Activity Three: Print a Lunar Habitat

EDUCATOR NOTES

Learning Objectives

Students will

- Understand the necessity of in-situ resource utilization (ISRU) for supporting sustainable lunar surface exploration
- Design and construct a model lunar habitat using an additive manufacturing process with simulated lunar concrete

Challenge Overview

In this challenge, students learn the importance of being able to use materials already available on the lunar surface in the construction of lunar base infrastructure. They will then design a lunar habitat and create a model of their design using a process that mimics 3D printing.

Suggested Pacing

120 to 180 minutes total spread out over 3 to 4 days.

National STEM Standards

Science and Engineering (NGSS)	
Disciplinary Core Ideas • MS-ETS1-2 Engineering Design Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem. • MS-ETS1-4 Engineering Design 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*** • Constructing Explanations and Designing Solutions: Apply scientific ideas or principles to design an object, tool, process, or system. • Engaging in Argument from Evidence: Argumentation is the process by which explanations and solutions are reached. • Develop a model to generate data to test ideas about designed systems, including those representing inputs and outputs.
Technology (ISTE)	
Standards for Students • Innovative Designer: Students use a variety of technologies within a design process to identify and solve problems by creating new, useful, or imaginative solutions	***Standards for Students (continued)*** • Global Collaborator: Students use digital tools to broaden their perspectives and enrich their learning by collaborating with others and working effectively in teams locally and globally.

Challenge Preparation

- Read the Introduction and Background section for this guide and the Educator Notes for this activity
- Print one student handout for each team
- Choose a recipe for your simulated lunar cement. Each team will likely need 4-6 cups of simulated cement to complete the activity. You can make it ahead of time, or have students help make it as part of the activity. If making it ahead of time, keep it sealed in plastic bags to keep it from drying prematurely. Two example recipes are given below, or you may research/create your own.
- Drywall Compound Based Cement
  - 4 cups of lightweight drywall compound
  - 1 cup of white glue or latex paint
  - Mix well until smooth
- Flour Based Cement
  - 3 cups of flour
  - 2 tablespoons of salt
  - 2 cups of warm water
  - 1 cup white glue
  - Mix well until smooth

Materials

- One student handout per team
- Scratch paper and writing utensils

- Large sheet of sturdy cardboard per team (approx. 24 inches x 24 inches)
- Large disposable cake decorating bags
- Large bowls
- Sink
- Paper Towels
- Scissors
- Large spoons or spatulas
- Simulated lunar cement (see challenge preparation for recipes)
- Sand and or fine gravel
- Small latex or non-latex balloons
- Extra scraps of cardboard

Safety

- Ensure students are mindful of any potential student allergies regarding the supplies used in this activity
- Ensure students wear eye protection when handling drywall compound and glue
- Ensure students wash hand if any drywall compound or glue gets on their hands
- Ensure students practice classroom safety while performing this activity and avoid creating slip hazards due to spills. Any floor areas that may get wet should be protected from foot traffic.
- Ensure students practice safe cutting techniques when using scissors and carefully support the piece being cut while using care on the placement of the hand not holding the scissors
- Ensure students avoid moving around the room with scissors or other sharp objects
- If you have any student with a latex allergy, wash the balloons before using. Have allergic students wear non-latex plastic gloves and inflate the balloons with a balloon pump (or form small teams and give the balloon handling part of the activity to non-allergic students).

Introduce the Challenge

- Provide context for this activity using the Information and Background section in this guide:
  - Discuss how difficult it is to launch heavy materials into space and how it is orders of magnitude more difficult to transport them to the surface of the Moon. How does this make In-Situ Resource Utilization (ISRU) important?
  - Discuss additive manufacturing and how we are now able to use 3D printers to make items out of a variety of materials. Ask the students if they think something as large as a house could be 3D printed on the Moon.
- Share the video "Teams Build 3D-Printed Habitats for Moon and Mars": https://youtu.be/-HT_MhzYkus Tell the students that they will be challenged to design and print a much smaller scale lunar habitat.
- Group students into teams of three to five. Consider assigning roles and tasks to individual students within the team. See the Teamwork section at the beginning of the guide for suggestions.
- Distribute the student handout and scratch paper to each team
- Explain the challenge to students:
  - Each team will be designing a habitat that can sustain a crew of four astronauts on the lunar surface
  - A 2D footprint of their design will be transferred onto a sheet of cardboard like a floor plan of a house
  - The size of the floor plan should not exceed 12x18 inches
  - Their 2D footprint will serve as the template for teams to 3D print their habitats using simulated lunar cement

Criteria	Constraints
Designs must contain necessary areas for a crew of four astronauts.	Simulated lunar cement cannot be applied by smearing or with any tool other than the frosting bag.
Design must fit on the cardboard sheet provided.	The size of the floor plan should not exceed 18x24 inches.
Must build the habitat by using 3D printing supplies provided by the teacher.	
May use inflated balloons or other items to support the roof of the structure as long as such items can be removed after structure dries.	

Facilitate the Challenge

ASK

- Share and discuss the following questions:
  - How much indoor space do you require to live?
  - What about your whole family?
  - What kind of separate spaces are needed in a house?
    - Possible answers: kitchen, bathroom, bedrooms, living room, etc.
  - If you had to downsize your living space, how could you minimize any of those separate spaces?
    - Possible answers: share bedrooms, sleep in living room, smaller kitchen/bathroom, etc.

IMAGINE

- Have the students imagine they had to live and work in a habitat on the lunar surface in a team of four. Discuss the other types of spaces they would need in their habitat.
  - Possible answers: Laboratories, storage space, an airlock
- Remind students that they will be tasked with making a 3D printed model of a lunar habitat and that it must contain all the spaces needed for a crew of four astronauts to live and work in space
- Ask them to discuss what their design could look like. Remind them to consider the build process as part of their design. The whole structure must be 3D printed from the ground up, using the simulated lunar cement. Additional materials, such as an inflated balloon, may be used to support the roofs during construction, but such item(s) must be removed after the structure dries.

PLAN

- On sheets of paper, have each team draw plans of what their lunar habitat will look like. The drawing must include an exterior shot to show its architectural shape as well an interior floor plan to show the layout, with the purpose of each room labeled.

CREATE

- Using their interior floor plan as a guide, have each team transfer their floor plan onto a large sheet of cardboard. The cardboard should be large enough that each room will be clearly defined when the model is complete, but not so large that it wastes materials and is too flimsy to construct.
- If breaking this activity into several days, this would be a good place to pause the activity for the first day
- For the 3D printing portion of the activity, pass out to each team:
  - Their cardboard floor plan templates
  - Premade simulated lunar cement (or the ingredients to make it themselves)
  - A few cake decorating bags
  - Scissors
  - Spoon or spatula

Share With Students

Brain Booster

European Space Agency astronaut Alexander Gerst works on the MICS experiment aboard the International Space Station

The Microgravity Investigation of Cement Solidification (MICS) project allows the testing of cement solidification in microgravity environments aboard the International Space Station. They can even use centrifuges aboard the station to test the low environment conditions on the Moon and Mars.

Learn more: www.youtube.com/watch?v=IsiyNZeUfUU&t=9s

On Location

Wide-angle view into the test chamber of the Space Environments Complex (SEC)

The Space Simulation Vacuum Chamber at NASA's Glenn Research Center is the world's largest vacuum Chamber. This facility allows NASA to test large pieces of equipment, including large-scale 3D printers, in an environment similar to that of the lunar surface.

Learn more: www1.grc.nasa.gov/facilities/sec/

    - Sand and or fine gravel
    - Cardboard scraps
- First students will test their simulated lunar cement; then they will adjust the mixture to find the right consistency that works for them. You want the consistency to be thick enough to be stack layers on top of each other, but not too thick to squeeze from the bag.
    - Have the students spoon a small amount of simulated lunar cement into a cake decorating bag
    - They should cut just a small amount off the tip of the bag to make a small hole.
    - Have the students use scrap pieces of cardboard to practice extruding the simulated lunar cement in straight and curved lines as well as trying to stack lines on top of each other to build three-dimensional shapes
    - Invite the students to experiment with the consistency of their cement by adding sand and/or fine gravel to the mixture

  Note: Adding sand and/or fine gravel to the cement will make it stronger and thicker, similar to how adding aggregate strengthens concrete. Adding too much, though, may make it more difficult to squeeze the cement from the cake decorating bags.
    - Students may also experiment with the size of the hole in the tip of their cake decorating bags. A larger hole will extrude a thicker and wider layer of cement with each pass. Have the students be careful not to cut too much off. The ideal thickness will be between 0.5 and 0.75 cm (or about ¼ to ½ inches) thick.
- Once the teams have made the adjustments to their simulated lunar cement mixtures, they can begin building the walls of their habitats, following the floor plans they created. Encourage the students to try making consistent lines around the perimeter and any interior walls, making each pass blend into the one below it, and trying to stay as level as possible.
- Once the teams have reached the maximum heights of their walls, and before they begin to add their roofs, have them pause
- If breaking this activity into several days, this would be a good place to pause the activity for the day. Have the students seal up any remaining simulated lunar cement in plastic resealable plastic bags and clean their workstations. They should very carefully place their incomplete models in a safe place until it is time to resume the activity. Their current walls should start to dry overnight.
- When the teams are ready to resume their models, have them carefully return them to their workstations
- Pass out the supplies needed to extrude the simulated lunar cement, and pass out small balloons and scraps of cardboard
- Allow students to decide how they are going to support the roof structure as they are printing it. Balloons can be inflated to the size they need to create domes. Cardboard can be cut to make arches or other shapes. To prevent the simulated lunar cement from permanently bonding to the temporary support structures, they can be dusted with powder or flour.
- Once the teams have completed the roofs of their lunar habitats, have them once again carefully place their models in a safe place to dry. Have teams clean their workstations.
- After the structures have dried, have the teams carefully remove any of the temporary supports they used to support the construction of the roof
- Their habitat models are now complete

TEST

- Have the teams inspect their lunar habitat models:
    - Do they have any damage?
    - What was the source of the damage? (Cracking from drying, bad adhesion, fell under its own weight, etc.)
- Perform some structural tests on the models. Have the students record the results.
    - Light shaking to simulate a Moon quake
    - Drop a small object such as a marble or coin on the model from a height of one meter to simulate a meteor impact
    - Toss a handful of sand and/or fine gravel at the model to simulate debris kicked up from the thrust of a landing or departing rocket

IMPROVE

- If time and supplies permit, allow students to repair any damage to their lunar habitat models

SHARE

- Have each team present their lunar habitat to the class, explaining their design and build process. The teams should also include answers to the following questions in their presentation.
  - What challenges did you face in the design and building of your lunar habitat model?
  - How did you overcome those challenges?
  - What was one contribution that each team member made to the project?
  - What idea, design, or technique did you implement that you think was novel or creative?
  - What was something about another team's model that impressed you?

Extensions

- Have the students try different recipes or ratios of ingredients to make several batches of different simulated lunar cement and build sample walls from each. When structures are dry, have the students come up with different tests to determine the strengths and weaknesses of each recipe.

Resources

- "NASA Report Outlines Plan for Sustained Moon Presence": https://appel.nasa.gov/2020/04/28/nasa-report-outlines-plan-for-sustained-moon-presence/#:~:text=In%20early%20April%2C%20NASA%20released%20a%20document%20prepared,required%20for%20the%20first%20human%20mission%20to%20Mars
- "In-situ resource utilization": www.nasa.gov/isru
- "NASA ScienceCasts: Cementing Our Place in Space": https://youtu.be/lsiyNZeUfUU

Activity Three: Print a Lunar Habitat

STUDENT HANDOUT

Your Challenge

Your challenge is to work as a team to design a lunar habitat for a crew of four astronauts. You will then transfer a floor plan, based on your design, onto a sheet of cardboard. Next you will use your floor plan as the template to begin making a model of your habitat with simulated lunar cement and 3D printing techniques.

Criteria	Constraints
Designs must contain necessary areas for a crew of four astronauts.	Simulated lunar cement cannot be applied by smearing or with any tool other than the frosting bag.
Design must fit on the cardboard sheet provided.	The size of the floor plan should not exceed 18x24 inches.
Must build the habitat by using 3D printing supplies provided by the teacher.	
May use inflated balloons or other items to support the roof of the structure as long as such items can be removed after the structure dries.	

? ASK

- Consider the following questions and discuss with your class as directed by your teacher:
  - How much indoor space do you require to live?
  - What about your whole family?
  - What kind of separate spaces are needed in a house?
  - If you had to downsize your living space, how could you minimize any of those separate spaces?

IMAGINE

- Imagine that you had to live and work in a habitat on the lunar surface in a team of four. Discuss the other types of spaces you would need in your habitat.
  - Remember that you will be tasked with making a 3D printed model of a lunar habitat and that it must contain all the spaces needed for a crew of four astronauts to live and work in space
  - What would your design look like? Remember to consider the build process as part of your design. The whole structure must be 3D printed from the ground up, using the simulated lunar cement. Additional materials such as an inflated balloon or pieces of cardboard may be used to support the roofs during construction but they must be removed after the structure dries.

Share With Students

FUN FACT!

Did you know that NASA has held competitions among universities and industry partners to develop designs and 3D printing techniques for a lunar habitat? These types of competitions allow multiple organizations to all approach a problem from unique perspectives, increasing innovation.

3D printed model of a lunar habitat created by Pennsylvania State University as part of NASA's 3D-Printed Habitat Challenge.

Learn more: www.nasa.gov/directorates/spacetech/centennial_challenges/3DPHab/index.html

CAREER CORNER

Nathan Gelino, a principal investigator with the Exploration Research and Technology programs at Kennedy, examines a Zero Launch Mass 3D printer in the Granular Mechanics and Regolith Operations Laboratory

Nathan Gelino is a principal investigator and lead of 3D printing projects at Kennedy Space Center's Swamp Works. The Swamp Works team's mission is to rapidly develop technologies needed to live and work on the surface of the Moon.

Learn more: https://www.nasa.gov/feature/kennedy-to-partner-with-previous-nasa-challenge-winner-for-lunar-research

PLAN

- On sheets of paper, draw plans of what your lunar habitat will look like. The drawings must include an exterior shot to show the habitat's architectural shape as well an interior floor plan to show the layout with the purpose of each room labeled.

CREATE

- Using your interior floor plan as a guide, transfer your floor plans onto a large sheet of cardboard provided by your teacher. The cardboard should be large enough for each room to be clearly defined when the model is complete, but not so large that it wastes materials and is too flimsy to construct.
- For the 3D printing portion of the activity, your teacher will provide
  - Your cardboard floor plan templates
  - Premade simulated lunar cement (or the ingredients to make it yourselves)
  - A few cake decorating bags
  - Scissors
  - Spoon or spatula
  - Sand and or fine gravel
  - Cardboard scraps
- First, test your simulated lunar cement; then adjust the mixture to find the right consistency that works for you
  - Spoon a small amount of simulated lunar cement into a cake decorating bag
  - Cut just a small amount off the tip of the bag to make a small hole
  - Using scrap pieces of cardboard, practice extruding the simulated lunar cement in straight and curved lines as well as trying to stack lines on top of each other to build three-dimensional shapes
  - Experiment with the consistency of your cement by adding sand and/or fine gravel to the mixture. You want the consistency to be thick enough to be stack layers on top of each other, but not too thick to squeeze from the bag. Note: Adding sand and/or fine gravel to the cement will make it stronger and thicker, similar to how adding aggregate strengthens concrete. Adding too much, though, may make it more difficult to squeeze the cement from the cake decorating bags.
  - Also experiment with the size of the hole in the tip of their cake decorating bags. A larger whole will extrude a thicker and wider layer of cement with each pass. The ideal thickness of each layer is between 0.5 and 0.75 cm (or about ¼ to ½ inches) thick. Be careful not to cut too much off the tip of the bag.
- Once your team has made your adjustments to your simulated lunar cement mixtures, you can now begin building the walls of your habitat, following the floor plans you created. Try and make consistent lines around the perimeter and any interior walls, making each pass blend into the one below it, and try to stay as level as possible.
- Once your team has reached the maximum heights of your walls and before you begin to add your roof, pause and wait for your teacher's instructions
- Your teacher will now also pass out small balloons and scraps of cardboard
- Decide how your team is going to support the roof structure as you are printing it. Balloons can be inflated to the size you need to create domes. Cardboard can be cut to make arches or other shapes. To prevent the simulated lunar cement from permanently bonding to the temporary support structures, they can be dusted with powder or flour.
- Once your team has completed the roof of your lunar habitat. Carefully place the model in a safe place to dry and clean your workstations.
- After the structures have dried, carefully remove any of the temporary supports you used to support the construction of the roof
- Your habitat model is now complete

TEST

- Inspect your lunar habitat model:
  - Does it have any damage?
  - What was the source of the damage?
- Your team will now perform some structural tests on your model. Record any damage to your model habitat.
  - Lightly shake the model to simulate a Moon quake

- Drop a small object on the model, such as a marble or coin, from a height of one meter to simulate a meteor impact
- Toss a handful of sand and/or fine gravel at the model to simulate debris kicked up from the thrust of a landing or departing rocket

IMPROVE

- If time and supplies permit, repair any damage to your habitat model

SHARE

- Prepare to present your lunar habitat to the class, explaining design and build process. Your team should also include answers to the following questions in their presentation:
  - What challenges did you face in the design and building of your lunar habitat model?
  - How did you overcome those challenges?
  - What was one contribution that each team member made to the project?
  - What idea, design, or technique did you implement that you think was novel or creative?
  - What was something about another team's model that impressed you?