA will need to send even more materials into space. Therefore, more astronauts will be needed to handle these materials. Saving travel time is also an important factor when sending items to space. For example, if astronauts are living and working on Mars, it will take at least 6 months to get a spacecraft there from Earth—astronauts might not be able to wait that long!



The Bigelow Expandable Activity Module (BEAM), developed for NASA by Bigelow Aerospace, is lifted into SpaceX's Dragon spacecraft for transport to the International Space Station.

NASA's Space Technology Mission Directorate (STMD) and others are working on ways to address these challenges. STMD is developing technologies that allow NASA to use materials more efficiently and effectively, including using in situ resources on other planetary bodies. STMD is also exploring how to use and manipulate materials autonomously, reducing the manpower needed. Imagine a few astronauts traveling to Mars, setting up a system that can start building structures and other foundational parts of a settlement autonomously, and overseeing this system remotely as it prepares for future astronauts to arrive. This is what NASA is working on.

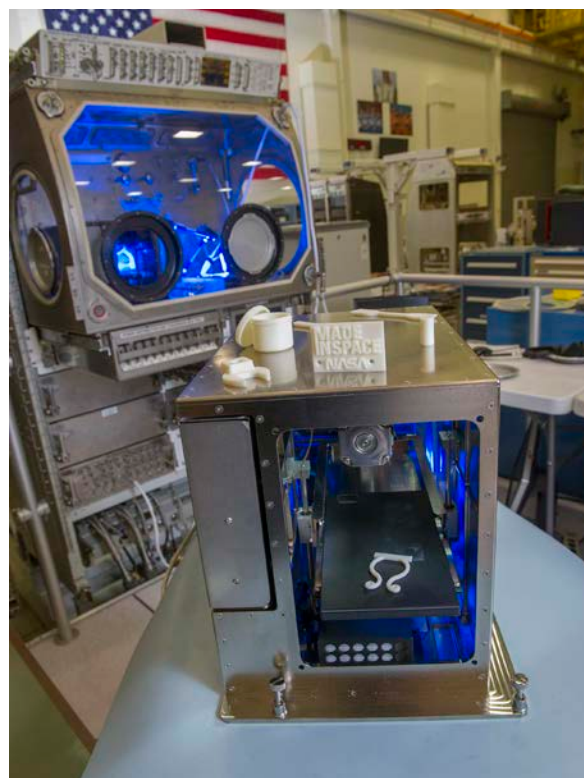


A Contour Crafting robot prints a road in front of a hangar for a lunar lander.

Currently, there is a 3D printer on the space station, which allows astronauts to print materials—such as tools—when needed. The first tool printed aboard the space station was a ratchet wrench in 2014. The wrench was designed on Earth and delivered to the space station as a file, ready for the astronauts to print. You can find the wrench file, along with other NASA 3D models, here: <https://nasa3d.arc.nasa.gov/>.

STMD is taking 3D printing, also referred to as **additive manufacturing**, to new levels by creating larger printers for new uses. This includes developing techniques that utilize in situ resources, such as Martian regolith, lunar regolith, or Earth-based soils, to 2D or 3D print roads, landing pads, building structures, radiation shelters, and other objects off Earth. For Earth-based projects, islands such as Hawaii can reduce building costs by manufacturing buildings and other structural needs using in situ resources instead of shipping materials to remote locations.

STMD's Additive Construction with Mobile Emplacement project has several goals, including investigating regolith and binder mixtures, demonstrating additive manufacturing for construction, analyzing materials for additive construction on other planets, and providing the first steps for using additive manufacturing in deep space missions.



The 3D printer on the space station allows astronauts to print materials when needed. The first ratchet wrench printed aboard the space station was designed on Earth, then sent as a file to the station and printed on the 3D printer in 2014.

Activity 1: Utilizing In Situ Resources

CLASS TIME



2 x 50 min

GROUP SIZE



Up to 4

To simulate the ACME project, students will become **materials engineers** by using sand, glue, and water to create “Martian bricks” and/or develop a building material that can be “3D printed.” Groups will then become **structural engineers** by designing and building a Martian structure with the bricks and/or printing media they have created. Students can use a limited amount of materials representing items brought from Earth (wooden craft sticks and aluminum foil) to add strength and stability to their structures. Structures must include one door and one window. Structures will be tested for protective abilities by shining a light on the structures to check for leaks. Finally, students will also calculate the square footage, perimeter, volume, or other aspects of their structure.

NOTE: This activity is messy! It is advisable to cover tables with newspaper or tablecloths. Bags of sand and rocks can be stored in plastic tubs. A cleanup area is also helpful.



Time Required

Approximately two 50-minute class periods, plus drying time.

Materials Needed

- Student activity guide (1 per student)
- Play sand (approximately 2 cups per group)
- Mixed gravel (approximately 2 cups per group)
- Glue (approximately 1 cup per group)
- Water
- Bowls or cups (several per group)
- Mixing spoons (several per group)
- Measuring cups
- Ice cube trays, plastic or silicon (2 per group)
- Petroleum jelly, cooking spray or plastic wrap to line ice cube trays (optional)
- Aluminum foil (1 square foot per group)
- Wooden craft sticks (several per group)
- Graph paper (1 sheet per group)
- Strong light, such as a flashlight or higher intensity desk light
- Scale for measuring mass (in grams)
- For the advanced version of this activity, in which students create their own molds: cardstock or other building material to create brick molds.
- For optional 3D printing activity: cake decorating bags and a variety of nozzles to simulate an in situ 3D printer (one set per group). If conducting the 3D printing activity, it is suggested to add thickening agents to printing material (sand, gravel, glue) mixture, such as cornstarch or flour, that can help create a thicker, more easily printed material.

Optional Literacy Component: Students can read a variety of stories about early American and western settlers and the materials they had to bring with them as they explored and/or settled in new lands. The following links can be used to find reading materials:

- <http://www.americaslibrary.gov/about/welcome.html>
- <https://americanhistory.si.edu/blog/2012/10/conestoga-wagons-and-the-american-frontier.html>

- <https://learningenglish.voanews.com/a/american-history-series-settlers-rush-to-claim-western-land-90841054/115787.html>
- <https://www.archives.gov/education/lessons/homestead-act>
- <http://www.loc.gov/teachers/classroommaterials/presentationsandactivities/presentations/timeline/colonial/indians/>

Procedures

Engagement Activity

To begin, ask students what they would need to pack if they went on a trip or vacation. Provide several scenarios that require the students to pack differently (such as staying in a hotel, camping in an RV, backpacking, etc.). Ask students how what they want to bring is different from what early American and western settlers packed.

Provide students with an overview of NASA's ACME project. Explain how space exploration to other planetary bodies presents comparable challenges to those faced by early settlers and explorers.

Part One: Materials Engineering

1. Students will mix together sand, glue, and water to create a dough-like material. The less glue used, the faster the drying time.
2. Students will record how much sand, glue, and water they used in their materials engineering data sheet included in their student activity guides.
3. Students will prepare ice cube trays by lining them with plastic wrap or coating them with cooking spray or petroleum jelly. Spoon the building mixture in each well of one ice cube tray. Each well should be packed tightly in order to make the most compact bricks possible.
Advanced version: Students can create custom molds of differing sizes for their bricks by using cardboard, cardstock, foam board, or similar materials.
4. Using the same mixing bowl, students should create a second batch of bricks, this time using both sand and gravel with a glue/water binder. Spoon this mixture into another prepared ice cube tray.



5. Students should again record how much of each material was used for the second set of bricks.
6. Set ice cube trays aside and allow to dry. Drying time will depend on the amount of glue/water used, temperature of the room, etc.

NOTE: Most bricks will take at least 24 hours to dry. It is sometimes helpful to remove sand bricks from the trays when they are partially dry. It can also be helpful to set trays in direct sunlight—warmer environments can help speed up the process. However, be careful not to remove the bricks too early or they may fall apart.

7. Carefully remove the bricks from the ice cube trays. Students should analyze the results of the bricks and record their findings in their materials engineering data sheet. This can include any combination of testing: visual observation, strength testing, durability, etc. The educator or students can develop ways to test these bricks. Ideas include, but are not limited to, spraying them with water, drop-testing them from an agreed-upon height, and placing heavy objects on top of them.



Part Two: Structural Engineering

1. Once the Martian bricks are dry and ready for use, students will complete the Structural Design section of their activity guides. Students will work with their groups to design their Martian structure. Groups should decide on any other materials they want to use in their structure, such as aluminum foil and/or wooden craft sticks. Students should carefully design their structure so as little light as possible penetrates the structure in order to best protect the astronauts inside. Students should also include one door and one window on their design.
2. Using graph paper as a building surface, students will construct their Martian structure. No glue or other adhesives can be used to build their structures.
3. Once the structures are completed, students should trace the outline of their structures and record their measurements on the graph paper and/or in their structural engineering data sheets. If students are asked to calculate the volume of their structure, they should measure the height of their structures as well. Students should record all measurements, calculations, and observations in their structural engineering data sheets. Depending on skill level, students can calculate the square footage, perimeter, and the volume of their structures. If design parameters were provided prior to the construction of their structure, students should check to make sure they stayed within those design constraints.

Quality Control Test and Evaluation

Students will test their structures' ability to "shield radiation" and protect the astronauts inside. Students will shine a bright light on their structures and look for areas where light permeates their structures. Students should record their results, any observations about build quality, and ideas for improvement in their data sheets. If time permits, students can make their changes and retest their structures. Students should share their results with their classmates. This can be accomplished through student presentations, tours of each group's shelter, or any other style desired. This guide includes an evaluation rubric, if desired.

Differentiation Ideas

- Give students limited design parameters—provide students with limited square footage, perimeter, and/or volume requirements as design constraints.
- Strength test individual bricks and/or completed structures. This can be done by adding items to the top of bricks/structures, blowing a fan at the bricks/structures, subjecting the bricks/structures to a heat lamp, etc.
- For students who may need more support with constructing a building or have motor control issues, prebuilt blocks such as LEGO bricks or other blocks can be used, since they are sturdier and of a more uniform size.

Optional Activity

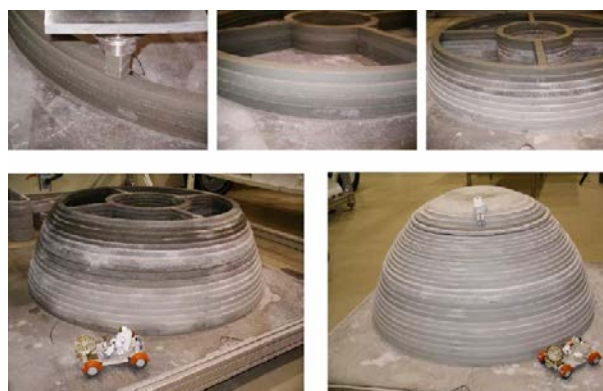
ACME is also studying the feasibility of using in situ resources for additive manufacturing, commonly referred to as 3D printing, to build structures on other planetary bodies. In this optional activity, students will develop a second recipe for rock, sand, and binding material that can be extruded from a nozzle to build a structure.

1. For this activity, cake decorating bags and nozzles will simulate 3D printers. Students should create a mixture using sand, rock (if desired), water, and glue. When creating this mixture, students should consider that the mixture will need to be extruded through a cake

decorating bag and nozzle. Adding ingredients such as cornstarch or flour may help create a more paste-like recipe to help the extrusion process.



2. Using graph paper as a building surface, students should construct a structure (or part of a structure) by extruding their sand mixture through the nozzle of their cake decorating bags. This task can be difficult; students will need to carefully consider their structure design. If students need suggestions, you can use the images included in this educator guide depicting how NASA is testing designs that mimic beehives.
3. Once the “3D printed” structures are completed, students can be asked to collect measurements and data similar to those described in Step 4 of the Part Two: Structural Engineering activity.



Glossary

In Situ Resources: The collection, processing, storing, and use of materials encountered in the course of human or robotic space exploration that replaces materials that would otherwise be brought from Earth.

Regolith: Loose rock, dust, and sometimes soil that is found on top of the solid rock on a planet, moon, or other planetary body.

Binder: Any material or substance that is used to hold other materials together.

Materials Engineer: An engineer who uses and improves existing materials and develops new materials.

Structural Engineer: An engineer who focuses on the design and construction of structures (bridges, buildings, dams, etc.).

Sabatier Process: A process whereby hydrogen and carbon dioxide, under high temperatures and pressures, in the presence of a nickel catalyst, produces methane and water.

Additive Manufacturing: Also known as 3D printing, additive manufacturing builds a structure by adding material to a structure, layer by layer, until it is complete.

Activity 2: Building Structures with Additive Manufacturing

CLASS TIME



2 × 50 min

GROUP SIZE



Up to 4

For this activity, students will work in groups to design and create a 3D printed structure. As an added challenge, the structure can be tested for “radiation shielding,” simulated by using a very strong flashlight or spotlight.



Examples of 3D printed habitats.

Time Required

Approximately two 50-minute class periods, printing time, plus one additional class period for testing (time required varies depending on student comfort level with 3D printing programs).

Materials Needed

- Student guide
- 3D printer and printing material
- Computer access and 3D printing program
- Graph paper, rulers, pencils

Procedures

Engagement Activity

Ask students what materials are needed to build a house. Students can make a list of required materials (wood, glass, drywall, wiring and electrical components, plumbing, carpet, cement, nails, screws, bolts and, other basic materials should be on their lists). Discuss how additive manufacturing, which utilizes 3D printing technology, would change the materials needed to build houses. Ask students to consider what materials are still needed when utilizing this technology, as well as the benefits and potential problems.

Activity

1. Before students begin designing, decide on the type(s) of buildings (living quarters, research lab, storage facility, etc.), students will create, and add any design constraints, such as height requirements. Groups can design the same type of structures, or each group can design different structures to meet different needs on Mars. Additionally, ask students to list the components that 3D printed structures still require to be functional, such as electricity, wiring, plumbing, windows, etc. Students should keep these components in consideration as they design their buildings.

NOTE: Students do not need to design or print the entire structure in one piece; however, structures should be easily assembled once printed. Explain that an easily assembled structure is desirable because ACME is exploring using robots on Mars to assemble structures.

2. Using graph paper, or the space provided in their activity guides, students should work in groups to design their Martian buildings. Review designs and provide any feedback to student groups.
3. Students will use 3D printer/CAD (computer aided design) software and prepare to print their structures. Once designs are completed and approved, students should print their structures and assemble, if necessary.

Evaluation

Students should test their structures' ability to "shield radiation" and protect the astronauts inside by shining a bright light on their structures and looking for areas where light permeates the structures. Students should record their results, any observations about build quality, and ideas for improvement in their data sheets.

Projects can also be evaluated based on design printability, compliance with design constraints, proper scaling, and design inclusion of additional building requirements, such as wiring, doorways, etc.

Activity 3: Excavation and Preparation

CLASS TIME



2–3 × 50 min

GROUP SIZE



Up to 4

ACME is also interested in a variety of technologies that will help automate excavation and materials handling in order to continuously produce in situ feedstock. This requires excavation, size sorting, and delivery systems. For this design challenge, students will construct a mechanism that can excavate, sort by size, and deliver materials to a specific location.

Time Required

Approximately two or three 50-minute class periods for designing and building; one additional class period for testing and evaluation.

Materials Needed

- Student guide
- A variety of gears and other building materials
- Play sand
- Gravel and/or small rocks
- *Optional:* Beads of varying sizes
- Large containers for mixed media (one per group)
- Small containers to use for holding sorted materials (one set per group)
- *Optional:* Programmable robot to automate the sorting and delivery process

Procedures

Engagement Activity

Ask students to create a two-column list, one column identifying resources needed for robots and rovers to build structures on Mars and one column listing the resources needed for humans to accomplish the same task. After students create and briefly discuss their lists, provide students with background information about in situ resource utilization and the need for automation in the creation of Martian settlements. Explain how automated systems could collect and sort in situ resources to use in the construction of basic infrastructural needs on Mars ahead of the arrival of astronauts.

Activity

Preparation before activity: Premix simulated Mars regolith. Use a combination of sand, gravel, small rocks, and beads (optional) of varying sizes.

1. Show students the simulated Martian regolith and explain that their objective is to develop mechanisms that can collect and sort the materials into separate containers. You can explain how the materials will be used to create structures on Mars (this relates back to Activity 1 of this guide). Students can either create one device to collect materials and another to sort or can combine this process.

NOTE: *If available, students can also use a programmable robotics system to accomplish these tasks.*

2. In groups, students will create designs for their devices. Educators should provide any available materials list or design constraints at this point.
3. Once designs are approved, students will build and test their devices.

NOTE: *For a competitive activity, create a point system to rank student devices. For example, award points to mechanisms that collect and/or sort the most materials in the least amount of time. Subtract points if mechanisms inaccurately sort materials.*

Evaluation

Projects should be evaluated on design (Did the students meet the design constraints?), quality of construction, and accuracy of the mechanism.

Evaluation Rubrics

Activity 1: Utilizing In Situ Resources

	0–1 point	2–3 points	4–5 points	Total Points Earned
Shelter Design	Students either did not design a shelter or did not follow any design parameters.	Students designed a shelter but did not follow all design parameters.	Students successfully designed a shelter, following all design parameters.	/5
Mathematical Calculations	Mathematical calculations were missing.	Mathematical calculations were incorrect or not completed according to directions.	Mathematical calculations were completed according to directions and were correct.	/5
Shelter Construction and Evaluation	The shelter was not completed and/or the evaluation was missing or incomplete.	Students built their structure and completed their evaluation. However, their shelter was not constructed according to design parameters and/or some of their evaluation was incomplete.	Students successfully built their structure according to design parameters and completed all evaluation steps.	/5
Shelter Improvement Plan	Shelter improvement plan was missing or incomplete.	Shelter improvement plan was included but did not address all required components needed for improvement.	Shelter improvement plan was complete and included all required components.	/5

Activity 2: Building Structures with Additive Manufacturing

	0–1 point	2–3 points	4–5 points	Total
Building Design	Initial building design is either missing or does not meet design requirements.	Initial building design meets most design requirements.	Initial building design meets design requirements.	/5
Computer Design	Computer building design is either missing or incomplete. Design may be unprintable.	Computerized building design somewhat aligns with initial building design. Most printing requirements are met.	Computerized building design aligns with initial building design. All printing requirements are met.	/5
3D Printing	Building was either not printed or was unprintable.	Building was printed but had a limited number of printability issues.	Building was successfully printed.	/5
Testing and Analysis	Building was not tested. Written analysis was either missing or mostly incomplete.	Printed building was tested. Written analysis was either incomplete or improvement plan was missing.	Printed building was tested. Written analysis, including improvement plan, was completed.	/5

Activity 3: Excavation and Preparation

	0–1 point	2–3 points	4–5 points	Total
Excavation	Excavation mechanism was either incomplete or was not successful in acquiring Martian resources.	Excavation mechanism was somewhat successful in acquiring Martian resources.	Excavation mechanism successfully acquired Mars resources.	/5
Sorting	Sorting mechanism was either incomplete or was not successful in acquiring Martian resources.	Sorting mechanism was somewhat successful in sorting Martian resources.	Sorting mechanism successfully sorted Martian resources.	/5
Delivery	Mechanism was either incomplete or was not successful in delivering sorted materials.	Mechanism was somewhat successful in delivering sorted materials to storage containers.	Mechanism successfully delivered sorted Mars resources to storage containers.	/5

NGSS Standards

Middle School

MS-LS2 Ecosystems: Interactions, Energy, and Dynamics

MS-LS2-3. Develop a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem.

MS-ESS3 Earth and Human Activity

MS-ESS3-3. Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.

MS-ETS1 Engineering Design

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.

Science and Engineering Practices

- Asking Questions and Defining Problems
- Constructing Explanations and Designing Solutions
- Analyzing and Interpreting Data
- Developing and Using Models

Disciplinary Core Ideas

- Defining and Delimiting Engineering Problems
- Developing Possible Solutions
- Optimizing the Design Solution

Crosscutting Concepts

- Systems and System Models
- Influence of Science, Engineering, and Technology on Society and the Natural World
- Interdependence of Science, Engineering, and Technology
- Cause and Effect
- Structure and Function

High School

HS-PS3 Energy

HS-PS3-1. Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.

HS-PS3-3. Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.

HS-LS2 Ecosystems: Interactions, Energy, and Dynamics

Use mathematical and/or computational representations to support explanations of factors that affect carrying capacity of ecosystems at different scales.

HS-ESS3 Earth and Human Activity

HS-ESS3-1. Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.

HS-ETS1 Engineering Design

HS-ETS1-1. Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

HS-ETS1-2. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

Science and Engineering Practices

- Asking Questions and Defining Problems
- Constructing Explanations and Designing Solutions
- Analyzing and Interpreting Data
- Developing and Using Models

Disciplinary Core Ideas

- Defining and Delimiting Engineering Problems
- Developing Possible Solutions
- Optimizing the Design Solution

Crosscutting Concepts

- Systems and System Models
- Influence of Science, Engineering, and Technology on Society and the Natural World
- Interdependence of Science, Engineering, and Technology
- Cause and Effect
- Structure and Function

Resources

https://www.nasa.gov/mission_pages/station/research/benefits/water_in_space

https://www.nasa.gov/sites/default/files/atoms/files/fs_acme_factsheet_150910.pdf

<https://techport.nasa.gov/view/17558>

<https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20160013562.pdf>

<https://www.bradley.edu/challenge/>

Another great activity to work on with students is the NASA “Survival!” activity, which compares essential needs of explorers on the Moon versus Jamestown.

https://www.nasa.gov/pdf/166504main_Survival.pdf

About this Lesson

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Wings Over the Rockies Air & Space Museum
Denver, CO

In collaboration with the

Space Technology Mission Directorate

National Aeronautics and Space Administration
Washington, DC

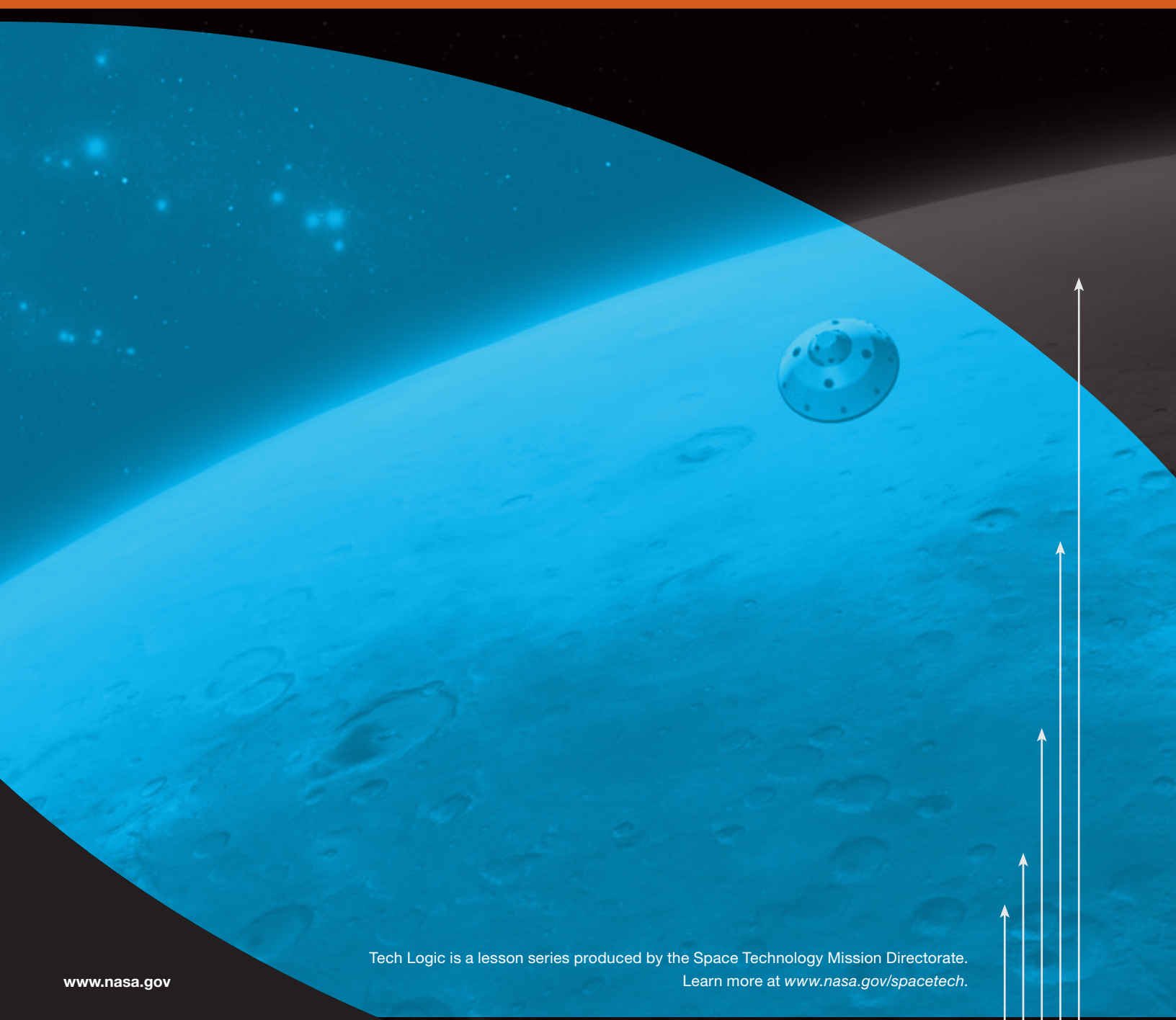
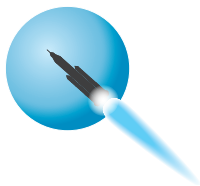
Acknowledgments

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Image Credits

Cover: Mars Science Laboratory spacecraft approaching Mars—NASA. **Page 1:** Backpacking—Kitty Terwolbeck (<https://www.flickr.com/photos/kittysfotos/7925291004/>); Covered wagon—U.S. Bureau of Land Management (<https://www.flickr.com/photos/mypubliclands/36346399930/>); Mars settlement—NASA. **2:** BEAM—SpaceX (<https://www.nasa.gov/press-release/nasa-progresses-toward-spacex-resupply-mission-to-space-station>). **3:** Contour Crafting Robot—Behnaz Farahi/NASA; Made In Space 3D printer—(https://www.nasa.gov/sites/default/files/_elg6172.jpg); Astronaut on the ISS—NASA (<https://www.nasa.gov/sites/default/files/iss042e046048.jpeg>); 3D-printed tool—Made in Space (https://www.nasa.gov/sites/default/files/ratchet_pic1.jpeg). **1-1–1-4:** Experimental setup photos—April Lanotte/NASA. **1-4:** Model of 3D printed habitat—Contour Crafting. **2-1:** Model of 3D printed habitat and illustration of 3D-printed building—Contour Crafting. **Back cover:** Illustration of Mars settlement—NASA; sand mixture in ice cube tray—April Lanotte/NASA; Astronaut on the International Space Station—NASA (<https://www.nasa.gov/sites/default/files/iss042e046048.jpeg>); Contour Crafting robot on the moon—Behnaz Farahi/NASA.

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