National Aeronautics and Space Administration

NASA EXPLORATION EXPERIENCE

STUDENT GUIDE

NASA Office of STEM Engagement Next Gen STEM

Developed in collaboration with AIAA and Students To Launch. Activity photos provided by Students To Launch.

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NASA EXPLORATION EXPERIENCE

SPACESUIT GLOVE DEXTERITY

STUDENT GUIDE

Welcome, Exploration Experience team members!

ACTIVITY BRIEFING

In this activity, you will be performing tests that will help NASA engineers better understand how **spacesuit** gloves might impact the **dexterity** of astronauts working on the surface of the Moon. Be sure to complete your tasks, assist others as needed, and remember to follow the instructions!

This activity is a testing session. You will be working in teams of two. Your team will test spacesuit gloves to see how they influence comfort and efficiency in tasks carried out on the Moon.

GOOD LUCK!

Caption: Astronaut Clay Anderson, Expedition 15 flight engineer, waves to the camera while participating in a session of extravehicular activity (EVA) as construction continues on the International Space Station. Credits: NASA

Developed in collaboration with AIAA and Students To Launch. Activity photos provided by Students To Launch.

JOB CLASSIFICATION TASK SHEET

This Task Sheet can be referenced throughout the activity to remind you of your responsibilities. Each member of your team will have the opportunity to take on the role of a Space Suit Engineer and a Test Facilitator.

Space Suit Engineer

- Try on the spacesuit gloves
- Provide feedback on the fit and comfort of the spacesuit gloves
- Complete as many bolt, washer, and wing nut assemblies as possible in 1 minute without spacesuit gloves
- Complete as many bolt, washer, and wing nut assemblies as possible in 1 minute with spacesuit gloves

Above: An astronaut performing a glove inspection on the International Space Station Credit: NASA

Test Facilitator

- Use a stopwatch to start and stop the 1 minute (60 second) test trial
- Record the number of bolt, washer, and wing nut assemblies completed by the Space Suit Engineer without wearing the spacesuit gloves
- Record the number of bolt, washer, and wing nut assemblies completed by the Space Suit Engineer while wearing the spacesuit gloves

Watch the Working With Spacesuit Gloves video

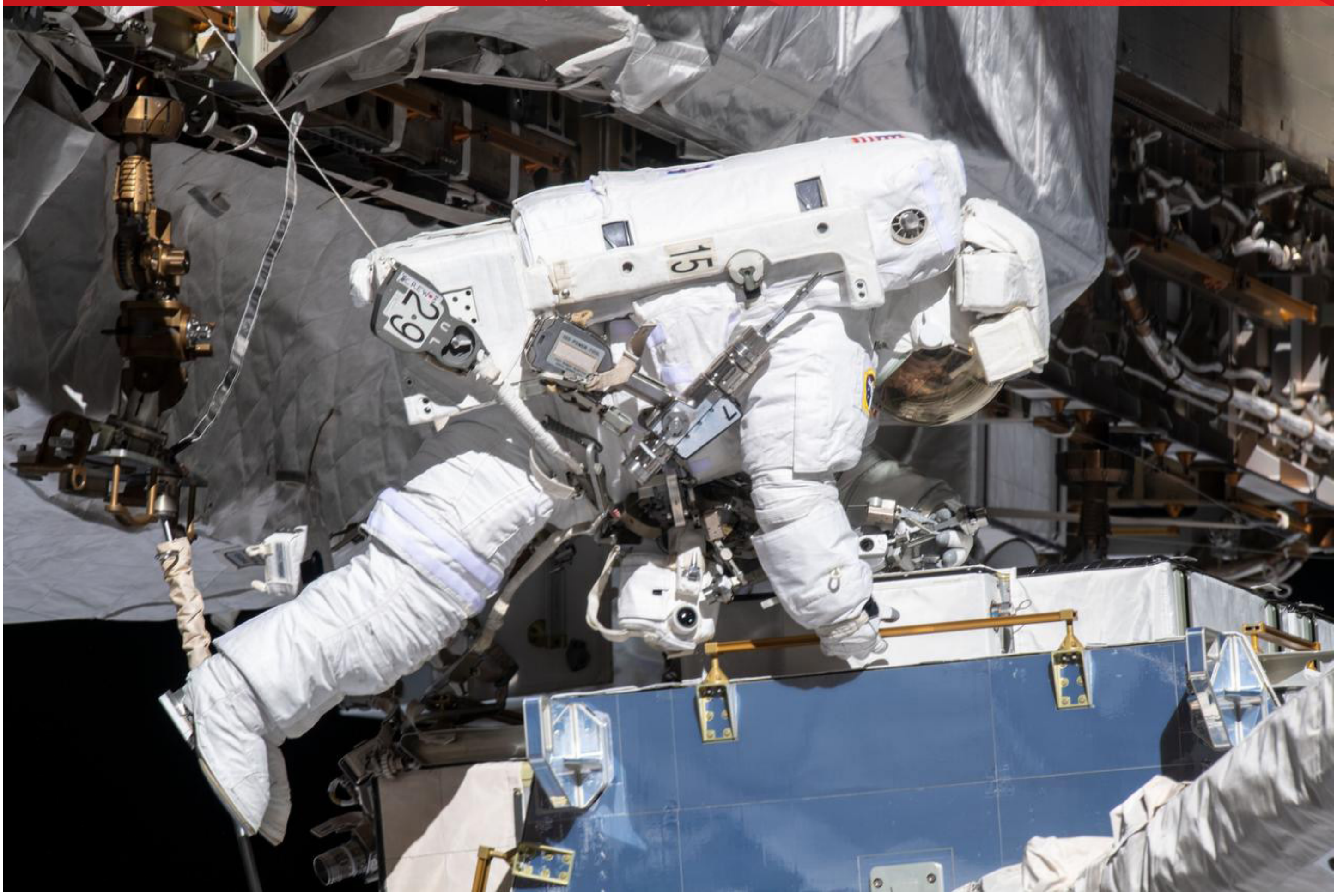
www.youtube.com/watch?v=AqaG40I1bh0

MATERIALS NEEDED

Qty	Testing Materials	Qty	Templates / Pages
20	3/8 in x 1 in bolts	1	Space Glove Dexterity Data Recording Sheet
20	3/8 in wing nuts		
20	3/8 in flat washers	**Qty**	**Tools**
1	Pair of nitrile (non-Latex) coated gloves	1	Stopwatch
1	Pair of nitrile exam gloves		
1	Pair of cotton or polypropylene liner gloves (cut-resistant gloves)		

Above: CAPE CANAVERAL, Fla. – These newly designed gloves were entries in the 2009 Astronaut Glove Challenge, part of NASA's Centennial Challenges Program, at the Astronaut Hall of Fame near NASA's Kennedy Space Center in Florida. Credits: NASA

ACTIVITY OVERVIEW



NASA astronaut Christina Koch works while tethered near the Port 6 truss segment of the International Space Station to replace older hydrogen-nickel batteries with newer, more powerful lithium-ion batteries. Credits: NASA

Tasks carried out on Earth become much more difficult under the hostile conditions of the Moon. Extreme changes in temperature represent one of the many challenges for spacewalking. Temperatures on **spacewalks** may vary from as hot as 250 ° F (121 °C) in the sunlight to as cold as –250 °F (–121 °C) in the dark. However, in the permanently shadowed region of the lunar South Pole, the temperature can reach –414 °F (–248 °C). Spacesuit gloves must be insulated to handle the low temperatures as well as strong enough to handle the sharpness of lunar dust. This means that the gloves must be insulated but also must allow the astronaut the dexterity to grip, turn, and work with a variety of tools.

In this activity, you will be working with wing nuts, bolts, and washers, examples of hardware commonly used by humans for structures on Earth and in space. Wing nuts and bolts are used to fasten things together. Washers are used with nuts and bolts to help distribute the force when tightening so that the surfaces they are being tightened against are not damaged. You will be performing tests while wearing three layers of different gloves to simulate working with spacesuit gloves. Data collected from these tests will help Space Suit Engineers design tools and work procedures that can be effectively used by humans wearing spacesuit gloves while living and working on the Moon.

SAFETY CONSIDERATIONS

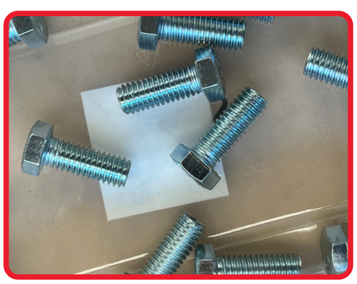
Be sure to follow all safety guidelines from your Mission Director and clean up your work area as you progress.

- Students should clean up as they go
- Ensure all hardware stays on the work surface and does not roll onto the floor where it could become a slip/trip issue if stepped on. Use a plastic container/dish to store all small hardware so it does not roll away and onto the floor.

PRACTICE HARDWARE ASSEMBLY

Follow the steps below to prepare for testing!

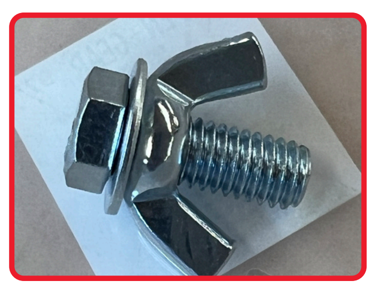
STEP 1: These are bolts. Count the bolts to make sure there are at least 20 in their container.



STEP 2: These are washers. Count the washers to make sure that there are at least 20 in their container.

STEP 3: These are wing nuts. Count the wing nuts to make sure there are at least 20 in their container.

STEP 4: Slide one of the washers onto a bolt. Twist a wing nut onto the bolt until tight. A completed assembly will look like this.



TRY ON THE SPACESUIT GLOVES

STEP 1: Choose a team member to be the Space Suit Engineer. The Engineer should put the moisture absorbing comfort layer on first.

STEP 2: Now put on the vapor barrier layer. Your teammate can assist you. Take your time so you do not tear this layer. Slide this layer down completely over each finger.

STEP 3: Next put on the outer protective layer. The three gloves should be bulky and tight but not too constrictive. If it is uncomfortable, remove them and try a larger size.

Testing Sequence

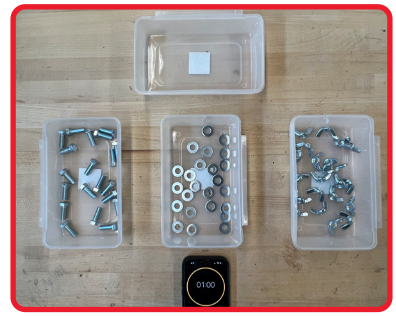
1. BEFORE beginning TESTING, each team member should predict how many hardware assemblies they think they can put together in 1 minute with and without spacesuit gloves and record the **predictions** on the Spacesuit Glove Dexterity Data Recording Sheet.
2. The Space Suit Engineer and Test Facilitator should read through steps 1-6 of the Testing Procedure.
3. Team members should stay in their roles and follow steps 1-6 of the Testing Procedure without gloves and then again with gloves.
4. Team members should then switch roles and repeat the Testing Sequence.

TESTING PROCEDURE

Be sure to read through these steps prior to testing and follow them accurately during testing!

STEP 1: The Test Facilitator should place the unassembled bolts, washers, and wing nuts in their containers as shown. An empty container for the hardware assembly should be placed above the other containers.

STEP 2: The Test Facilitator should set their countdown timer to 1 minute.



STEP 3: The Test Facilitator should say "Ready, set, go!" As soon as the Space Suit Engineer hears "go!" they should begin putting together the hardware assemblies.

STEP 4: Once a hardware assembly is completed and finger tight, the Space Suit Engineer should place the assembly in the container above the washer, wing nut, and bolt containers.

STEP 5: When the timer gets to 10 seconds, the Space Suit Engineer should count down the final 10 seconds: "10, 9, 8, 7, 6, 5, 4, 3, 2, 1" and then say, "Stop!"

STEP 6: When the Space Suit Engineer hears the word "stop", they should immediately stop assembling hardware. Incomplete assemblies do not count toward the total!

Follow these final steps!

- Count the number of washers, bolts, and wing nuts that were assembled by the Space Suit Engineer.
- Record your data in the Test Data Table in your Spacesuit Glove Dexterity Data Recording Sheet.
- Complete the rest of the Spacesuit Glove Dexterity Data Recording Sheet.

SPACESUIT GLOVE DEXTERITY DATA RECORDING SHEET

Directions: Use this data recording sheet to record your observations, predictions, and test data.

PART 1: BEFORE YOU START: MAKE A PREDICTION!

Prediction Table

Team Member Name	# of Hardware Assemblies ***without*** spacesuit gloves in 1 minute	# of Hardware Assemblies ***with*** spacesuit gloves in 1 minute
Name:		
Name:		

PART 2: TEST YOUR DEXTERITY

Test Data Table

Team Member Name	# of Hardware Assemblies ***without*** spacesuit gloves in 1 minute	# of Hardware Assemblies ***with*** spacesuit gloves in 1 minute
Name:		
Name:		

PART 3: TEST YOUR DEXTERITY

Test Data Table

Team Member Name	Notes and observations about spacesuit gloves comfort and fit and how they influence hand movement	
Name:	Comfort / Fit	Influence on Hand Movement
Name:	Comfort / Fit	Influence on Hand Movement

Describe your data: How did your prediction compare to your actual test results? Does wearing spacesuit gloves influence your dexterity? Back up your response with data from this activity.

You are a NASA engineer that has been asked to improve the spacesuit glove design. Describe three modifications, improvements, or changes you would implement.

1.

2.

3.

NASA EXPLORATION EXPERIENCE

GETTING A GRIP ON THE MOON

STUDENT GUIDE

Welcome, Exploration Experience team members!

Scientist-astronaut Harrison H. Schmitt, Apollo 17 lunar pilot and **geologist**, collects, collects lunar rake samples at Station 1 during the mission's first spacewalk at the Taurus-Littrow landing site. This picture was taken by astronaut Eugene A. Cernan, commander. The lunar rake, an Apollo lunar geology hand tool, is used to collect discrete samples of rocks and rock chips ranging in size from one-half inch (1.3 centimeters) to 1 inch (2.5 centimeters). Credits: NASA

ACTIVITY BRIEFING

Humans are returning to the Moon. To make this effort successful, Artemis astronauts will need to conduct in-depth scientific investigations on the lunar surface. This will require more advanced lunar sample collection equipment than was used during the Apollo missions. To assist in that effort, your team's task will be to use Problem-Based-Learning (PBL) to increase lunar rock sample collection rates. Your team will be constructing Apollo era inspired tools, testing them, then making modifications to increase their effectiveness. You've got this!

GOOD LUCK!

Developed in collaboration with AIAA and Students To Launch. Activity photos provided by Students To Launch.

PROBLEM-BASED LEARNING PROCESS

NASA astronauts Zena Cardman and Drew Feustel wearing mockup spacesuits after performing an engineering test run before a week of simulated moonwalks. Credits: NASA

In this experience, you will be working in a team to solve a problem using the sequence of steps shown in the flow chart to the right. A more detailed explanation of Problem-Based Learning is given below.

- Meet the Problem: Identify the problem, introduce new vocabulary, and discuss previous experiences with the problem
- Explore Knowns and Unknowns: Use resources to explore the knowns and unknowns.
- Generate Possible Solutions: Brainstorm possible solutions based on resources and prior experience with the problem.
- Consider Consequences: Examine the pros and cons of each solution to determine a viable solution
- Present Findings: Communicate and discuss the process and solutions as a team

PHASE I

Part 1: Meet the Problem

Problem Overview

Artemis astronauts need efficient lunar rock collection tools! Tasks carried out on Earth become much more difficult under the hostile conditions of the Moon. In the Apollo era, NASA design engineers developed tools based on each mission. Even with Artemis advanced spacesuits, astronauts will need better tools that can achieve the advanced scientific objectives of the Artemis mission. The tool is a system that uses multiple attachments that can be placed on a single handle, enabling use for a variety of purposes. This saves mass and uses less storage space, which is very important for space-based activities. The tool is intended to be used by astronauts on the Moon to efficiently collect lunar rock samples. Time is of the essence when working on the surface of the Moon! Your observations and innovations are vital to advancing NASA's efforts.

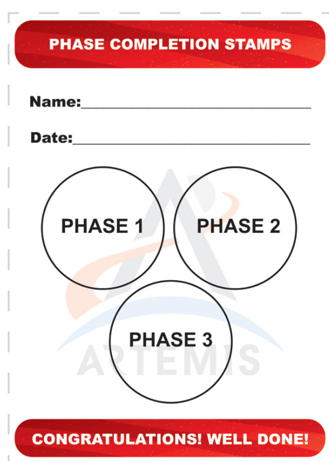
NASA officials have presented you with the following problem scenario:

Design, build, and test an Apollo era inspired tool to collect rock samples more efficiently. This tool needs to be modified based on the data and observations recorded during a test scenario.

Getting a Grip on the Moon Role Selection and Preparation

In this activity, you will be working in teams of four to solve a problem. Each member of your team will be taking on a real NASA career role. Below are the instructions for role selection and preparation.

1. Have each team member select a badge from the supply bin.
2. DO NOT trade or change your badge with your team members.
3. Have each person cut out and tape a single Stamp Card to the back of your badge. (Your team will receive your stamp cards from your Mission Directors, see example on the right.)
4. Put on your badges and the included safety glasses.
5. Each team member will now perform the specific tasks of the job listed on their badge during this activity.



Now, closely watch the Creating Artemis Tools video and then review the Job Classification Task Sheet on page 13 to answer the question on the next page.

www.youtube.com/watch?v=qv0oTVCkrUA

JOB CLASSIFICATION TASK SHEET

Based on what you heard in the video and information from the Job Classification Task Sheet, what are the individual tasks you are responsible for throughout the phases of this activity?

Have each team member write a response, in pencil, to this question in the space below.

Tools Engineer

Your Name: ______________________________

Mission Specialist - Geologist

Your Name: ______________________________

Human Factors Engineer

Your Name: ______________________________

Project Manager

Your Name: ______________________________

JOB CLASSIFICATION TASK SHEET

This Task Sheet can be referenced throughout the activity to remind you of your responsibilities.

Tools Engineer

- Build the lunar rake attachment
- Test the tool and collect tool performance data
- Redesign and build a modified lunar rake attachment
- Test the redesigned tool
- Collect redesign performance data
- Provide final recommendations to NASA for the lunar rake

Mission Specialist - Geologist

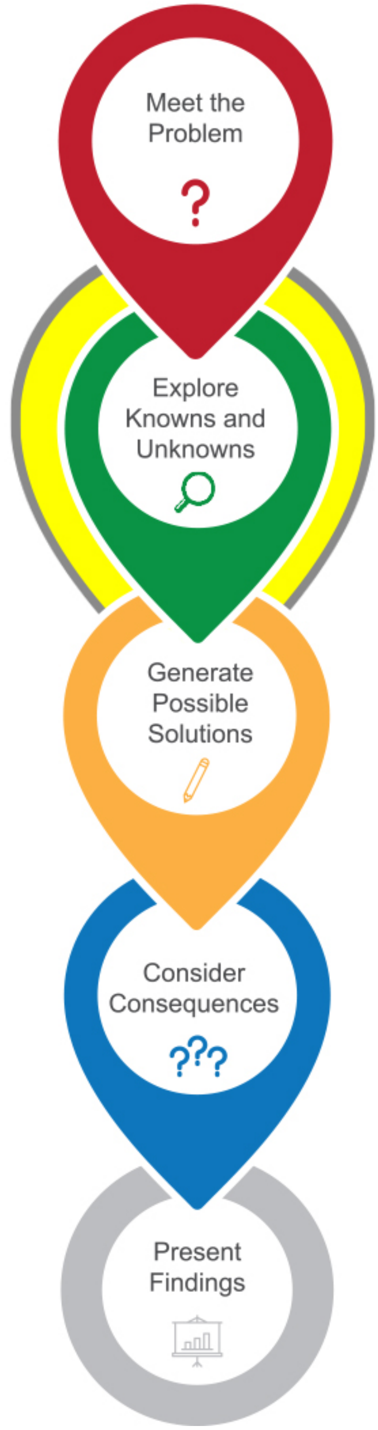
- Build the lunar collection cup attachment
- Test the tool and collect tool performance data
- Redesign and build a modified collection cup attachment
- Test the redesigned tool
- Collect redesign performance data
- Provide final recommendations to NASA for the collection cup

Human Factors Engineer

- Build the lunar tool handle
- Test the tool and collect tool performance data
- Redesign and build a modified tool handle
- Test the redesigned tool
- Collect redesign performance data
- Provide final recommendations to NASA for the tool handle

Project Manager

- Build the lunar tongs
- Test the tool and collect tool performance data
- Redesign and build modified lunar tongs.
- Test the redesigned tool
- Collect redesign performance data
- Provide final recommendations to NASA for the lunar tongs
- Assist team members with tool build responsibilities
- Contact Mission Director when each phase is complete to get a red completion sticker



Building the Getting a Grip on the Moon Tool (overview)

This step is divided into four build components, with each team member performing individual tasks overseen by your Project Manager. During the builds, you will explore knowns and unknowns related to the initial tool **prototype**. For each tool component, you will be given the build instruction pages by your Project Manager to guide you during construction. As you build, consider ways that the tool components and construction method could be improved. Once all the build components have been completed, your team will conduct testing on a simulated lunar surface to help inform potential design modifications. Take care of these pages and your build materials as you work and place the paperwork back in the binder when your task is completed.

Brief History of Lunar Sample Collection Tools

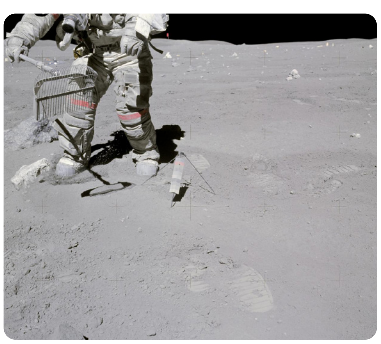
The pressure suits worn by the Apollo astronauts restricted their **mobility**, particularly their ability to bend over, while on the Moon. For this reason, special tools were designed to allow them to collect rocks and soil for return to Earth. The design of these tools changed somewhat from mission to mission as experience was gained about what worked best. The photographs shown here illustrate the general nature of these tools.

Tongs were used to pick up rock samples. Apollo 12 photograph AS12-47-6932.

Close-up view of a set of tongs, an Apollo Lunar Hand Tool, being used by astronaut Charles Conrad Jr., commander, to pick up lunar samples during the Apollo 12 extravehicular activity. This photograph shows Conrad's legs and a good view of the lunar soil. Credits: NASA

Scoops were used to collect soil samples. Several different scoop designs were used during the Apollo program. A shovel-like trenching tool was also used on one mission. Apollo 17 photograph AS17-146-22371.

Scientist-astronaut Harrison Schmitt, Apollo 17 lunar module pilot, uses an adjustable sampling scoop to retrieve lunar samples during the second Apollo 17 extravehicular activity (EVA), at Station 5 at the Taurus-Littrow landing site. Credits: NASA



Rakes were used to collect small pebbles. The tines on the rake are 1 centimeter apart. The rake was dragged through the soil and then shaken. Small particles fell through the tines and larger particles were trapped in the rake and dumped into a sample bag for return to Earth. Apollo 16 photograph AS16-116-18629.

Astronaut John W. Young collects samples at the North Ray Crater geological site during the mission's third and final Apollo 16 extravehicular activity (EVA). He has a rake in his hand, and the gnomon is near his foot. Credits: NASA

LET'S GET STARTED!

1. Inform your team's Project Manager (PM) you are ready to receive your build instructions specific to the career on your badge.
2. Locate all the build materials for your tool component from the material bin.
3. Follow your build instructions exactly and in numerical order.
4. If you need help at any point, ask your PM first. They will locate a Mission Director if they are unable to assist you directly.
5. If you find an error in your instructions, please have your PM report it immediately to a Mission Director.
6. When you are finished with the build, inform your PM. Your Project Manager will double check your work for completion and place a blue sticker in the project manager check and approve sheet located at the end of each phase in the student binder.
7. After all team members have successfully completed their Phase I responsibilities, each team member will receive a red sticker of approval on their badge from a Mission Director. This allows your team to move on to Phase II of this Mission.

Above: Artist rendering of the Apollo Moon boot print on the surface of the Moon with the Earth in the distance. Credit: NASA

MATERIALS NEEDED

Qty	Build Materials per Tool	Qty	Tools
3	Magnets	1	Permanent Marker
1	Test Rake Profile	1	Metric Ruler
1	1 in PVC Pipe	1	Scissors
1	3/4 in PVC Pipe	1	Pencil
1	1 in long Dowel Rod	**Qty**	**Fabrication Lab Station Tools**
1	4 in x 6 1/2 in Cardboard	1	Warm Melt Glue Tool
1	Steel Can or Coda Can	1	PVC Cutter
1	Masking Tape	**Qty**	**Lunar Tongs**
1	Plastic Mesh	2	Paint Sticks
1	Pool Noodle section (foam grip)	3	Rubber Bands
Several	Blue & Red or Decorative Stickers	1	Dowel Rod
Qty	**Templates / Pages**		
1	Test Rake Template		

SAFETY CONSIDERATIONS

Be sure to follow all safety guidelines from your Mission Director and clean up your work area as you progress.

- Students should wear safety goggles and cut resistant gloves when working with scissors, PVC cutters, and warm melted glue
- Students should practice safe cutting techniques when using scissors and PVC cutters. Be sure to carefully support the piece being cut. Be careful about where free hand is placed. Avoid moving about the room with scissors or PVC cutters in hand.
- Students should use only the warm melt glue tool at the glue station and adhere to the following precautions:
  - Warm melt glue tool tips can be extremely hot; use caution
  - Do not use the warm melt glue tool in a high traffic area
  - Protect the power cord so it is not loose; it could get caught on something or become a trip hazard
  - Store the warm melt glue tool in holder when the warm melt glue tool is not in use
  - Maintain a clear area with no clutter
  - Do not set the warm melt glue tool on combustible materials, and keep the area clear of combustible materials (loose paper)
  - Use a drip mat under the warm melt glue tool
  - Do not do any overhead work with the warm melt glue tool
  - Do not leave the warm melt glue tool unattended while plugged in and not in use
  - Use protective eyewear and keep loose hair and clothing tied back
- **Students should clean up as they go**
- **Take your time. It's more important to be accurate than to be first!**

Above: A metal table top with the NASA insignia embossed and a pair of gloves and safety goggles setting on the top.

Phase I – Part 2: Explore Knowns and Unknowns - Tools Engineer

BUILD THE LUNAR RAKE ATTACHMENT

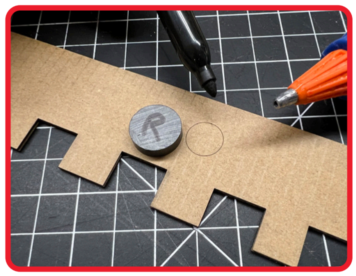
STEP 1: Before you begin, make sure you have all the materials needed in your kit. Be aware that your project team may have made slight changes to the kit. If in doubt, please direct your questions to a Mission Director for support.

Materials

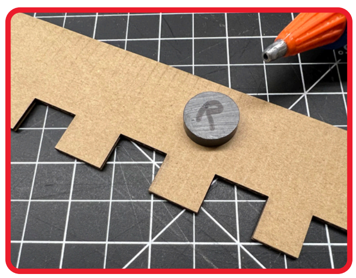
- Magnets
- Test Rake Profile PDF
- 1 in PVC Pipe
- 1 in long Dowel Rod
- Masking Tape
- Permanent Marker
- Metric Ruler
- Scissors

STEP 2: Take one of the magnets and label one side of it with an "H" for handle. Take a second magnet and let it attach to the side with the "H." On the side of the second magnet that touches the "H," put an "R" for rake. Do the same for a third magnet; on the side that touches the "H" place the letter "C" for cup. Two other team members will be asking for their magnet (the "H" and "C") so get this step done quickly.

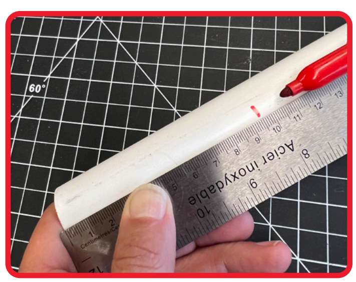
STEP 3: Use the magnet to trace a circle above the middle tine of the rake profile. The circle should be centered between the top of the middle tine and the top of the rake profile as shown.



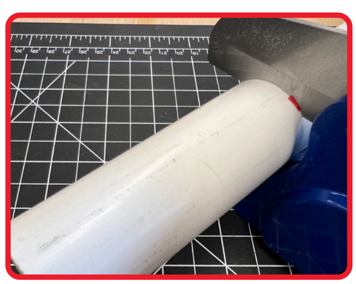
STEP 4: Wear safety goggles. At the warm melt glue station, attach the "R" magnet you just marked to the initial test rake profile. The "R" should be visible after gluing on the circle etched location marker. Set it aside.



STEP 5: Go to the PVC cutting station. Using a ruler and a permanent marker, measure and mark a cut line on the larger 1 in PVC pipe. The distance for the cut line is 9.5 cm (3-¾ in).

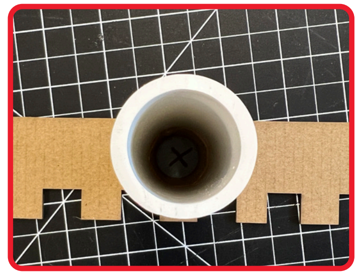


STEP 6: Wear safety goggles. At the PVC cutting station, carefully use the ratcheting pipe cutter to cut the pipe on the mark you just made. Take your time and focus on how the tool operates.



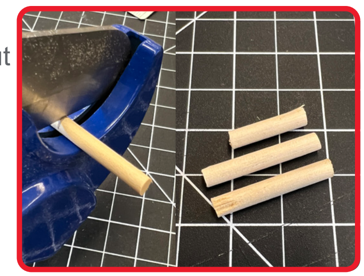
Phase I – Part 2: Explore Knowns and Unknowns - Tools Engineer (continued)

STEP 7: At the glue station, attach the tube to the rake profile around magnet as shown. The tube should surround the magnet evenly.

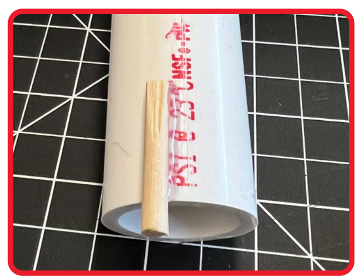


STEP 8: Like a welder, lay a "bead" of glue around the tube where it is attached to the rake profile. This will provide extra strength to this attachment point. Set it aside.

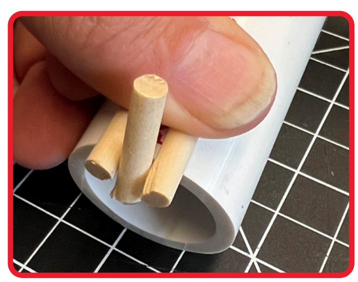
STEP 9: Go to the PVC cutting station. Cut two 3 cm (about 1-3/16 in) and one 2 cm (about 13/16 in) pieces of dowel rod. Cut them using the PVC pipe cutting tool.



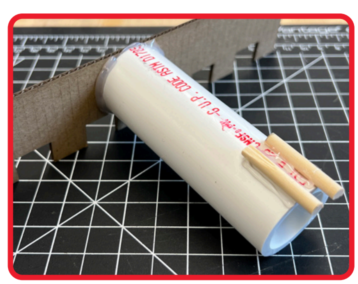
STEP 10: With the rake positioned as in the photo, glue the first 3 cm (about 1-3/16 in) dowel rod to the tube as shown. 2 cm (about 13/16 in) of the dowel rod should be glued to the tube, leaving 1 cm (about 3/8 in) hanging out over the edge.



STEP 11: Repeat the last step with the other 3 cm (about 1-3/16 in) dowel rod. Position it exactly the width of the 2 cm (about 13/16 in) dowel rod away from the first.



STEP 12: Congratulations! Your finished rake head should look like this. Set it aside for testing in Phase II.



BUILD THE COLLECTION CUP

STEP 1: Before you begin, make sure you have all the materials needed in your kit. Be aware that your project team may have made slight changes to the kit. If in doubt, please direct your questions to a Mission Director for support.

Materials

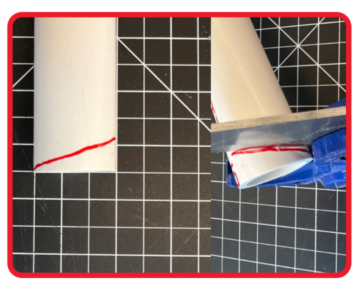
- Soda Can
- Masking Tape
- PVC Pipe
- Magnet
- Mesh
- Dowel Rod
- Permanent Marker
- 4 in x 6-1/2 in Cardboard

STEP 2: Take the 11 cm (about 4-5/16 in) x 16.5 cm (about 6-1/2 in) piece of cardboard and roll it gently around the steel can or soda can so that you can connect the sides, making a cylinder.

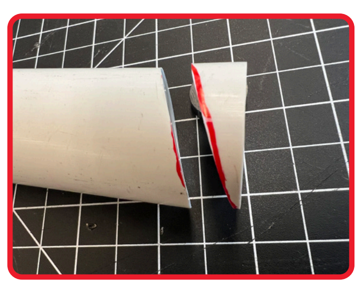
STEP 3: Tape the cardboard together so that it stays as a cylinder.

STEP 4: Go to the PVC cut station. Cut a piece of 1 in (larger) PVC to 10 cm (about 3-15/16 in) at the PVC cutting station.

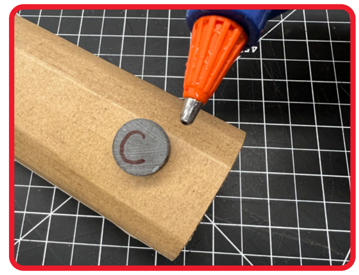
STEP 5: Using the same tool, mark and very carefully make a 45-degree angle cut on one end of the tube as shown.



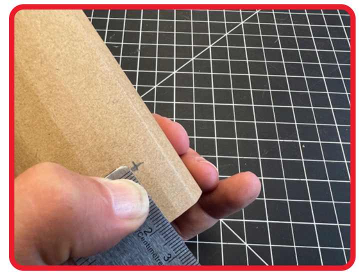
STEP 6: Your cut tube should look like this.



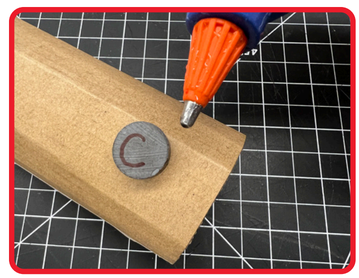
STEP 7: Ask your team member building the rake tool to give you the magnet with a letter "C" written on it.



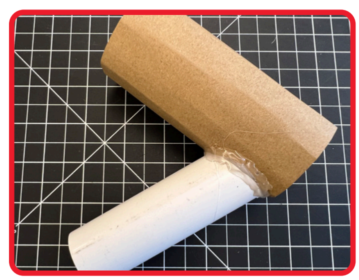
STEP 8: At the glue table, measure about 2 cm (about 13/16 in) up from the bottom edge of your cardboard tube and make a mark to glue the magnet labeled with the letter "C."



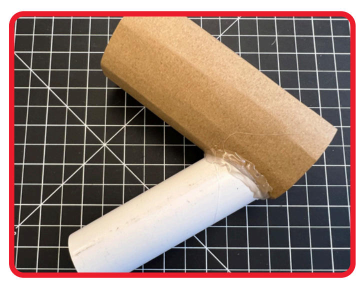
STEP 9: Glue the magnet on the cardboard cylinder with the "C" being visible.



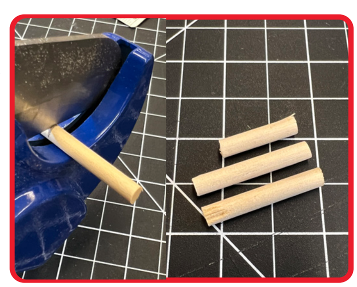
STEP 10: Center the 45-degree angle cut end of the PVC around the "C" magnet and glue into position as shown.



STEP 11: Like a welder, lay a "bead" of glue around the base of the PVC where it meets the cardboard for extra strength.



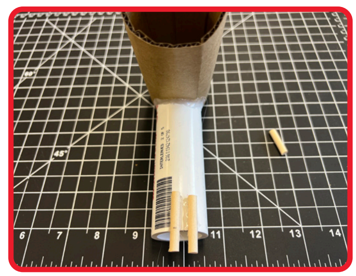
STEP 12: Go to the PVC cutting station. Cut two 3 cm (about 1-3/16 in) and one 2 cm (about 13/16 in) pieces of dowel rod. Cut them using the PVC pipe cutting tool used earlier.



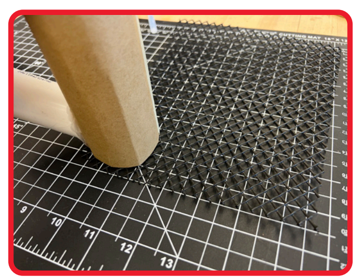
STEP 13: With the collection cup positioned as in the photo, glue the first 3 cm (about 1-3/16 in) dowel rod to the tube as shown. 2 cm (about 13/16 in) of the dowel rod should be glued to the tube, leaving 1 cm (about 3/8 in) hanging out over the edge.

STEP 14: Repeat gluing the other 3 cm (about 1-3/16 in) dowel rod next to the first using the 2 cm (about 13/16 in) dowel rod to position it one dowel rod width away from the first. Let cool.

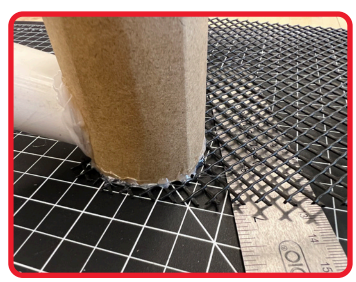
STEP 15: It should look like this.



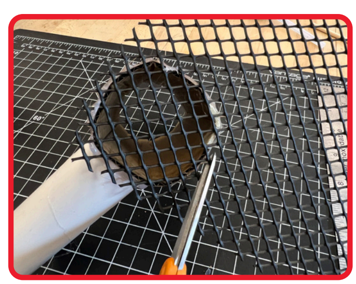
STEP 16: Place plastic mesh on the glue mat as shown; then place your collection cup in the corner of the mesh.



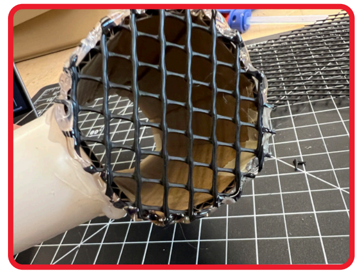
STEP 17: Lightly glue the mesh to the bottom of the collection cup. Do not use too much glue right now. You do not want to glue everything to the mat! If it does stick slightly, slide your ruler under the mesh to loosen it.



STEP 18: Using scissors, carefully trim the mesh to the perimeter of the collection cup.



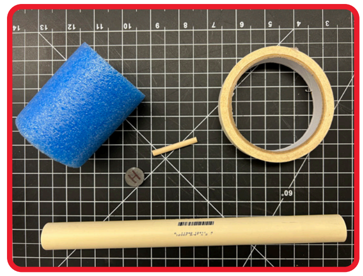
STEP 19: Reinforce the mesh connection to the cup with a continual bead of glue around the cup's perimeter.



STEP 20: Congratulations! Your finished collection cup should look like this! Set it aside for testing in Phase II.

BUILD THE TOOL HANDLE (FOLLOW THE INSTRUCTIONS IN ORDER)

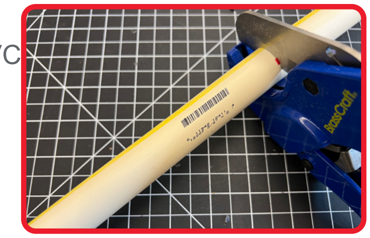
STEP 1: Before you begin, make sure you have all the materials needed in your kit. Be aware that your project team may have made slight changes to the kit. If in doubt, please direct your questions to a Mission Director for support.



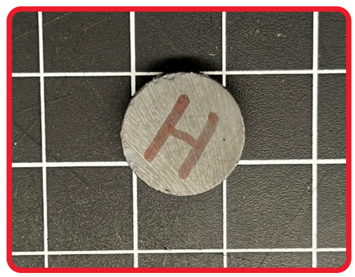
Materials

- Pool Noodle section
- Magnet
- Masking Tape
- Dowel Rod
- PVC Pipe

STEP 2: At the PVC cutting station, measure and cut a 36 cm (about 14 3/16 in) piece of the 3/4 in (smaller) PVC using the PVC cutting tool.

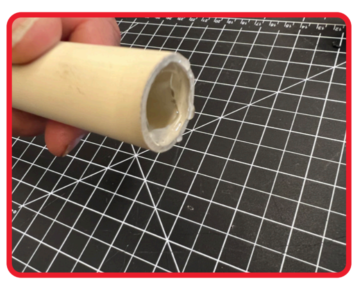


STEP 3: Ask your team member building the rake tool to give you the magnet with a letter "H" written on it.

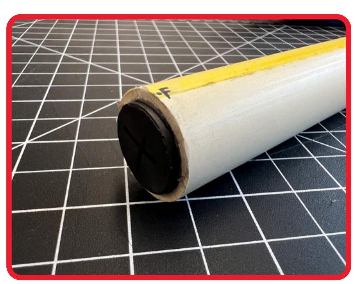


STEP 4: Take the magnet with an "H" and place it into the end of the PVC pipe you just cut. Before you glue it into position, make sure the magnet fits properly in the end of the tube. This is called 'dry fitting'.

STEP 5: At the glue table, apply glue to the interior wall of the tube and let the glue slightly harden.



STEP 6: Press the magnet into the hole with the "H" facing outwards as shown. Leave the face of the magnet just very slightly protruding out the end of the tube as shown.

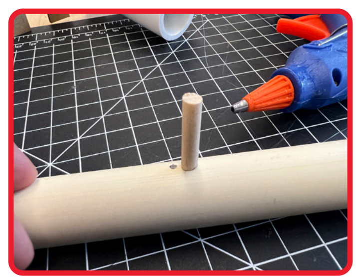


STEP 7: STOP!!! Assist the rake and collection cup tasks since you need both to move forward from here! When the rake and cup are completed, proceed to the next step.

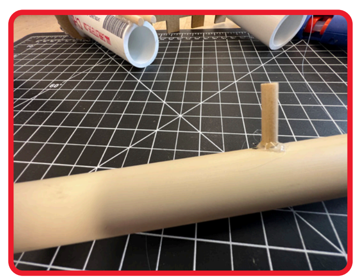
STEP 8: Insert the handle with the magnet end into each of the two tools. Mark the location nearest the large tube between the dowel rods with a pencil or marker for each tool.

STEP 9: Your two marks should be within 1 cm (about 3/8 in) of each other. If they are beyond 1 cm (about 3/8 in) apart, ask your Mission Director to change the length of your dowel rods so that the indexing system will work.

STEP 10: On the mark furthest back from the magnet, glue a 2 cm (about 13/16 in) long dowel rod perpendicular to the tube as shown. Both the RAKE and CUP tasks have a 2 cm (about 13/16 in) cut dowel rod you can use.

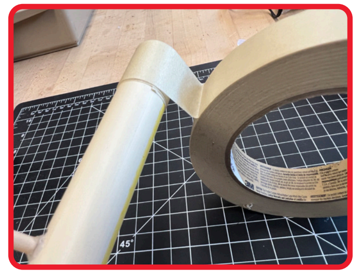


STEP 11: Put a small bead of glue around the base of the dowel rod for added strength. Let cool.

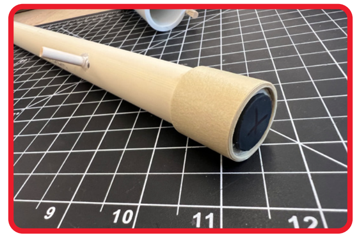


STEP 12: When glue has cooled, insert the handle into each tool to confirm it locks in place and does not allow the handle to spin.

STEP 13: The handle should have a loose fit in the larger PVC pipe on the tools. We will eliminate this "play" by making two bushings from masking tape.

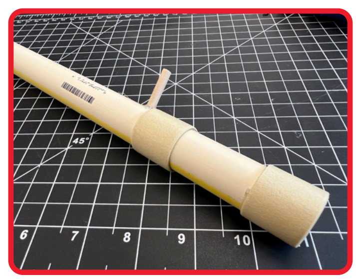


STEP 14: Wrap a few layers of masking tape onto the end of the tube near the magnet and near the indexing dowel rod as shown.



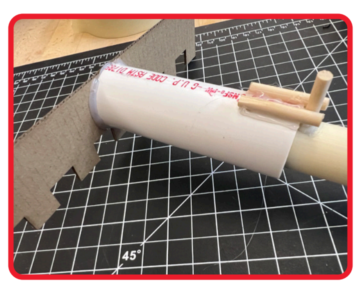
STEP 15: Continue to wrap masking tape until you have filled the gap between the two pieces of PVC as shown. If it is too snug or does not fit, remove some of the tape.

STEP 16: Make another masking tape bushing lined up with the base of the dowel rod, similar to the other bushing you made in STEP 4 to STEP 15.



STEP 17: Check to make sure that the magnet on the handle has a secure hold on the rake attachment.

STEP 18: For the last step in handle construction, lightly glue the foam grip approximately 5 cm (about 2 in) up from the end of the handle as shown.

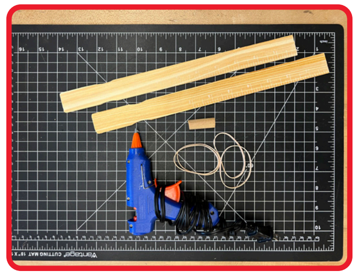


Congratulations! You're done!
Inform your PM of your completed work to get it signed off.

Phase I – Part 2: Explore Knowns and Unknowns - Project Manager

BUILD THE LUNAR TONGS; CHECK AND APPROVE TEAM'S PHASE I TASKS

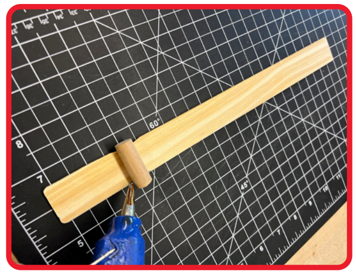
STEP 1: Acquire all necessary materials for the lunar tongs build.



Materials

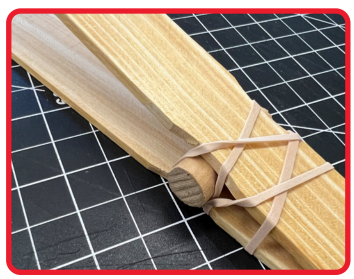
- 2 Paint Sticks
- 3 Rubber Bands
- Dowel Rod

STEP 2: Measure over 4 cm (about 1-9/16 in) on one of the paint stir sticks and glue the dowel rod as shown. Run a bead of glue on both sides of the dowel rod with the warm melt glue tool just like a welder.



STEP 3: Place another paint stir stick on top of the glued dowel rod so that it aligns at the ends as shown.

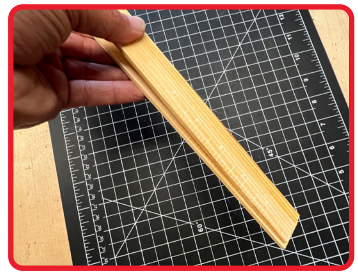
STEP 4: Wrap a rubber band over the stir sticks and dowel rod as shown so that the rubber band holds the tongs in an open position.



STEP 5: Here is another view of the rubber band wrapped around the dowel.

STEP 6: Your completed lunar tongs should look like this. You can wrap another rubber band on the end of the tongs to increase stability.

Phase I – Part 2: Explore Knowns and Unknowns - Project Manager (continued)



STEP 7: Pinch down on the tongs to grip lunar rocks that you want to pick up.

STEP 8: Assist your team members as needed until all components are complete.

STEP 9: Check and approve team member Phase I tasks. Place blue stickers on the Phase I task sheet as tasks are completed.

STEP 10: Contact a Mission Director for final approval and a red sticker for Phase I badge.

Congratulations!
Your Team's Lunar Getting a Grip on the Moon Kit is now ready for testing!

Blue Sticker

Phase I Build: Tools Engineer

- Build the lunar rake attachment

Blue Sticker

Phase I Build: Mission Specialist - Geologist

- Build the lunar collection cup attachment

Blue Sticker

Phase I Build: Human Factors Engineer

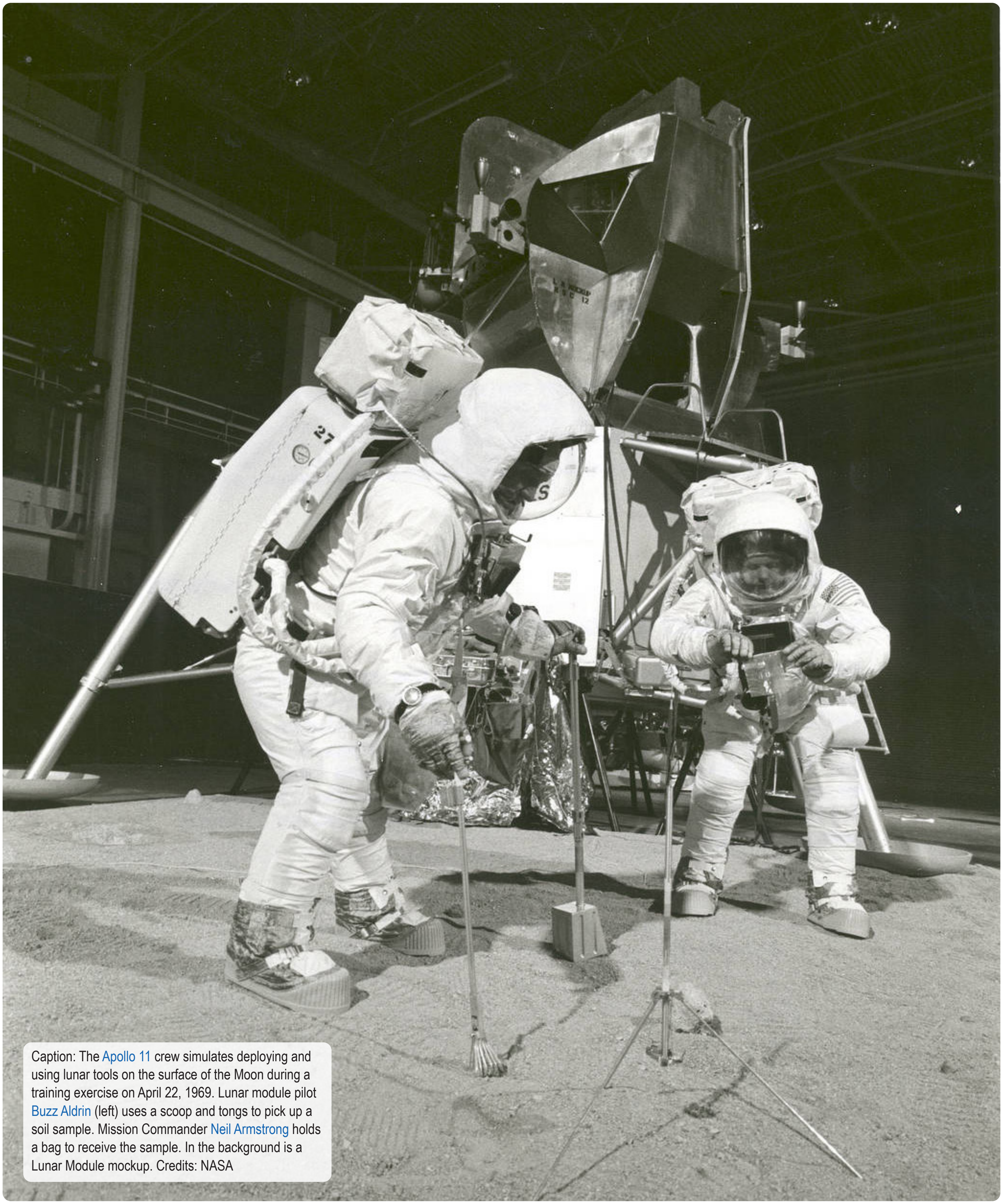
- Build the lunar tool handle

Red Sticker

Phase I Build: Project Manager

- Build the lunar tongs
- Assist team members with tool build responsibilities
- Check and approve team tasks. Apply blue sticker to this sheet as team members complete their tasks.
- Contact Mission Director when each phase component is complete to get red sticker

Congratulations!!! You are now ready to conduct initial tool testing in Phase II!

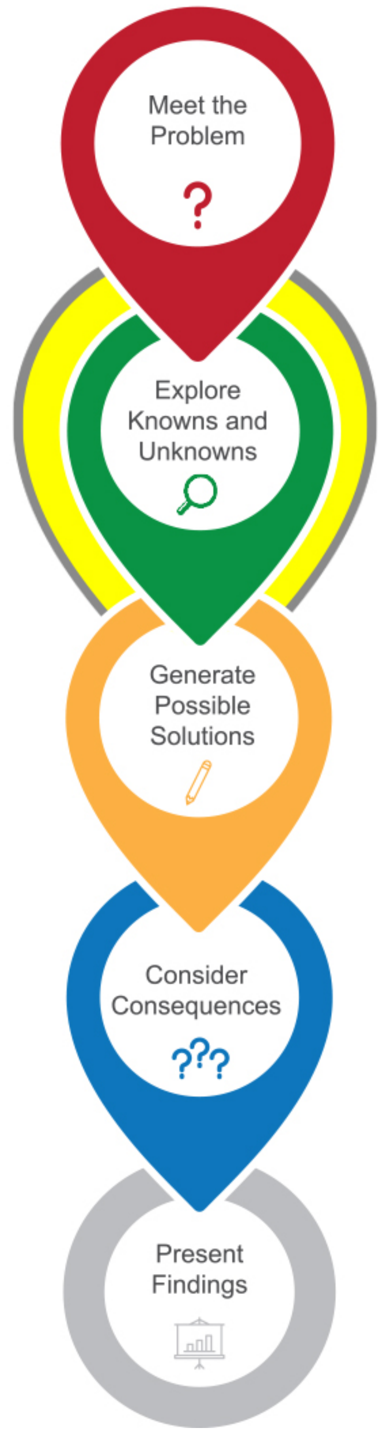


Caption: The Apollo 11 crew simulates deploying and using lunar tools on the surface of the Moon during a training exercise on April 22, 1969. Lunar module pilot Buzz Aldrin (left) uses a scoop and tongs to pick up a soil sample. Mission Commander Neil Armstrong holds a bag to receive the sample. In the background is a Lunar Module mockup. Credits: NASA

PHASE II

Part 1: Explore Knowns and Unknowns/Baseline Testing of Tool

Astronaut Charles M. Duke Jr., Apollo 16 lunar module pilot, has a sample bag in his hand, and a lunar surface rake leans against the large boulder. Credits: NASA



In Part 1 of Phase II, your team will continue to explore knowns and unknowns as you test your team's tool and collect data related to its performance. While conducting the test, you will be wearing simulated spacesuit gloves from a previous NASA/team activity. You will not be permitted to recover or pick-up samples directly with your hands; only the tool can be used (while you are wearing the spacesuit gloves). Be sure to review the testing procedure and the Tool Feedback Form (TFF) carefully prior to conducting your testing. Attention to detail and recording of data during testing in Part 1 will provide valuable information that will help you to generate possible solutions in Part 2.

Good luck!

Phase II - Part 1: Explore Knowns and Unknowns/Baseline Testing of Tool

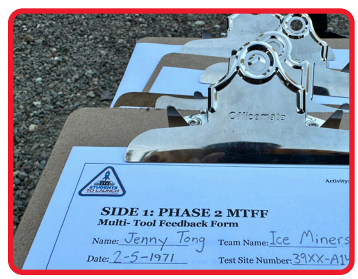
TOOL BASELINE TESTING PROCEDURES

STEP 1: Go with your team to your assigned testing site, that will include a simulated Moon surface with lunar rock and lunar **regolith**. Take all four tool components and four copies of the Phase II TFF with you. (A Mission Director may have already brought over your TFFs. Ask questions if needed for clarification.)

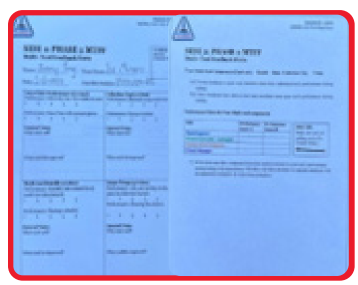
STEP 2: Determine who will be timing your tests with the stopwatch. If it is students and not a Mission Director, each student will take a turn timing another student. Use this time to learn how to use the stopwatch. If needed, ask a Mission Director for help.

STEP 3: Place all your team's tool components in the marked tool component stage area of the test site. Check with a Mission Director to make sure your test site has been prepared and cleared for testing.

STEP 4: Place your TFF in the provided clipboard if this was not done by a Mission Director. Fill out the test evaluator section in pencil (NAME, TEAM NAME, DATE, TEST SITE NUMBER).



STEP 5: Pre-read both sides of your TFF to prepare for what you are expected to report on after your test session. Then discuss with your team any questions you may have.

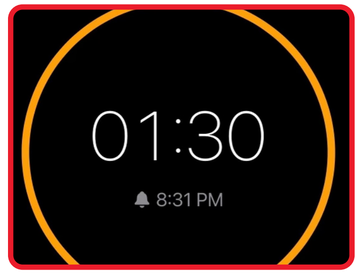


STEP 6: Each member will have a 1 minute 30 seconds time frame to collect as many simulated lunar rocks and the least amount of the simulated lunar regolith as possible by raking, scooping, and picking up with the tongs with the spacesuit gloves on.

Phase II - Part 1: Explore Knowns and Unknowns/Baseline Testing of Tool

STEP 7: Collect as many lunar rock specimens as possible using the tool attachments and place them in the collection bucket. All the tools in the kit must be used during the testing time. Remember, do not use the gloves to directly pick up the samples.

STEP 8: After 1 minute and 30 seconds the timer should say "Stop!" Stop collecting rocks. Any rocks that have not been placed in the collection bucket should be placed back into the test site.



STEP 9: When the first team member is finished, they should count the number of rocks collected with the tool and record the number on their TFF.

STEP 10: Repeat the testing process for the remaining three team members. When testing is completed, each student should complete Side 1 only of the Tool Feedback Form (TFF) about their testing trial. Good luck! Happy Testing.

Great job completing initial testing of the Tool!

Now it is time for your team to share their observations and data in a Stand-up presentation.

A. Group members should stand in a circle.
B. The maker of the tool component (lunar rake, collection cup handle, or lunar tongs) should refer to the notes on the TFF and speak for 1 minute about its performance to their team members.
C. Each team member should then share their feedback about the tool component (refer to notes on TFF) with the maker of the component (lunar rake, collection cup, handle, or lunar tongs). The maker should record the feedback on SIDE 2 of their TFF.

Steps A-C should be repeated for the remaining team members until everyone has SIDE 1 and SIDE 2 of their TFFs completed.

SIDE 1: PHASE II Tool Feedback Form (TFF)

NUMBER OF ROCKS COLLECTED:

Student Name: ____________________ **Team Name:** ____________________

Date: ____________________ **Test Site Number:** ____________________

Lunar Rake (5 is best)

A. Performance: Efficiently find rocks hidden in sand.

1 2 3 4 5

B. Performance: Ease of use with spacesuit gloves.

1 2 3 4 5

General Notes

What went well?

What could be improved?

Collection Cup (5 is best)

A. Performance: Efficiently scoop rocks into bucket.

1 2 3 4 5

B. Performance: Placing in bucket.

1 2 3 4 5

General Notes

What went well?

What could be improved?

Tool Handle (5 is best)

A. Performance: Stability and connection to tool attachments.

1 2 3 4 5

B. Performance: Placing in bucket.

1 2 3 4 5

General Notes

What went well?

What could be improved?

Lunar Tongs (5 is best)

A. Performance: Grip and pickup rocks and place in collection bucket.

1 2 3 4 5

B. Performance: Clearing fine debris.

1 2 3 4 5

General Notes

What went well?

What could be improved?

SIDE 2: Phase II Tool Feedback Form (TFF)

Your Tool Component (Circle one): Handle Rake Collection Cup Tongs

A. Provide feedback to your team members about their individual tool's performance during testing.
B. Collect feedback from each of your team members about your tool's performance during testing.

Performance Data for Your Tool component.

Role	Performance Score: A	Performance Score: B
Tools Engineer		
Mission Specialist - Geologist		
Human Factors Engineer		
Project Manager		

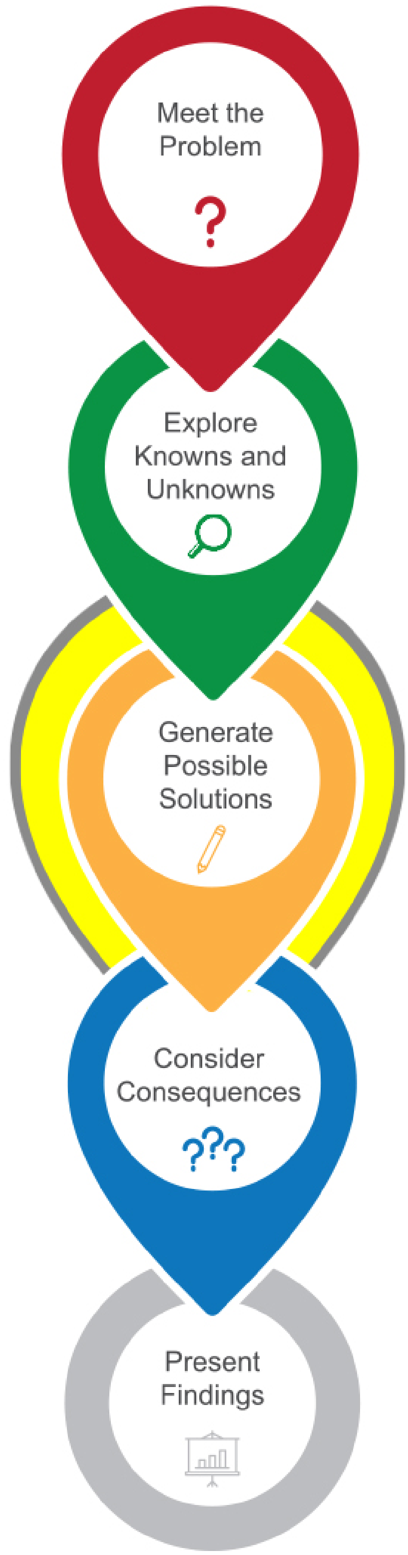
PRO TIP:
Make sure you are getting scores for **YOUR TOOL** from your team members!

C. Write down any other comments from team members related to your tool's performance during testing in the space below. **YOU WILL USE THESE NOTES TO CREATE A DESIGN FOR AN IMPROVED VERSION OF YOUR TOOL IN PART 2!**

PHASE II

Part 2: Generate Possible Solutions/Tool Redesign

Congratulations on completing your first round of testing with your initial prototypes. In Part 2 of Phase II, you will Generate Possible Solutions. Each team member will redesign their Tool component using the data recorded on the TFF from testing and your team's stand-up discussion. The original maker of each tool will be responsible for rebuilding the part for round two of testing. To facilitate the redesign and rebuild step, we have supplied some of the basic building components so that you can focus more time on the part that needs customization/changing. You will have until the end of Phase II to complete your tool's redesign. Work efficiently – time is tight.



Tool Component Redesign Instructions

STEP 1: Discuss with your team: What materials will be needed for each component's redesign? This will ensure that there are enough materials to complete your modifications. Write down what materials and tools you will need; then work with a Mission Director on securing those items for your rebuild.

STEP 2: Complete a brainstorm sketch on the Tool Redesign Sketch Sheet on the following page. Use the 3D-view plus orthographic format. That's a top view, front view, and right-side view of the tool. In the upper right corner, do your best to draw a 3-D sketch of your redesign.

STEP 3: Use the materials in your team's supply bin and other items requested from a Mission Director to create your redesign. As time gets close to the end you may find yourself working faster to make sure your project is completed on time. SLOW DOWN, BE SAFE, FOCUS ON QUALITY!

Sketch Sheet: Tools Engineer

TOP

(3D)

FRONT

RIGHT SIDE

Sketch Sheet: Mission Specialist - Geologist

TOP

(3D)

FRONT

RIGHT SIDE

Sketch Sheet: Human Factors Engineer

TOP

(3D)

FRONT

RIGHT SIDE

Sketch Sheet: Project Manager

TOP

(3D)

FRONT

RIGHT SIDE

Blue Sticker

Phase II Baseline Test: Tools Engineer

- Complete testing of your tool
- Provide tool feedback to your team in a stand-up presentation
- Complete TFF Side 1
- Complete TFF Side 2 focusing on lunar rake feedback
- Redesign and rebuild your tool

Blue Sticker

Phase II Baseline Test: Mission Specialist - Geologist

- Complete testing of your tool
- Provide tool feedback to your team in a stand-up presentation
- Complete TFF Side 1
- Complete TFF Side 2 focusing on collection cup feedback
- Redesign and rebuild your tool

Blue Sticker

Phase II Baseline Test: Human Factors Engineer

- Complete testing of your tool
- Provide tool feedback to your team in a stand-up presentation
- Complete TFF Side 1
- Complete TFF Side 2 focusing on handle feedback
- Redesign and rebuild your tool

Red Sticker

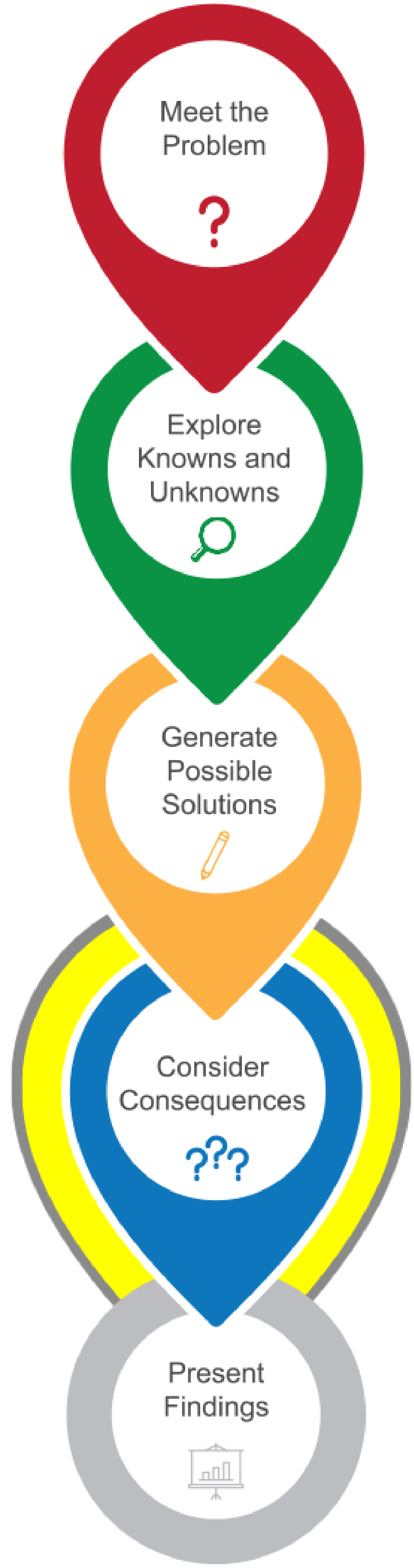
Phase II Baseline Test: Project Manager

- Complete testing of your tool and provide tool feedback to your team in stand-up presentation
- Complete TFF Side 1 & Side 2 focusing on lunar tongs feedback
- Check and approve team tasks. Apply blue sticker to this sheet as team members complete their tasks.
- Contact Mission Director when each phase component is complete to get red sticker
- Redesign and rebuild your tool

PHASE III

Part 1: Consider the Consequences/Evaluate Tool Redesigns

Close-up view of a set of tongs, an Apollo Lunar Hand Tool, being used by Astronaut Charles Conrad Jr., to pick up lunar samples during the Apollo XII mission, November 19, 1969. Credits: NASA



In Part 1 of Phase III, you and your teammates will conduct testing on the redesigns you built in Phase II. Be sure to review the testing procedure from Phase II and the Tool Feedback Form (TFF) carefully prior to conducting your testing. You will use this testing data to Consider the Consequences. In other words, you will reflect on your tool component redesign and evaluate the pros and cons of the redesign performance. This will help you decide how you will be moving forward. These findings will then be discussed with Mission Directors and other teams when you Present Findings later in Phase III.

Tool Testing Procedure for Redesigns

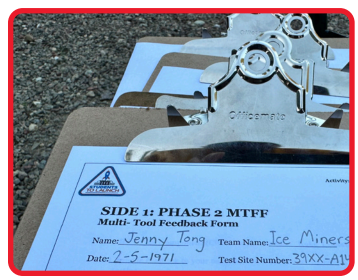
Follow the instructions you carried out in Phase II in the first round of testing.

STEP 1: Go with your team to your assigned testing site. Take all four redesigned tool components and four new copies of the Phase III TFF with you. (A Mission Director may have already brought over your TFFs. Ask questions if needed for clarification.)

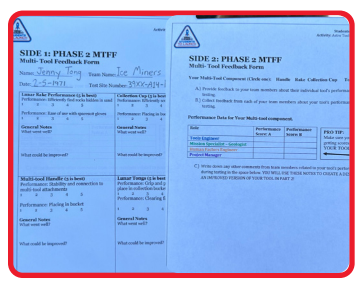
STEP 2: Determine who will be timing your tests with the stopwatch. If it is students and not a Mission Director, each student will take a turn timing another student. Use this time to learn how to use the stopwatch. If needed, ask a Mission Director for help.

STEP 3: Place all your team's tool components in the marked tool component stage area of the test site. Check with a Mission Director to make sure your test site has been prepared and cleared for testing.

STEP 4: Place your TFF in the provided clipboard if this was not done by a Mission Director. Fill out the test evaluator section in pencil (NAME, TEAM NAME, DATE, TEST SITE NUMBER).



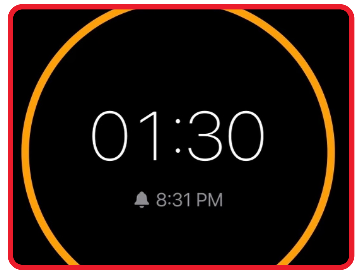
STEP 5: Pre-read both sides of your TFF to prepare for what you are expected to report on after your test session. Then discuss with your team any questions you may have.



STEP 6: The Tools Engineer will test first. PUT ON THE SPACESUIT GLOVES as explained in Phase II. Each member will have a 1 minute 30 second time frame to collect as many lunar rocks as possible by raking, scooping, and picking with the spacesuit gloves.

STEP 7: Collect as many lunar rock specimens as possible using the Tool attachments and place them in the collection bucket. All the tools in the kit must be used during the testing time. Remember, do not use the gloves to directly pick up the samples.

STEP 8: After 1 minute and 30 seconds the timer should say "Stop!" Stop collecting rocks. Any rocks that have not been placed in the collection bucket should be placed back into the test site.



STEP 9: When the first team member is finished, they should count the number of rocks collected with the Tool and record the number on their TFF.

STEP 10: Repeat the testing process for the remaining three team members. When testing is completed, each student should complete Side 1 only of the Tool Feedback Form (TFF) about their testing trial. Good luck! Happy Testing.

Great job completing retesting of the tool!

Now it is time for your team to share their observations and data in a stand-up presentation.

A. Group members should stand in a circle.
B. The maker of the tool component (lunar rake, collection cup handle, or lunar tongs) should refer to the notes on the TFF and speak for 1 minute about its performance to their team members.
C. Each team member should then share their feedback about the tool component (refer to notes on TFF) with the maker of the component (lunar rake, collection cup, handle, or lunar tongs). The maker should record the feedback on SIDE 2 of their TFF.

Steps A-C should be repeated for the remaining team members until everyone has SIDE 1 and SIDE 2 of their TFFs completed.

SIDE 1: PHASE III Tool Feedback Form TFF

NUMBER OF ROCKS COLLECTED:

Student Name: ______________________ **Team Name:** ______________________

Date: ______________________ **Test Site Number:** ______________________

Lunar Rake (5 is best)

A. Performance: Efficiently find rocks hidden in sand.

1 2 3 4 5

B. Performance: Ease of use with spacesuit gloves.

1 2 3 4 5

General Notes

What went well?

What could be improved?

Collection Cup (5 is best)

A. Performance: Efficiently scoop rocks into bucket.

1 2 3 4 5

B. Performance: Placing in bucket.

1 2 3 4 5

General Notes

What went well?

What could be improved?

Tool Handle (5 is best)

A. Performance: Stability and connection to tool attachments.

1 2 3 4 5

B. Performance: Placing in bucket.

1 2 3 4 5

General Notes

What went well?

What could be improved?

Lunar Tongs (5 is best)

A. Performance: Grip and pickup rocks and place in collection bucket.

1 2 3 4 5

B. Performance: Clearing fine debris.

1 2 3 4 5

General Notes

What went well?

What could be improved?

SIDE 2: PHASE III Tool Feedback Form TFF

Your Tool Component (Circle one): Handle Rake Collection Cup Tongs

A. Provide feedback to your team members about their individual tool's performance during testing.
B. Collect feedback from each of your team members about your tool's performance during testing.

Performance Data for Your Tool component.

Role	Performance Score: A	Performance Score: B
Tools Engineer		
Mission Specialist - Geologist		
Human Factors Engineer		
Project Manager		

PRO TIP:
Make sure you are getting scores for **YOUR TOOL** from your team members!

C. Write down any other comments from team members related to your tool's performance during testing in the space below.

PHASE III

Part 2: Present Findings/Discuss Final Recommendations

Astronauts Reid Wiseman of NASA (left), Jeremy Hansen of the Canadian Space Agency (middle), and Victor Glover of NASA (right) pay close attention to Moon samples as they receive a lesson in the Apollo Lunar Lab at NASA's Johnson Space Center in Houston on May 9, 2023. Credits: NASA

Congratulations on completing your evaluation of your redesigned prototypes. You will now PRESENT YOUR FINDINGS and recommendations to NASA!

Prepare for a Group Presentation & Discussion!

Be prepared to answer the following questions using insights gathered from your tool experience, your TFFs, and the Recommendation Form found at the end of Phase III.

1. Review the problem situation: what problem were you trying to solve? (Meet the Problem)
2. What areas of needed improvement were revealed when you tested and evaluated the original prototype? (Explore Knowns and Unknowns)
3. How did your redesign address the needed areas of improvement? (Generate Possible Solutions)
4. What are your final recommendations for the tool attachment you were responsible for? (Consider Consequences)

BE SURE TO COMPLETE A RECOMMENDATION FORM, FOUND ON THE NEXT PAGES, FOR YOUR TOOL. YOU WILL USE THESE FORMS ALONG WITH THE TOOLS YOU MADE TO GUIDE YOUR PRESENTATION.

Lunar Rake Recommendation Form

1. What modifications were made during Phase II? Why did you decide to make these modifications?

2. Did the modifications improve performance? (Compare the number of rocks collected and the performance score data in your Phase II TFF with your Phase III TFF.)

3. Make a list of Pros and Cons related to this component.

Pros	Cons

4. Is this component ready to be used on the Moon? If yes, why? If no, why not? Be sure to provide data from the tool experience to support your response.

5. If the answer to question 3 was no, what recommendations do you have to make it Moon ready?

Collection Cup Recommendation Form

1. What modifications were made during Phase II? Why did you decide to make these modifications?

2. Did the modifications improve performance? (Compare the number of rocks collected and the performance score data in your Phase II TFF with your Phase III TFF.)

3. Make a list of Pros and Cons related to this component.

Pros	Cons

4. Is this component ready to be used on the Moon? If yes, why? If no, why not? Be sure to provide data from the tool experience to support your response.

5. If the answer to question 3 was no, what recommendations do you have to make it Moon ready.

Handle Recommendation Form

1. What modifications were made during Phase II? Why did you decide to make these modifications?

2. Did the modifications improve performance? (Compare the number of rocks collected and the performance score data in your Phase II TFF with your Phase III TFF.)

3. Make a list of Pros and Cons related to this component.

Pros	Cons

4. Is this component ready to be used on the Moon? If yes, why? If no, why not? Be sure to provide data from the tool experience to support your response.

5. If the answer to question 3 was no, what recommendations do you have to make it Moon ready.

Lunar Tongs Recommendation Form

1. What modifications were made during Phase II? Why did you decide to make these modifications?

2. Did the modifications improve performance? (Compare the number of rocks collected and the performance score data in your Phase II TFF with your Phase III TFF.)

3. Make a list of Pros and Cons related to this component.

Pros	Cons

4. Is this component ready to be used on the Moon? If yes, why? If no, why not? Be sure to provide data from the tool experience to support your response.

5. If the answer to question 3 was no, what recommendations do you have to make it Moon ready?

Team Presentation & Share

Once your team's recommendation form has been completed and checked off by your team's Project Manager, inform a Mission Director to get your RED sticker and to say that your team is done and ready to present. They may have you present directly to them for verbal feedback or place you in a queue for a whole group presentation. Either way, these are the basic elements you will need for the presentation:

1. Each team member discussing the original tool design. What was good about it and what were its weak points?
2. Each team member discussing what they did to modify the original design, why they did it, and the pros and cons of this modification.
3. Each team member discussing what they would do if the project was to move ahead.
4. How did your team work together to get the project completed?
5. A visual presentation of the two versions of each tool.

You may discuss other items you feel are important, but the total time on the presentation should not exceed 3-4 minutes. Remember to speak clearly and succinctly. Also, hold your prototype tools while you are talking about them.

Congratulations!

NASA is proud of your service and dedication! Your research, testing, and recommendations will go a long way in furthering our knowledge of lunar geology!

Blue
Sticker

Phase III Retest: Tools Engineer

- Test your redesigned rake attachment
- Record your data in your Phase III TFF
- Summarize and present your findings to the group

Blue
Sticker

Phase III Retest: Mission Specialist - Geologist

- Test your redesigned collection cup
- Record your data in your Phase III TFF
- Summarize and present your findings to the group

Blue
Sticker

Phase III Retest: Human Factors Engineer

- Test your redesigned handle attachment
- Record your data in your Phase III TFF
- Summarize and present your findings to the group

Red
Sticker

Phase III Retest: Project Manager

- Test your redesigned lunar tongs
- Record your data in your Phase III TFF
- Summarize and present your findings to the group. Check and approve team tasks. Apply blue sticker to this sheet as team members complete their tasks.
- Contact a Mission Director when each phase component is complete to get the red sticker

GLOSSARY

Dexterity – Skill and ease in performing tasks, especially with the hands.

Geologist – An expert in (or student of) geology, which is the study of Earth's processes and structures.

Mobility – The ability to move or be moved freely and easily.

Prediction – The act of attempting to tell beforehand what will happen.

Prototype – An engineering unit that is built to address all critical scaling issues and operated in a relevant environment to demonstrate performance in the actual operational environment and platform (ground, airborne, or space).

Regolith – A layer of loose, unconsolidated rock, mineral, and glass fragments covering solid rock (e.g., on the lunar surface).

Spacesuit – A self-contained living environment for pilots and astronauts that consists of everything needed for short-term survival, including breathing oxygen, the pressure exerted on the body, and a heating and cooling system.

Spacewalk – Any human activity in space that takes place outside a vehicle. A spacewalk is also called an extravehicular activity (EVA)

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