National Aeronautics and Space Administration

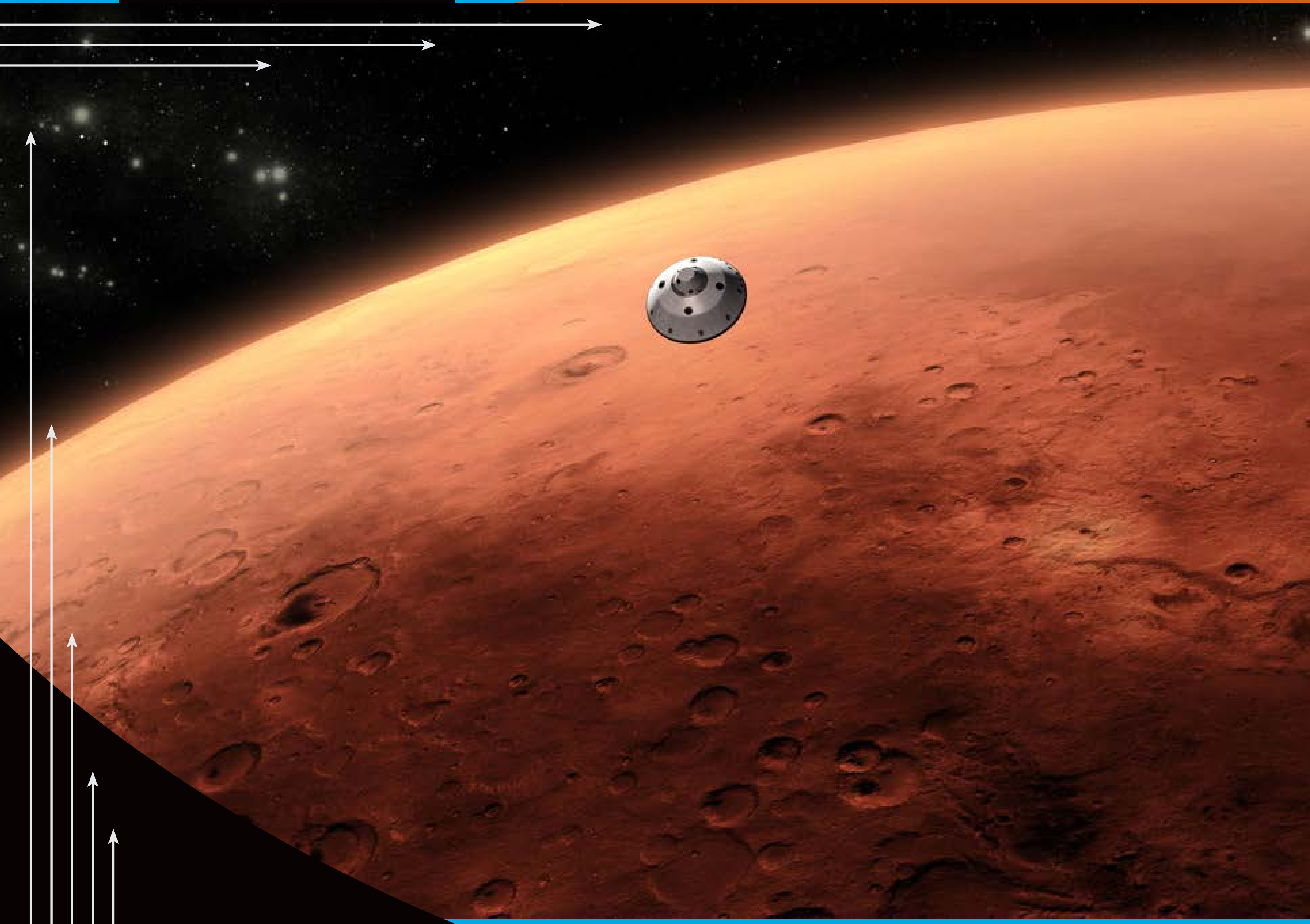
Tech Logic
LESSON SERIES

You Can't Take It All With You

Additive Construction with Mobile Emplacement (ACME)

GRADES 6–12

STUDENT ACTIVITY GUIDE



EXPLORE SPACE TECH

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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** materials 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.

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.

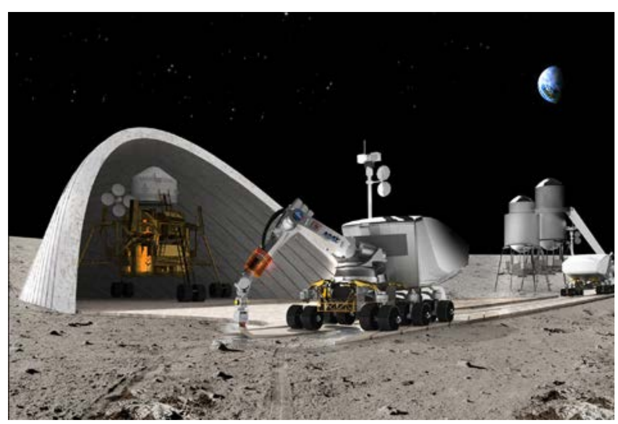
Every kilogram of material sent into space requires lots of fuel, takes up valuable cargo space, and usually needs to be replaced by more materials created and prepared on Earth. Once materials arrive in space, astronauts need to unpack and manage these materials. This is why reusability is crucial on 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 Sebatier 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!

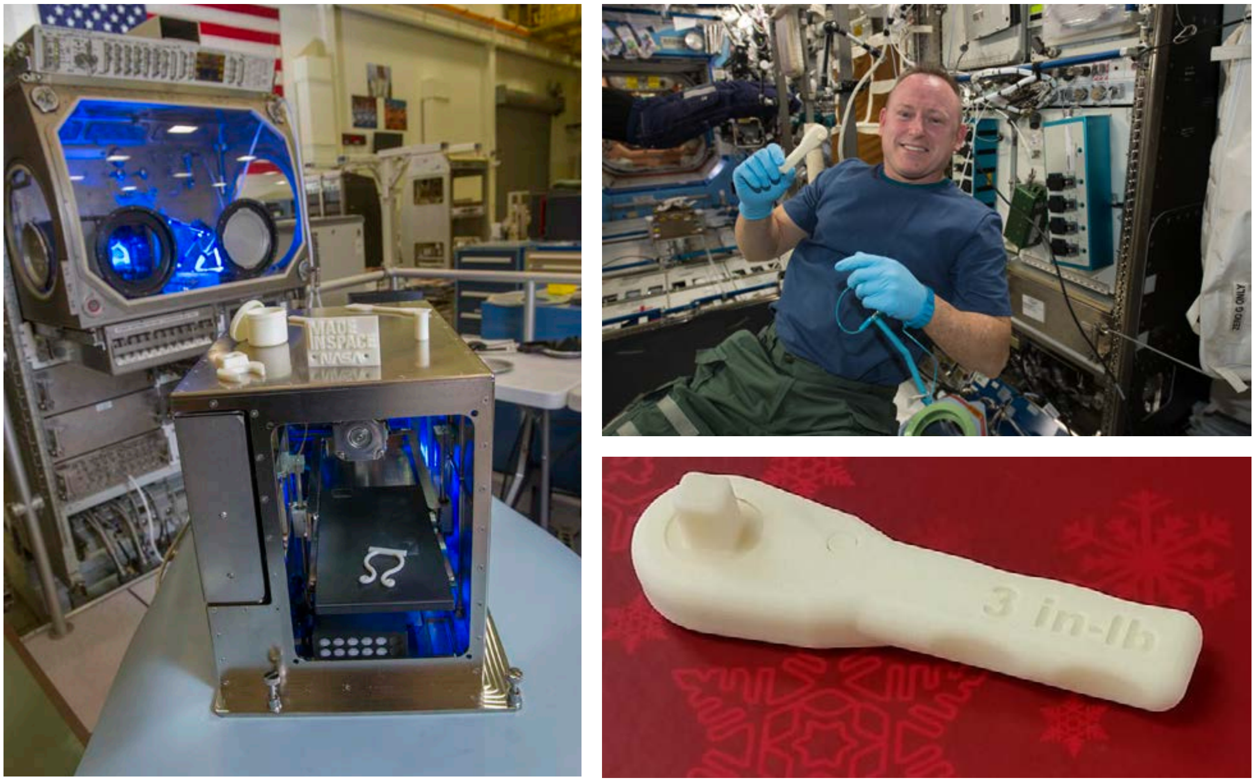
The Bigelow Expandable Activity Module (BEAM), developed for NASA by Bigelow Aerospace, is lifted into SpaceX's Dragon spacecraft for transport to the International Space Station.

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



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.

on Earth and delivered to the space station as a file, ready for 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.

Activity 1: Utilizing In Situ Resources

For the first part of this activity, you will become a **materials engineer**. Using sand, glue, and water, representing in situ resources found on Mars, you will create building bricks that can be used to build a Martian structure. For the optional part of this activity, you will develop a new material (using the same ingredients listed above) that can be used to "3D print" a structure.

Next, you will become a **structural engineer** as you design and build a Martian structure with your bricks and/or print the media you created. You can use a limited amount of "Earth-based materials" (wooden craft sticks and aluminum foil) to add strength and stability to your structure. 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, you may be asked to calculate the square footage, perimeter, volume, or other aspects of their structure.

Note: *This activity is messy! Cover tables with newspaper or tablecloths.*

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) and/or
- 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 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: Your teacher can instruct you to 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.

Procedures

Engagement Activity

Consider what items you would take with you if you were going on vacation. How would the items you need change if you were staying in a hotel? What about camping in an RV? What if you were backpacking and needed to carry everything yourself?

How is this different from what early American and western settlers needed to take with them when they traveled to new lands? Furthermore, how is this different from what future space explorers will need to bring to other planetary bodies?

Part One: Materials Engineering

1. Mix together sand, glue, and water in order to create a dough-like material.
2. Record how much sand, glue, and water is used in materials engineering data sheet section of this student activity guide.
3. Prepare ice cube trays by lining them with plastic wrap or coating them with cooking spray or petroleum jelly. Spoon the building mixture in to each well of one ice cube tray. Each well should be packed tightly in order to make the most compact bricks possible.

   Advanced version: Create custom molds of differing sizes for your bricks by using cardboard, cardstock, foam board or similar materials. Once completed, prepare your molds using plastic wrap and spoon the building mixture into the molds. Pack tightly.

4. Set ice cube tray aside and allow to dry.
5. Using the same mixing bowl, 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 and pack tightly.
6. Record how much of each material you used for the second set of bricks in your materials engineering log.
7. Set the ice cube tray aside and allow the bricks 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.*

8. Carefully remove the bricks from the ice cube tray. Following your teacher's specific instructions, analyze the bricks created and record this on the data sheet on the following page.

Materials Engineering Data Sheet

	Materials/Amounts Used	Data and Observations	Analysis and Conclusions
Test Batch 1			
Test Batch 2			

Part Two: Structural Engineering

1. Once your Martian bricks are dry and ready for use, complete the Structural Design section of your activity guide. Work with your assigned group to design a structure. Include a detailed, labeled sketch of your design in the space provided in this student activity guide. Your group should decide on any other materials you want to use in your structure, such as aluminum foil and/or wooden craft sticks. Your design should include one door and one window. Carefully design your structure so as little light as possible penetrates the structure in order to best protect the astronauts inside.
2. Using graph paper as a building surface, construct your Martian structure. No glue or other adhesives can be used to build your structures.
3. Once your structure is completed, trace the outline of your structure and record all measurements on the graph paper and/or in your structural engineering data sheet. As instructed by your teacher, complete all assigned calculations, including volume, square footage, perimeter, etc. Record all measurements in your data sheet. If design parameters were provided prior to construction, make sure your group complies with these design constraints.

Structural Engineering: Design

Use the space below to draw a detailed design for your structure, be sure to comply with all assigned design parameters.

Structural Engineering Data Sheet

Use the space below to record your structure's measurements and complete all assigned calculations.

Quality Control Test and Evaluation

1. Test your Martian structure for quality of construction and ability to protect any astronauts inside by shining a bright light on the structure. Look for areas where the light shines through to the inside of the structure.
2. Record the results of this quality control test and any observations about build quality and ideas for improvement.
3. If time permits, you may make corrective changes to your structure and retest. Record all additional steps, observations, and results if you retest your structure.
4. Share your findings and results with your class; your teacher will provide guidance on how best to complete this task.

Quality Control Test Data Sheet

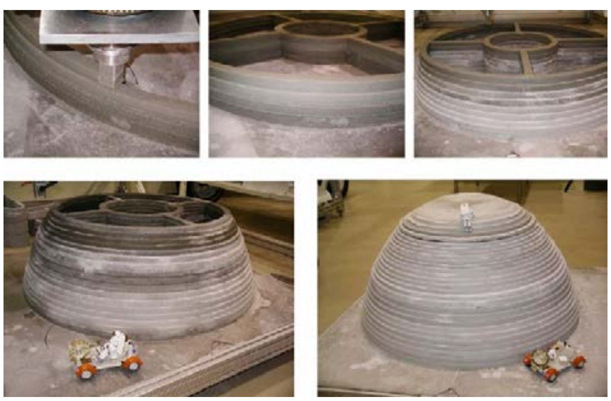
	Test Results and Observations	Suggested Improvements	Analysis
Test 1			
Test 2			

Optional Activity

Have you ever watched a 3D printer extrude plastic? ACME is studying the feasibility of using in situ resources for additive manufacturing, commonly referred to as 3D printing, to build structures on other planetary bodies. For this activity, you will simulate 3D printing and develop a mixture of 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. Create another mixture using sand, rock (if desired), water, and glue. Keep in mind that this 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, construct a structure (or part of a structure) by carefully extruding the sand mixture through the nozzle of the cake decorating bags.
3. Once your "3D printed" structure is completed, collect all measurements and data as instructed by your teacher. Record your data in your Materials Engineering Data Sheet.



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.

Materials Engineering Data Sheet: Print Material

	Materials/Amounts Used	Data and Observations	Analysis and Conclusions
Print Material Mixture			

Activity 2: Building Structures with Additive Manufacturing

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

Examples of 3D printed habitats.

Procedures

Engagement Activity

As instructed by your teacher, list all materials required to construct a house. If you were to use additive manufacturing, which utilizes 3D printing technology, to build a house, how would that change the materials needed? Can you identify any potential benefits and/or problems of using additive manufacturing to build houses?

Activity

1. Your teacher will assign your group the specific type of building you are responsible for designing (living quarters, research lab, storage facility, etc.), along with any design constraints. List the components 3D printed structures still require to be functional, such as electricity, plumbing, windows, etc. You should keep these components in consideration as you design the building.

NOTE: *You do not need to design or print the entire structure in one piece; however, structures should be easily assembled once printed.*

2. Using graph paper or the space provided in your activity guide, work with your group to design your Martian building. Be sure to label the different parts of your building. Submit your design to your teacher to review and approve.

3. Use 3D printer/CAD (computer aided design) software to prepare and print your structure. Assemble your structure, if necessary.

Evaluation

Test your structure’s ability to “shield radiation” and protect the astronauts inside by shining a bright light on the structure and looking for areas where light permeates the structures. Record your results, observations about build quality, and ideas for improvement in your data sheets.

Building function: ______________________________

List building components to be added after printing (electricity, wiring, etc.): ______________________________

____

____

____

Design:

Approval signature: ______________________________

Activity 3: Excavation and Preparation

ACME is also interested in excavation and ways to manage and handle the material that is excavated in order to continuously produce in situ feedstock. This requires continuous excavation, size-sorting, and a delivery system. For this design challenge, you will construct a mechanism that can accomplish these three tasks. To do this, you will excavate materials from a container that contains various-sized objects—your mechanism needs to scoop, size-sort, then deliver each type of object to a specified location.

Materials Needed

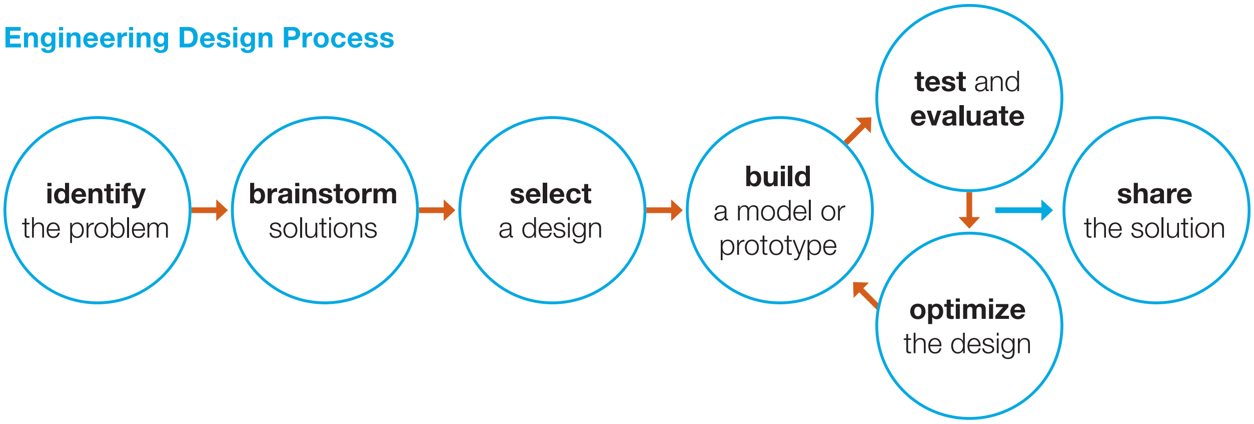
- A variety of gears and other building materials
- Sand, gravel, and/or small rocks and beads of varying sizes
- Large containers for mixed media (one per group)
- Small containers to use for holding sorted materials (one set per group)
- *Optional:* Programmable robot to automate the sorting and delivery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

Procedures

We need different materials and systems if we have robots on Mars versus humans on Mars. On the chart below, create a list of what is needed for robots/rovers and what is needed for humans. When you finish, be prepared to discuss your lists with others.

Robot/Rover Resources Needed on Mars	Human Resources Needed on Mars

Engineering Design Process



Both robotic and human needs on Mars include the need for in situ resources that can be mined or excavated on the planet. Much of this work will be automated, with little human oversight. You will now work with your teammates to design a mechanism that can excavate, sort, and deliver materials. You will be provided materials to use, any robotics technology you might have available, and rules for your design challenge. Engineering follows the Engineering Design Process, which is found above.

Since you’ve already been provided with the problem, the next step is to brainstorm a solution(s), followed by selecting a design. Each person in your group should develop an idea(s) for the mechanism you will build. This can be first done individually, or it can be done as a group from the beginning. Use the space below to brainstorm your ideas. Get your design approved before starting to build your design.

Design:	**Materials needed:**
	Design considerations (What guidance were you provided? Are there any limitations? Summarize what your mechanism needs to do.):
	Approval:

About this Lesson

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In collaboration with the

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National Aeronautics and Space Administration
Washington, DC

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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*); Contour Crafting Robot—Behnaz Farahi/NASA. **3:** Made In Space 3D printer—*https://www.nasa.gov/sites/default/files/_elg6172.jpg*); Astronaut on the International Space Station—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*). **1-1–1-2:** Experimental setup photos—April Lanotte/NASA. **1-6:** Experimental setup photos—April Lanotte/NASA; Model of 3D printed habitat—Contour Crafting. **2-1:** Model of 3D printed habitat, 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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