Touching Our Solar System – Introduction for Students

Our Overall Guiding Question for the Year:

What can we learn about Mars by studying impact craters from asteroids and comets?

Introduction:

The sun and eight planets are the largest objects in the solar system. There are also billions of smaller asteroids and comets. We sometimes call these small bodies the "egg shells" left over from the time when the planets formed. Do you remember holding the pieces of asteroids during our Readiness Academy in June on Mount Lemmon? Do you remember how old those rocks from space are? How about the ingredients we used to build our model comets? Do you remember the recipe we used to make our comets? Asteroids and comets themselves can be fascinating to study. But they can also be used to help us study the larger planets. That's what this project is about.

An astonishing amount of energy is released when an asteroid or comet collides with the surface of a planet or moon. The impact can crush and vaporize huge amounts of rock and eject the debris for hundreds or thousands of kilometers, even sending some debris into space. Long after the dust settles the hole in the ground – the impact crater – may still be recognized millions or even billions of years later. These impact craters have a story to tell about the solar system. They can help us study many other aspects of the moons and planets that we find the craters on.

Listing Our Wonders:

In many ways science is more about asking questions than it is about finding answers. For every answer we find we'll probably come up with several new questions. During this project there will be many times when we find ourselves wondering about something. For example, "I wonder why there's a mountain in the middle of that crater?" Or, "How deep is that crater?" We're going to keep track of these in our List of Wonders. Some of the things you might wonder about will have answers that we can find from our models or with online research, but other wonders won't have answers yet. That could be because nobody has thought to wonder about it before.

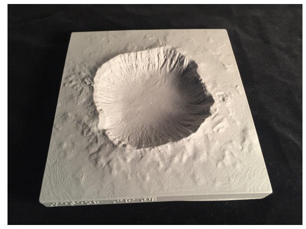
Gathering Our Data:

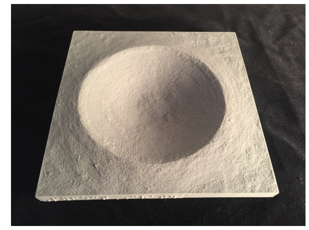
The 3D models will be our initial sources of data. For example, we'll take measurements of features in the models to help us figure out sizes in the real crater. Then we'll try to relate these sizes to things that might be familiar to us in everyday life. By doing this we will be able to better appreciate what it would be like to explore these craters in-person. We might also find answers to some of the things we've been wondering.

Presenting Our Work:

One of the most important aspects of science is sharing with other people what we have been doing. Not just sharing the answers we find, but also how we found them. It is also important to talk with other people about some of the things we still wonder about, that we haven't been able to find answers to. Each month we'll make a presentation about our work. At first, we'll just use a few sentences and a short 30 to 60 second recording of our voices. Later, as we get more comfortable presenting our work, we'll make longer presentations using demonstrations and activities so our audience can better understand what we've been doing.

Segment #1 – A Tale of Two Craters





Tactile Tools:

3D model of Meteor Crater in Arizona
3D model of a Perfect Crater on the moon

Brief Introduction:

Meteor Crater in Arizona formed when an asteroid collided with Earth about 50,000 years ago. It is the most famous and widely studied impact crater on our planet. We're going to use this crater to compare to all the other craters in this project. In this first segment we are comparing Meteor Crater to a different crater found on the moon. We call the lunar crater a Perfect Crater because it has a very smooth symmetrical structure. Perfect Crater on the moon was formed about 10 million years ago. All of the details in these two models are real parts of the terrain around and in these craters. Nothing has been subtracted or added, except the labels on the sides of the models.

Starting Your List of Wonders:

1) Study the shapes and textures of the two craters. Can you still find the visitor center and museum buildings at Meteor Crater? Take your time studying the models. You want to notice small features as well as large ones. Try to determine the ways that the structures of the craters are similar to each other and different from each other. What do these characteristics make you wonder about the craters, or the asteroids that formed them? Start building your List of Wonders. Keep in mind that you can add wonders to your list at any time. Wonders can happen at any time during the science process, not just at the beginning. Ask your university mentor what things they put on their own List of Wonders.

Gathering Your Data:

One question that might already be on your List of Wonders is, "How big are these craters in real life?" We're going to gather data from the model craters in order answer this question and gain an appreciation for the real sizes of these craters. We'll do this by taking measurements of the models and then scaling up to the actual sizes of the real craters. We also need to understand that while each model is about the same size, the real craters that the models represent might have very different sizes. We will record our data in a journal that we can share with our mentors. Journals can be anything you like, including written files or spoken voice threads. Find something that will be easy for you and your university mentor to share with each other.

2) Let's begin. How many centimeters across are the craters in your models, from one rim of a crater across to the opposite rim? Take several measurements and then find the average. Record the distances you measure and the average distances in your journal and briefly describe how you found them. (Did you use a ruler? A piece of string? Your finger?) After making these measurements do you need to add anything new to your List of Wonders?

3) For our model of Meteor Crater, each centimeter in the model represents 100 meters in the real crater. Based on your measurements how far across is the real Meteor Crater? Use this information to find the distance around the outside of Meteor Crater along the rim. How long would it take you to walk along a smooth path all the way around Meteor Crater? Describe in your journal how you found this time. Your university mentor can help you with this part. Ask them how long it would take them to complete the same walk.

4) For our Perfect Crater on the moon there are 220 meters represented by every centimeter in horizontal distance on the model. If you could walk at the same pace on the moon as you do on Earth how long will it take you to walk all the way around the rim of the Perfect Crater?

5) Think of a way to measure the depth of the two model craters from the level of the top of the rim straight down to the level of the bottom of each crater at its center. How far are these depths in centimeters? In your journal describe your measurement technique.

6) Use your measurements to find the depth of the real Meteor Crater in meters. How many Statues of Liberty could we stack up at the center of the real Meteor Crater before the stack reached above the rim? A fun way to demonstrate this to someone else might be to make a little clay model of the Statue of Liberty and place it inside the model crater. With your university mentor come up with two other ways of relating to the depth of Meteor Crater.

7) Our Perfect Crater model has a different scaling in the vertical direction than in the horizontal direction. Each centimeter of vertical distance in the Perfect Crater model represents 440 meters on the moon. How much deeper is Perfect Crater compared to Meteor Crater?

8) The asteroid that formed Meteor Crater was about 50 meters across. What size would this asteroid be in your model of Meteor Crater? Find or make an object this size and place it in the center of Meteor Crater. Study the model crater and your model asteroid together. Is there anything new to add to your List of Wonders now? Check in with your university mentor to see if they added anything to their own List of Wonders.

9) Have you been able to answer anything on your List of Wonders yet? Research Meteor Crater and other craters on the Internet and try to answer at least two more things from your List of Wonders. Remember, not everything on your list will have an answer. Describe what you find in your journal, along with other interesting information you learn. Your university mentor can help you find online resources. Here are a few places to start your online research:

   en.wikipedia.org/wiki/Meteor_Crater
   solarviews.com/eng/tercrate.htm

www.britannica.com/science/meteorite-crater/The-impact-cratering-process

Presenting Your Work:

Communicating with others about our work is an essential part of science. We're going to start this month with a short presentation of just 30 to 60 seconds. We will work our way up to longer and more complex presentations over the next few months. For this first presentation a good plan might be to focus on what we learned from the models about the sizes of the craters, and how we learned this. An important tip to keep in mind as you are building your presentation is, "Never try to tell them everything you know." You won't have time to tell people everything you've done, so pick one or two things you think are most interesting and build your presentation around these.

10) <u>Using only your voice</u> practice giving a brief 30 to 60 second presentation about Meteor Crater to a friend or family member. Even though this is a very short presentation, don't let that fool you. It still takes a lot of practice. And remember to include an introduction and conclusion.

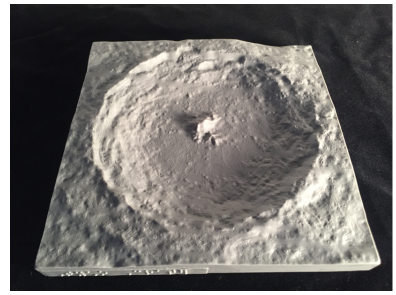
11) When you are comfortable with your presentation record yourself giving it and share the recording with your university mentor.

12) Ask your friends, family members, and your university mentor for comments and feedback about your recorded presentation. Then prepare to give your presentation again to your industry mentor. Sometimes people who watch or hear your presentation will ask you questions you hadn't thought of before. Did this happen to you? Do you need to add anything to your List of Wonders?

13) Give your presentation to your industry mentor and then have a conversation about the project.

14) The last step is to share a recording of your presentation with XXXX and XXXX so that we can follow your progress. Use the WhatsApp group messages to find out a good way to share your presentation.

Segment #2 – Something in the Center



Tactile Tools:

3D model of Tycho Crater on the moon

Brief Introduction:

Earth's moon is completely covered with craters formed by impacts of asteroids and comets. One of the most prominent is the 110-million-year-old impact crater named Tycho (Tee-ko). Because of its southern location on the moon and its distinctive shape the crater was once referred to as Umbilicus Lunaris (meaning navel of the moon). It is now named after the very famous 16th century Danish astronomer Tycho Brahe.

Continuing Your List of Wonders:

1) You now have models of three different impact craters. Study the shape of your new Tycho Crater. Try to determine ways that the structure of Tycho is both similar to and different from Meteor Crater. One difference is obvious, but other differences can be subtle and hard to detect. Take your time in comparing the crater models. Do the characteristics of Tycho make you wonder anything about the crater, or about the asteroid that formed it? Maybe you are wondering about the moon itself, where the crater is located? Start adding things to your List of Wonders. Remember that wonders may occur to you at any time during the science process. Ask your university mentor what things they are adding to their own List of Wonders.

Gathering Your Data:

One new question on your List of Wonders may be, "What is that thing in the center of Tycho Crater?" Tycho is in a class of more complex impact structures called central-peak craters. In order to better understand central-peak craters like Tycho, we are going to gather data from our new model and compare it with Meteor Crater. Remember that while each model is about the same size, the real craters can have sizes that are very different. As you gather data, record the process in your journal and share it with your university mentor. You may also need your journal in order to refer back to your earlier work with Meteor Crater. So, keep your journal handy.

2) Let's begin. Each centimeter across horizontally in your model of Tycho crater represents about 7 kilometers on the moon. How many of the real Meteor Craters would fit across the diameter of the real Tycho Crater? Let's put the size of Tycho Crater into a perspective we can all understand. Imagine that a car could be driven on the moon and that a road wrapped around the outside of Tycho Crater. How long would it take someone to drive you all the way around Tycho Crater? In your journal, describe how you determined these two things. (For example, did you measure the distance around, or use math to find it?)

3) Each centimeter in vertical height in the model of Tycho Crater represents about 3.5 kilometers of real vertical height on the moon. Notice that this is different from the horizontal scale. The vertical height of the model was exaggerated by a factor

of 2 so it is easier to feel and see the features. Use the vertical scale of your model to find out how deep the real Tycho crater is from the level of the rim to a flat part at the bottom of the crater. How tall is the central mountain, from the bottom of the crater to the mountain peak? In your journal describe how you found these distances.

4) Now that you understand how much bigger Tycho is compared to Meteor Crater, do you need to add anything new to your List of Wonders?

5) Arizona's Humpreys Peak in the San Francisco mountain range is the highest peak in our state. It towers over 1700 meters above the city of Flagstaff and is covered in snow much of the year. The San Francisco mountains stretch about 10 km across at their base. Imagine that you are able to place this huge mountain range inside Tycho Crater. How do the mountains compare to the height of the rim and the size of the central peak of Tycho? In order to help your mentors visualize this comparison, make a simple clay model of the San Francisco mountains at the same horizontal and vertical scales that the Tycho model uses. Then place the clay model inside your Tycho model. In your journal describe the comparisons.

6) Your clay model of the San Francisco mountains is about the same size as the asteroid that impacted the moon to form Tycho Crater. This asteroid was about 300 times larger in radius than the asteroid that formed Meteor Crater. The explosive energy of an asteroid impact is related to the radius of the asteroid cubed (radius times radius times radius). How much more explosive energy was involved in forming Tycho Crater compared to the impact that formed Meteor Crater? Check in with your university mentor if you need any help understanding how this step works.

7) Have you been able to answer anything on your List of Wonders yet? Research Tycho Crater and central-peak craters on the Internet and try to answer at least two more things from your List of Wonders. See if you can find out how the enormous amount of explosive energy in larger impacts can cause the formation of a central peak. Remember, there may not be answers for everything on your list. Describe what you find in your journal, along with other interesting information you learn. Your university mentor can help you find resources. Here are a few places to start your online research:

   Wikipedia:
   - en.wikipedia.org/wiki/Tycho_(lunar_crater)
   - en.wikipedia.org/wiki/Complex_crater

   Space.com:
   - www.space.com/19623-tycho-brahe-biography.html

   Physics Stack Exchange:
   - physics.stackexchange.com/questions/26091/how-does-the-central-peak-in-moon-craters-form

Presenting Your Work:

For this short video presentation make a plan that includes using some kind of demonstration in the video. Your demonstration can include your crater models or your clay mountains or something completely different. Remember that your mentors already have the same models that you have, but other people watching your presentation may not have seen these models before. Finally, use what you learned about presenting during your previous presentation experience and keep in mind the tip from the last segment, "Never tell them everything you know."

8) <u>Using your voice and your demonstration,</u> practice giving a brief 2 to 3-minute presentation about Tycho Crater to a friend or family member. This is a slightly more complex presentation than last time, so it may take a lot of practice.

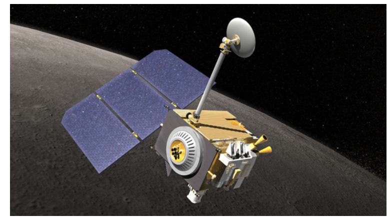
9) When you are comfortable with your presentation, record a video of yourself giving it and share the recording with your university mentor.

10) Ask your friends, family members, and your university mentor for comments and feedback about your recorded presentation. Then prepare to give your presentation again to your industry mentor. Sometimes people who watch or hear your presentation will ask you questions you hadn't thought of before. Did this happen to you? Do you need to add anything to your List of Wonders?

11) Give your presentation to your industry mentor and then have a conversation about the project.

12) The last step is to share the video recording of your presentation with XXXX and XXXX so that we can follow your progress. Ask others on the WhatsApp group how they plan to share their presentations. This video file may be too large to send in an email or text message, so you may have to learn how to post it to a private YouTube channel and then share the link.

Segment #3 – Mapping the Moon



Tactile Tools:

Model of NASA's Lunar Reconnaissance Orbiter spacecraft
Diagrams of primary spacecraft components

Brief Introduction:

Earth's moon has been explored by more spacecraft than any other object in the solar system. Currently, we're using NASA's Lunar Reconnaissance Orbiter (called LRO for short) to study the moon. The LRO spacecraft orbits 30 kilometers (about 20 miles) above the surface of the moon and travels once around the moon every 100 minutes. LRO has cameras, lasers, radios, radar, and other instruments. We are using LRO to build maps of all the features on the surface of the moon. These maps are used to make the 3D models of craters for this project, such as Tycho crater from Segment #2 and Perfect Crater from Segment #1.

Continuing Your List of Wonders:

1) Carefully unpack the individual parts of the LRO spacecraft from the box. Along with the different components of LRO there are four pages of diagrams. These diagrams label important parts and indicate where they attach together. The diagrams also show where smaller parts of LRO are found, such as the star tracker and cosmic ray telescopes. Organize the tactile diagrams and seven main spacecraft parts so you can easily locate each component of LRO. If you are curious about any of the parts or instruments add your thoughts to your List of Wonders.

Assembling Your Spacecraft:

2) The main part of a spacecraft is called the bus. LRO's bus holds the computers and electronics that operate the science instruments. All other components of LRO are attached to the spacecraft bus. Some components are already attached, such as the radar, cosmic ray telescope, and omni-directional communication antenna. Other components will need to be added. Our first step in building the model is to join main engine to the bottom of LRO's bus. You'll need to use a small amount of glue to hold it together. We make the models out of urethane plastic and normal super glue works with them.

3) Next, find the neutron detector. Have you heard of neutrons before? Why would we want to study neutrons coming from the moon? What could they tell us? You may want to add something about this to your list of wonders for later research. In your diagrams find where the neutron detector attaches to the LRO bus. The round part of this detector should face in the same direction as the radar and angle slightly downwards. A small drop of superglue will hold the neutron detector onto the bottom corner of the bus.

4) All spacecraft need power to operate. LRO uses solar panels to charge batteries that then power the spacecraft. The solar panels slip into a small round hole near the bottom of the spacecraft bus. Use the diagrams to help find where this hole is located, then attach the solar panels. Solar panels are designed to rotate so they always face the sun, so only glue them in if they won't fit snug.

5) From Earth we communicate with most spacecraft using radio waves. LRO is equipped with two radio antennas to both receive commands and also to send data back to Earth. The high gain antenna is the primary one. The round radio dish attaches to the end of the high gain antenna boom. This boom has joints that work like our wrists. They let LRO always point its high gain antenna towards Earth. Large amounts of data are sent and received by this dish along a straight line to and from Earth. In our model of LRO the high gain antenna boom has a square peg. Use the diagram of the spacecraft bus to find the square hole where this boom attaches. It should fit nice and snug, but a small drop of glue can be used.

6) A backup antenna, in case the high gain fails, is the omni-directional one already attached to the top part of the spacecraft bus. Many people have omni-directional antennas in their homes. They are how our wi-fi networks operate, by sending signals out in all directions. Other spacecraft orbiting the moon or on its surface can communicate with LRO and with each other over the network used by the omni-directional antenna. In this way LRO serves as a communication satellite for other missions in addition to its role as a research satellite.

7) LRO's instrument module holds the main tools for mapping the moon. Two identical cameras – the narrow angle cameras – can take very detailed images of the surface of the moon. These cameras are so powerful they can be used to see the tracks left by the Apollo astronauts when they walked on the moon. An instrument called an altimeter fires a laser at the moon to measure the height of mountains and depths of craters. This instrument is nick-named LOLA, which stands for Lunar Orbiter Laser Altimeter. LOLA has fired its laser over 6 billion of time to build up a map of the entire lunar surface. But nobody can see LOLA's laser because it uses infrared light instead of visible light. Laser altimeters are also instruments on spacecraft studying Mars, Mercury, and other planetary objects. A laser altimeter on an airplane collected the data we used to make the model of Meteor Crater from segment #1. Can you find out how LOLA and these other laser altimeters work?

8) Use the tactile diagram to find the location where the instrument module attaches to the spacecraft bus. The orientation of the instruments is important so the peg and the hole are designed to only fit together one way. The laser altimeter and narrow angle cameras should face the same direction that the radar, cosmic ray detector, and neutron detector face. While LRO orbits the moon all of these instruments point down to the surface of the moon while the star tracker telescopes point away from the moon. What is the purpose of the star tracker telescopes?

9) Your model of the LRO spacecraft should now be complete. To find out more information about some of the instruments on LRO try these resources :

NASA:
www.nasa.gov/mission_pages/LRO/overview/index.html
lola.gsfc.nasa.gov

Space.com:
www.space.com/22106-lunar-reconnaissance-orbiter.html

Wikipedia:
en.wikipedia.org/wiki/Lunar_Reconnaissance_Orbiter
en.wikipedia.org/wiki/Lidar

Presenting Your Work:

For this short presentation think about ways to demonstrate how LRO is used to map the moon. Will you focus on power and communication? What about LOLA or the star tracker telescopes? Did you find out something completely different about LRO that you want to present, maybe about the neutron detector? Remember, don't try to present everything you know. Make a plan for your presentation that includes using some or all of your model of LRO and a simulated lunar surface. The moon's Tycho crater could be part of your simulated surface. Your mentors are building the same LRO model so they will be familiar with it.

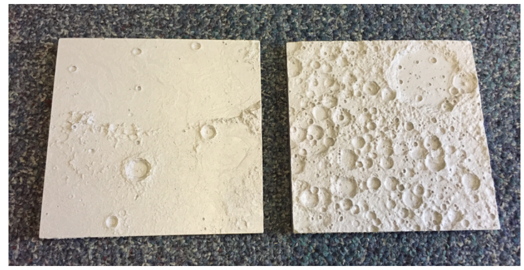
10) Using your demonstration, practice giving a brief 2 to 3-minute presentation about LRO to a friend or family member. Ask for their comments and questions to help you improve. Do you need to add anything to your List of Wonders after hearing their thoughts?

11) When you are comfortable with your presentation, record a video of yourself giving it and share the recording with your university mentor. Ask them for comments also.

12) Give your presentation to your industry mentor and then have a conversation about the project.

13) The last step is to share the video recording of your presentation with XXXX and XXXX so that we can follow your progress. Ask others on the WhatsApp group how they plan to share their presentations. This video file may be too large to send in an email or text message, so you may have to learn how to post it to a private YouTube channel and then share the link.

Segment #4 – Counting Craters



Tactile Tools:

3D Model of Lunar Maria
3D Model of Lunar Highlands
(Braille labels are on the south edge of each model)

Brief Introduction:

Earth's moon is dominated by two dramatically different types of surfaces. One of these surface types is called lunar maria (pronounced ma-ree-uh). The maria are low lying regions of the moon that are relatively dark. Before telescopes, people looking at the moon thought the lunar maria might be oceans or seas. That's where the name comes from, maria is a latin term meaning seas.

In your model of the lunar maria the large crater near the center is named after Nicholas Copernicus. Copernicus was an astronomer who lived about 500 years ago and helped to show that the sun was at the center of the solar system. Eratosthenes is the second largest crater, to the North-East of Copernicus. Have you ever heard of the person named Eratosthenes? You might want to look him up and find out what he did to earn a crater named after him.

The other type of suface on the moon is called the lunar highlands. As you notice in your models, the highlands are dominated by impact craters. The large crater in the North-East corner of the model is named Mendeleev. This very large crater is named after the Russian chemist Dmitri Mendeleev, who invented the periodic table. Notice that Mendeleev crater is almost four times larger in diameter than Copernicus. Are you curious why Mendeleev would have a crater larger than Copernicus?

In Segment #3 last month you built a model of the Lunar Reconnaissance Orbiter. This spacecraft has given us a complete map of the moon, revealing many details of the maria and highlands. Data from the LOLA instrument was used to produce the two models in this segment. Do you remember what LOLA is and how it works?

Continuing Your List of Wonders:

1) Study your two models of the maria and highlands. Think about how you would describe the differences between these two types of surfaces. What about their similarities? Are there any similarities? Do the differences or similarities make you wonder anything about how these surfaces could have formed? Start adding things to your List of Wonders. Remember that wonders may occur to you at any time during the science process. Ask your university mentor what things they are adding to their own List of Wonders.

Gathering Your Data:

The surface of the moon suffers from asteroid impacts in a random way. No area is shielded from impacts. Yet you can tell from your models that the Lunar Maria are significantly different from the Lunar Highlands, in terms of the number of impact craters in each region. This means that something must have erased old craters in the maria regions. (Are you wondering about what could erase impact craters?) We can use craters on the moon as a tool to help us understand how much older the highlands are compared to the maria.

2) The two models of the different surface types on the moon are each the same size, representing areas about 800 km (500 miles) long on each edge of the models. Before we start gathering our data let's think about Tycho crater. Remember, Tycho is the crater with the tall mountain in the middle. How big would Tycho crater be on the scale of the maria and highlands models? To calculate it, you can use a talking calculator device or your iPhone. Are any of the craters similar in size and structure to Tycho? Do you feel any central peaks in any of the craters? We'll use Tycho as a guide to study the new models.

3) For the maria and highlands models, count how many craters are as big or bigger than Tycho. Rather than using a ruler it may help to find an easy technique for measuring craters of this size in your new models. For example, maybe Tycho would be the size of the end of one of your fingers or your thumb. Then by sliding a finger back and forth across each model you can count how many craters each has that are as big or bigger than Tycho. Counting craters will be more challenging with the highlands because so many of the craters are overlapping. If you are not an expert on tactile exploration you'll need to work slow at first. It also is very helpful to count 3 or 4 times and then take the average of your counts. Rotate the model each time you count so you have a different perspective. In the highlands model more than one big crater is partially covered by smaller craters. Try not to miss these big ones. Be patient and thorough as you try to find these hidden craters. You can also use some material to mark each craters as you count them, like a bit of clay pressed into them, or a sticker.

4) Which of the two regions has an older surface? How can you tell? Try to think of a way you could explain this to someone. Is there an analogy from your everyday life that someone else could understand.

5) If you know how often asteroids impact the moon you can find the age of different regions by counting the craters on it. Early in the history of the solar system the moon was being hit by an asteroid big enough to make a crater at least the size of Tycho in each of our model areas about once every 50 to 60 million years. We call this the cratering rate. If you count how many craters exist that are at least the size of Tycho in each model, you can use the cratering rate to find the difference in age of the two regions. We'll do that next.

6) Find the difference in the number of Tycho-or-larger craters on the highlands model compared to the number on the maria model. Then apply this difference to the cratering rate (50 to 60 million years required for each crater). Your answer will be the difference in age between the surfaces. For example, if I count 5 Tycho-size craters on the maria model and 27 on the highlands model, then there are 22 more craters on the highlands. If it takes 50 to 60 million years to form each crater and I have 22 more craters it would take between 1100 and 1320 million years to form them all. Said another way, that's between 1.1 and 1.3 billion years! So if my crater counts are accurate then the highlands would be more than one billion years older than the maria. Get it? Now try it with the craters you counted.

7) Continue your research and try to answer at least two things from your List of Wonders. Remember, there may not be answers for everything on your list. Describe what you find in your journal, along with other interesting information you learn. Your university mentor can help you find resources. Here are a few places to start your online research:

   NASA:
   - https://moon.nasa.gov/about/in-depth/
   - https://www.nasa.gov/feature/jpl/study-finds-new-wrinkles-on-earths-moon

   Wikipedia:
   - https://en.wikipedia.org/wiki/Crater_counting
   - https://en.wikipedia.org/wiki/Lunar_mare
   - https://en.wikipedia.org/wiki/Moon

   Space.com:
   - https://www.space.com/19582-moon-composition.html

Presenting Your Work:

For this presentation we're going to introduce something new. This time make a plan that includes using some kind of <u>activity</u> for people to do so they can better understand how counting craters can help us understand how old a surface is. Your activity should be simple enough that even non-science people can participate. Also, think back to what you learned about presenting during our previous activities and use those experiences to help you this time.

8) <u>Using your activity,</u> practice giving a 4 to 5-minute presentation about crater counting and the age of the two types of surfaces on the moon. Like before, practice with a friend or family member. This is a more complex presentation than last time because you are trying to get people to follow your directions for the activity, so it might take more practice. Once you are confident with the contents of your presentation and your activity, think about other aspects of communication like body language and tone of voice. For example, are you using gestures and facial expressions appropriately? Are you varying the direction you face, changing the tone of your voice, and so forth? Ask for feedback on these subtle things from your

listeners after you present, then work to develop your non-verbal skills based on their suggestions.

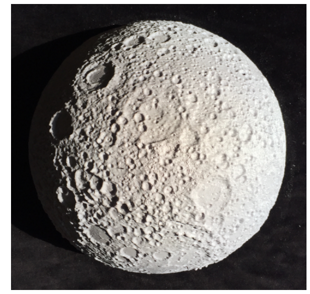
9) When you are comfortable with your presentation, record a video of yourself to share with Our Project. Here are some tips for making a good recording using a phone camera:
    a. Have your phone positioned horizontally, so the screen is wide. This way the video will look professional when viewed on a computer monitor.
    b. Whether using a tripod or having someone hold your phone, be sure your camera at a reasonable height and distance so it records the entire scene, not just your face.
    c. Try to keep your body facing mostly toward the camara. Avoid turning your back on the camera.
    d. Project your voice strongly so the microphone picks it up.
    e. Play back the recording for yourself so you can experience what your presentation was like. This is an important step. You may feel awkward hearing your voice but this is an important step that will help you notice aspects of your presentation you might want to work on.
    f. Make a couple recordings and then choose a favorite to share with your university mentor.

10) While you are practicing and recording ask your friends, family members, and your university mentor for comments and feedback that can help you improve. Then prepare to give your presentation again to your industry mentor. Did anyone ask you questions that you hadn't thought of yourself? Do you need to add anything to your List of Wonders?

11) Give your presentation to your industry mentor and then have a conversation about the project.

12) The last step is to share the video recording of your presentation with XXXX and XXXX so that we can follow your progress. Ask others on the WhatsApp group how they plan to share their presentations. This video file will be too large to send in an email or text message. Some people have been sharing their presentations using a private YouTube channel or a Google Drive account. Find what works best for you.

Segment #5 – Two-Faced Moon



Tactile Tools:

Tactile diagram of moon's rotation and orbit
3D models of moon hemispheres
(Braille and text labels are on the inside on the southern edge of each hemisphere, with a small protrusion marking the exact south pole)

Introduction:

As the moon orbits around Earth it always keeps the same side facing our planet. We call this hemisphere the Near Side of the moon. The other side of the moon always faces away from Earth. This hemisphere is refered to as the Far Side of the moon.

The tactile diagram illustrates how this works for different positions of the moon in its orbit around Earth. Take a few minutes to study the tactile diagram so that you understand what the terms Near Side and Far Side really mean. Does the tactile diagram help you? You can ask your University Mentor if you are confused.

Before the space age began nobody on Earth had ever seen the Far Side of the moon (how could they have?). In 1959 a Russian robotic spacecraft named Luna 3 became the first to send images back to Earth showing what the Far Side looked like. Because the Russians were the first to do this, they got to name most of the features on the Far Side. (Do you remember Mendeleev crater from Segment #4?)

Do you have your LRO model from Segment #3? Using data collected with the LOLA instrument on LRO we are able to make 3D models of the moon's Near Side and Far Side. On the inside of each 3D model are labels that identify the Near Side or Far Side hemispheres. These labels are on the southern edge of each model, near the south pole. You can use these labels to help align the hemispheres if you want to hold them together. A small protrusion marks the exact south pole of each hemisphere.

On the inside of the hemispheres there are also markers to indicate the locations of other models we used in earlier segments. A small "button" is underneath Tycho crater and two squares are under the locations of the lunar maria and lunar highlands models. Tycho crater is only about 4 millimeters across and might be hard to find. Copernicus in the lunar maria region and Mendeleev in the lunar highlands region are easier. Can you find them?

Continuing Your List of Wonders:

1) Compare your models of the two sides of the moon. Think about the similarities and differences between the two faces of the moon. What features are distinctive for each side? Hold the two hemispheres together with the Near Side facing you.

Think about how the moon moves. If the moon rotates and also orbits around Earth, how is it possible that it keeps one side always facing us?

Now it is time to add to your List of Wonders. But, don't forget that wonders may occur to you at any time during the scientific process. Share what you add to your list with your university mentor and ask them what new things are on their list.

Gathering Your Data:

By now you know that the Far Side of the moon has almost none of the smooth maria regions. In fact, the only prominent mare on the Far Side is Mare Moscoviense, or the "Sea of Moscow." To find Moscow first locate Mendeleev crater again. About 3 centimeters north-east of Mendeleev you'll find a ringed crater a fair bit larger than Mendeleev. The Sea of Moscow is inside that ringed crater.

2) Let's start by finding all the craters on the Far Side that are as big or bigger than the Sea of Moscow. I count more than 5 but less than 10. Some are really easy to notice but a couple others are more of a challenge. The biggest of them all is huge and hiding right out in the open. It may be easier to feel for it with your hand.

3) In the previous segment last month we researched how lunar maria form. Asteroid impacts crack through the lunar crust and the cracks let lava flow up to the surface. The lava fills in the crater basins, erasing old craters and hardening into to a smooth flat fresh surface. But this didn't happen in most of the crater basins on the Far Side. Why not? To help us understand lets compare the thickness of the crust in the Far Side and Near Side models. This is not as easy as you may think. We want the thickness in the center of each hemisphere, not around the edge where the models connect.

4) Try to think of <u>three</u> different techniques that you can use to measure the thickness of the crust in the center of the Near Side and Far Side models. The only rule is that you can't drill a hole into the model! Use each of your techniques and then take the average of the thickness you get for each model.

5) Which hemisphere has the thicker crust? Can you think of a way to explain to someone why this difference is important? Is there an analogy you could use that might help explain the importance of thick crust? (Have you ever been ice fishing?)

6) Continue your research and try to answer at least two things from your List of Wonders. One thing to keep in mind is that sometimes there can be competing ideas for explaining something and that researchers are still trying to figure out which one of them is correct, or if both are wrong. That's what is happening now with the Far Side of the moon. Briefly describe in your journal what you find through your research. Here are a few places to start your online search:

   UC Santa Cruz Research, Big Splat May Explain Moon's Far Side
   https://news.ucsc.edu/2011/08/big-splat.html

EarthSky.org, Far Side of the Moon Mystery Solved
https://earthsky.org/space/dark-side-of-the-moon-mystery-solved

Space.com, Does the Moon Rotate?
https://www.space.com/24871-does-the-moon-rotate.html

Accessible Science (Perkin eLearning):
https://www.universetoday.com/19699/does-the-moon-rotate/

Presenting Your Work:

For our presentation this month we're going to combine two things we worked on in previous months, an activity and a demonstration.

First, design an activity that your audience can do with you during your presentation to help them understand how the moon rotates and how it orbits around Earth. Use the tactile diagram to help you design this activity. The main idea is to help people understand that the moon rotates one time for every one orbit it makes around Earth.

Second, design a demonstration to help explain one of the techniques you used to find the thickness of the crust for the Near Side and Far Side models.

7) Using your activity and your demonstration, practice giving a 5- to 7-minute presentation about what you've learned about the differences between the Near Side and Far Side of the moon. You can practice it with a friend or a family member. This presentation has a lot of moving parts, so be sure to practice several times. While you are practicing, ask questions of any people helping you. For example, you can ask them if you are using gestures appropriately? Or are you varying the direction you face, changing the tone of your voice, and so forth? Ask for feedback on these subtle things from the people you practice with, then work to develop your non-verbal skills based on their suggestions.

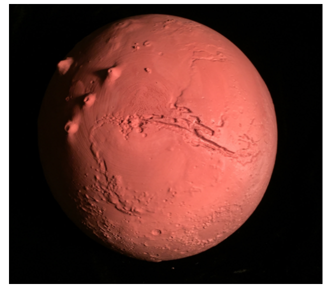
8) When you are confident with your presentation, record a video of it and share it with your university mentor. You will have to ask them to pause the recording to gather material for the activity and then resume when they are ready. Also, let's repeat last month's tips and tricks for making a good recording using a phone camera:
    a. Position the phone horizontally for a wide-screen professional look.
    b. Be sure the camera records the entire scene, not just your face.
    c. Avoid turning your back to the camera.
    d. Project your voice strongly so the microphone picks it up.
    e. Play back the recording for yourself so you can experience what your presentation was like. This is an important step. You may feel awkward hearing your voice but this will help you notice aspects of your presentation you might want to work on improving.

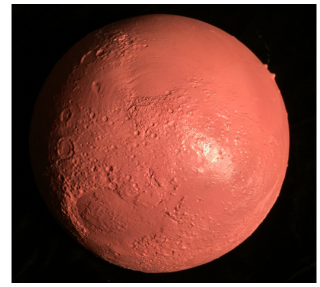
9) Based on the feedback from your friends, family members, and your university mentor, prepare to give your presentation again to your industry mentor. You can do this live or using a recording.

10) Share your presentation with your industry mentor and then have a conversation about the project.

11) The last step is to share the video recording of your presentation with XXXX and XXXX so that we can follow your progress. Some people have been sharing their presentations using a private YouTube channel or a Google Drive account. Find what works best for you.

Segment #6 – Moving To Mars





Tactile Tools:

East and West hemispheres of Mars
(Braille and text labels are on the inside on the southern part of each hemisphere, with a small protruding marker inside at the exact south pole)

Introduction:

During the first five segments of This Project we've been using impact craters to study the moon. We started small by studying a few different types of craters. Then we expanded our view to the maria and highland regions. We learned that we could use craters to determine ages of these different surfaces. Finally, last month we turned our attention to the Moon as a whole, to the vastly different Near Side and Far Side.

Now we're moving to Mars. With Mars we will start globally with a full model of the entire red planet. Over the next few months we'll study smaller details that we can learn about again using impact craters. You will find that craters on Mars can be very different from those on the Moon, and they have secrets to tell. Our goal is to use these Martian craters to learn what the planet might have been like in the distant past. The insides of the hemispheres have different shaped markers to indicate the locations of smaller areas that we'll use in activities over the next few months.

Continuing Your List of Wonders:

1) Study your models of the two hemispheres of Mars. Use the labels inside to determine which hemisphere is East and which is West. Compare the two hemispheres. What are the primary similarities between them? What about their differences?

   The four large volcanoes on Mars should be easy to notice, but can you find the 7 smaller ones? Are there any other large features you notice immediately?

   Begin adding Martian wonders to your list. Reach out to your University Mentor and share with them the new things you've put on your List of Wonders. Ask them what new things are on their list.

Gathering Your Data:

For this Martian activity we're primarily concerned with comparing your model of Mars to your earlier model of the Moon. So have your models of the Near Side and Far Side of the Moon ready for the activities below. The data we are gathering here is more qualitative descriptions rather than quantitative measurements or counting like we have done in the past.

2) Let's start by describing similarities between the two objects. Think about the ways that you notice in which Mars is similar to the Moon. How many big similarities can you find? More than one? More than two? Ask your University Mentor how many they can find.

3) Now comes the easy part. List the ways that Mars is different from the Moon. Can you come up with at least five main differences? What if we turn this into a competition with your student partner, or University Mentor, or a brother, or sister? Who can find the most differences between the models of the Moon and Mars?

4) Next we're going to try to compare the Northern and Southern hemipsheres of Mars. To do this, first find the marker indicating the South Pole for each Martian hemisphere. This marker is on the inside edge near the braille label. Using this marker as a guide, try to find the North Pole ice cap on each hemisphere. This will be 180 degrees opposite the South Pole marker. It may be hard to feel the North Pole ice cap because it's cut in half and each half doesn't stick up very high in the models. But you should feel it right along the Northern edge on the surface of each hemisphere.

5) Using the South Pole marker and the North Pole ice cap to guide you, study the differences between the Northern and Southern hemispheres of Mars. Do you notice the fundamental differences between the Southern regions of Mars and the Northern regions? Do these differences inspire you to add anything to your List of Wonders?

6) Martian geologists (i.e., human geologists who study Mars, not little green geologists) refer to these two regions as the Northern lowlands and Southern highlands. We have long puzzled over the causes of the difference between these regions on Mars. What are they telling us about the past on Mars? Several robotic spacecraft have been sent to the boundary region between the Northern lowlands and Southern highlands to help find clues. We'll be studying this boundary region more in the months ahead.

7) Using on-line research try to find answers to at least two things from your List of Wonders. Briefly describe in your journal what you find through your research. Here are a few places to start your on-line search:

   NinePlanets.org: Mars Facts
   https://nineplanets.org/mars/

   National Geographic: Planet Mars Explained
   https://www.nationalgeographic.com/science/space/solar-system/mars/

   Wikipedia: Martian North/South Dichotomy
   https://en.wikipedia.org/wiki/Martian_dichotomy

Smithsonian Air and Space Museum: Mars Volcanoes
https://airandspace.si.edu/exhibitions/exploring-the-planets/online/solar-system/mars/surface/volcanoes/

NASA Jet Propulsion Laboratory: Mariner Valley
https://mars.jpl.nasa.gov/gallery/atlas/valles-marineris.html

Presenting Your Work:

For our presentation this month we're going to use the Moon models from last month and the new Mars models from this month. Using these models develop a "Show and Tell" type presentation so that your audience can follow along with your description of the overall differences and similarities between the Moon and Mars. Although the models are the same size you may want to find out how big Mars is compared to the Moon. I'm sure someone will ask.

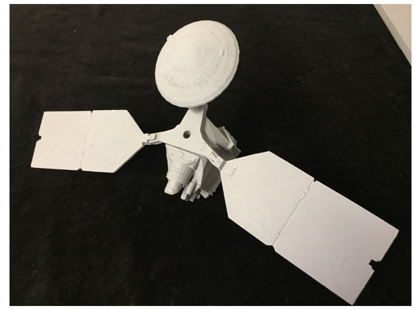
8) Using your Moon and Mars models, practice giving a 5-minute presentation about what you've learned about the differences between the Moon and Mars. You can practice it with a friend or a family member. While you are practicing, ask questions of any people helping you. For example, ask them if they understand what you are saying or if you need to phrase it differently? Also ask for feedback on your subtle non-verbal communication habits so you can improve in that area as well.

9) When you are confident with your presentation, record a video of it and share it with your university mentor. Don't forget to use the tips and tricks for making a good recording with your phone that we've talked about the last two months.

10) Based on the feedback from your friends, family members, and your university mentor, prepare to give your presentation again to your industry mentor. You can do this live or using a new recording.

11) Share your presentation with your industry mentor and then have a conversation about the project.

12) The last step is to share the video recording of your presentation with XXXX and XXXX so that we can follow your progress. Some people have been sharing their presentations using a private YouTube channel or a Google Drive account. Find what works best for you.



Segment #7 – Mars in High Definition

Tactile Tools:

Model of NASA's Mars Reconnaissance Orbiter spacecraft
Tactile diagrams of primary spacecraft components with assembly instructions

Brief Introduction:

Nine different robotic spacecraft are currently exploring the planet Mars. These include a rover driving on the surface, a lander drilling into the ground, and many orbiters circling the red planet in space. One of NASA's longest running Mars missions is the Mars Reconnaissance Orbiter (called MRO for short). The MRO spacecraft orbits above the Martian atmosphere. We use six different instruments on MRO to study Mars. The instruments include telescopes, cameras, and radar. The University of Arizona in Tucson operates the primary instrument on MRO – an imaging telescope named HiRISE. HiRISE stands for High Resolution Imaging Science Experiment. It is the most powerful telescope ever sent to another planet.

Continuing Your List of Wonders:

1) Carefully unpack the individual parts of the MRO spacecraft from the box. Along with the different components of MRO there are five pages of diagrams. These diagrams label important spacecraft components and indicate where the different parts attach together. The diagrams also show where smaller instruments of MRO are found on the spacecraft, such as the radar and antennae. Organize the five diagrams and eight main spacecraft parts so you can easily locate each component of MRO. If you are curious about any of the parts or instruments add your thoughts to your List of Wonders.

Assembling Your Spacecraft:

2) The main part of a spacecraft is called the bus. MRO's bus holds the electronics and computers we use to operate the science instruments and communicate with people on Earth. The bus also includes the small star tracker telescopes. Our first step in building MRO will be to attach the Engine Module to the bus. Find the bus and the engine module. The main engine is what MRO used to slow down when it arrived at Mars in order to insert itself into an elliptical orbit around the planet. Then we used a technique called aerobraking to change MRO's orbit from elliptical to circular.

3) Use the tactile diagram to locate the place where the engine module attaches to the bus. Align the engine module so its shape agrees with the shape of the bottom of the bus. The SHARAD instrument should be flush with the bus edge on the side with the star tracker telescopes. Use a small amount of glue to attach them together. Superglue works very well with these urethane plastic parts, but be

careful not to accidentally glue your fingers together! Of course, if you do this, maybe you'll have another interesting wonder for your list ("I wonder how I get my fingers unglued?").

4) MRO's instrument module includes four science instruments. NASA gives each of these instruments an acronym nickname. For example, MARCI is the nickname for the Mars Color Imager instrument and CTX is the Context Camera. All of these instruments point down at Mars as MRO orbits around the planet above the atmosphere in space.

5) Use the tactile diagram to find the location where the instrument module attaches to the MRO spacecraft bus. The orientation of the instruments is important. CTX goes alongside the HiRISE telescope. On the bus there is a small round part of CTX already in place next to HiRISE. Find this and use it as a guide for attaching the instrument module. A small amount of superglue is needed for attaching the instrument module.

6) Now it is time to add the HiRISE telescope. Telescopes use curved mirrors to magnify images. Together the mirrors work like the lens of a magnifying glass. The primary mirror of the HiRISE telescope is in a housing along with the camera that records the images. This housing needs to be joined to the HiRISE shroud that holds the secondary mirror. First dry-fit them together to make sure they will connect well. Then separate them and use a small drop of glue on the lip around the shroud and reconnect. Finally, attach the HiRISE telescope to the bus using the diagrams to align the diagonal edge of the shroud properly. If you've done this correctly HiRISE and all the other instruments should point in the same direction. Because they all point in the same direction, HiRISE, CRISM, and CTX can all work together at the same time to study the same area of Mars.

7) Our final step in building MRO is to connect the spacecraft peripherals, which are the high gain antenna for communication with Earth and the solar panels for power. Find the diagram with these parts. On the left-wing solar panel notice the braille letter "l" on the panel. Find the same braille letter "l" on the high gain antenna support structure. Notice the notch at the end of this left support arm. The solar panel has a connection that fits into this notch. With the support held flat on a table place a small drop of superglue in the notch on the support and slip in the connection for the left solar panel. You may want to dry-fit first and use a small nail file on the connection to allow it to fit smoothly into the notch. Connect the right-wing solar panel in the same way. Are you curious about why there are two identical solar panels, instead of just one like on the LRO spacecraft you built for studying the moon? A clue to the reason is in their description as "wings" and in the technique MRO used to reach a circular orbit (see #2 above).

8) After letting the glue dry on the solar panels, we need to attach them to the bus. Align the hole on the high gain antenna support with the round peg at the top of the

bus. Position the flat edge of the support along the lip on the bus below HiRISE. Use a small amount of superglue to attach the support to the bus at this position.

9) Your model of the MRO spacecraft should now be complete. Do you need to add anything to your List of Wonders after completing the model? Review your List of Wonders and ask your University Mentor what they have on their list. Then, pick two items from the Lists and conduct some research to look for answers. For more information about HiRISE and other MRO instruments try these sources:

University of Arizona HiRISE Telescope:
https://hirise.lpl.arizona.edu
https://twitter.com/HiRISE

NASA:
https://www.nasa.gov/mission_pages/MRO

Space.com:
https://www.space.com/18320-mars-reconnaissance-orbiter.html

Presenting Your Work:

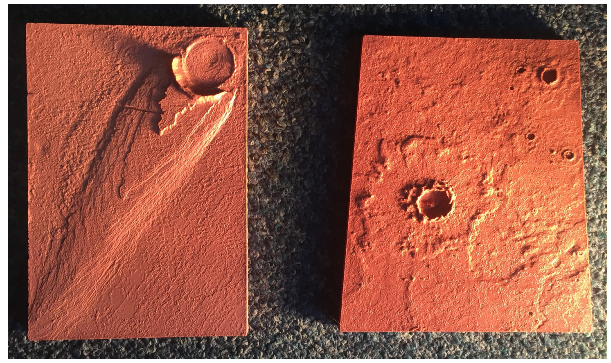
For this presentation think about ways to explain and demonstrate the major differences between MRO and the LRO model spacecraft you built back in September. Both models are designed at the same scale. This means if a certain part is bigger in the MRO model compared to LRO, then it is bigger on the real spacecraft as well. For example, one difference is in the size of the high gain antennae on the two spacecraft. Can you find other important differences? What about in the types of instruments included on each spacecraft? How about in the number and size of the solar panels and how they are positioned on each spacecraft? Remember, in your presentation don't try to discuss everything you've learned. Just pick one or two things that you find fascinating. Make a plan for your presentation that includes using both your MRO and LRO models. You might want to use some of your other models as well as simulated surfaces. Your mentors are building the same models as you so they will have them in order to follow along with your presentation.

10) <u>Using your voice and a demonstration</u>, practice giving a 3- to 5-minute presentation about MRO and LRO to a friend or family member. Ask for their comments and questions to help you improve. Do you need to add anything to your List of Wonders after hearing from them?

11) When you are comfortable with your presentation, record yourself giving it and share the recording with your university mentor. Also ask them for comments to help you improve your presentation skills.

12) Give your presentation to your industry mentor and then have a conversation about the project and what each of you have learned about exploring Mars.

Segment #8
Martian Craters Tell Tall Tales



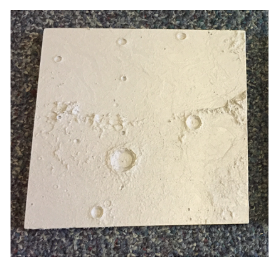
Tactile Tools:
Crater in the Athabasca Valles region of Mars
Davies Crater in the Northern lowlands Mars

Introduction:
Today Mars is a cold, dry, dusty desert planet. But it was not always such a desolate place. Mars was once a warmer and wetter world. We're going to look for evidence of all that water in the past and try to figure out where the water is today.

In the last activity we built a model of the Mars Reconnaissance Orbiter spacecraft, also known as the MRO. Studying Mars with the HiRISE telescope on MRO gives us our best view of the terrain on the red planet. This month we'll use models created from HiRISE observations. Two particular impact craters on Mars can tell us tales about the secret wet past of the red planet and where the water is today. In this activity we'll focus on a Martian region known as Athabasca and on a crater named Davies.

Continuing Your List of Wonders:

1) Compare your two new models with your earlier craters from the moon. In particular, compare the new Mars craters with the lunar maria model from the Counting Craters activity (#4). Study the characteristics of the Martian craters and the lunar craters. For Davies the details are subtle, so be patient as you explore features on that model. The differences in the Athabasca model are more striking and easier to notice. Think about differences and similarities between these Martian craters and lunar craters. Add to your List of Wonders and share your thoughts with your University Mentor.



Begin Our Exploration:
Let's start our exploration by learning about the size and scale of the features in these two models.

2) Each horizontal centimeter in the Athabasca model represents 300 meters on Mars. Using the ruler we sent in the earlier activities find the diameter of the round crater in the corner of the Athabasca model. In your journal write the result in meters, kilometers, and also miles.

3) Now find the long diagonal sloping feature that comes off of the crater. This feature is streamlined, kind of tapered like a tear-drop, so we'll call it the "streamline." How many miles long is the streamline?

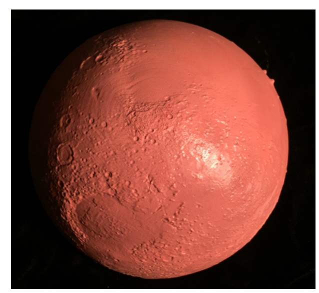
4) To appreciate how long the streamline is, it sometimes helps to think about what it would be like to walk along it. How long would it take you to walk the entire length

of the streamline? Don't worry about wearing a space suit in the Martian atmosphere, or the fact that gravity on Mars is a lot weaker than on Earth. Just think about how fast you walk on Earth and use that speed.

5) There's one last element of the Athabasca model that we can measure. Can you find the small crack that cuts through part of the model? This fault line formed during an earthquake (actually, a marsquake!). By touch alone this fault line will be very challenging to find. With the braille label facing you the fault is about 600 meters below and to the left of the crater, on the slope of the streamline.

6) Have you ever done a long-jump in school? Would you be able to jump across this fault? How wide is it? With the lower Martian gravity the best long-jumper on Earth would be able to jump about 50 feet on Mars. Would they be able to jump across this fault?

7) The streamline did not form at the same time as the crater. And that fault did not form at the same time as the smooth flat terrain surrounding the streamline. Think about the order in which all these overlapping features in Athabasca must have formed. Which do you think formed first? The fault? The crater? The streamline? The smooth flat terrain? See if you can come up with a logical sequence to explain the order in which these four charateristics must have formed. Ask your University Mentor what their sequence is. Do you both agree? If you don't agree, ask them to explain their logic, then you explain yours. Hopefully you can come to an agreement on an order.



8) The Athabasca region on Mars is located in the Eastern Hemisphere. Feel on the inside of our East Hemisphere model (from Activity #6). There are several markers inside. One of these markers is shaped like a round bump, another like a hollow crater, a third like a tadpole. A fourth marker is rectangular. This rectangular marker indicates where the Athabasca region is on the outside of the Eastern Hemisphere. Unfortunately, the crater we are studying is so tiny you won't even notice it compared to the entire planet of Mars. It takes the HiRISE telescope to see if from space. But you will notice that Athabasca is in the very smooth northern lowlands of Mars. HiRISE has revealed many (many!) other streamlined features in the Athabasca region. Part of your online research will be to learn how these formed. A hint is in the name we've given to the features – streamlined.

9) Davies crater is our second Martian model. Davies itself is the largest of several craters in the model. It is located on the prime meridian of Mars, meaning at zero degrees longitude. That's the exact line that seperates the East and West hemispheres of our models. This means half of Davies would be in one hemisphere and half in the other. Although Davies crater is almost 50 kilometers in diameter (30 miles) it is too small to notice either half in our hemisphere models.

10) How would you describe the area around Davies crater? We sometimes call the area surrounding Davies a debris apron. Can you feel the apron around Davies? It

isn't exactly round, but it does wrap around the entire crater. The apron ends about 50 km away from the rim of Davies crater, so about equal to the diameter of Davies itself. If you use a very gentle touch you may notice that the smaller craters on the model also have aprons of debris. In fact, nearly every single crater in the Northern lowlands of Mars has a debris apron like Davies, even the really tiny craters. Craters like Davies are called Rampart Craters because of these surrounding aprons.

11) What we see in the Athabasca region today formed during a time called the Noahcian period on Mars, about 3.5 billion years ago. The name for this period is derived from the biblical character Noah and gives us another clue about the origin of the streamline in the model. Have you figured it out? The Athabasca region is telling us a tale of great floods of water on Mars in the distant past. Flowing water eroded the crater in Athabasca and formed the streamline as sand settled out of the water to form an island downstream from the crater. The streamline used to be an island.

12) On the other hand, Davies and its debris apron formed much more recently, during what is called the Amazonian period. Mars is in the Amazonian period right now. Davies tells us a tale of frozen water just under the dusty surface. Impacts of asteroids melt this ice and make mud. During the blast from the impact the mud is pushed along the ground away from the crater in all directions. As the mudflow re-freezes a debris apron is left behind.

Researching Your Questions:

Look at your List of Wonders. Pick one thing and search online to see if you can find any answers. Briefly describe in your journal what you find through your research. Here are a few recent news stories start your online search:

Discover Magazine: Buried Ice On Mars
discovermagazine.com/the-sciences/scientists-mapped-water-on-mars-and-found-it-buried-just-inches-deep

Popular Mechanics: Disappearing Water on Mars
popularmechanics.com/space/moon-mars/a30472571/water-evaporating-mars-atmosphere/

Rampart Craters, from Arizona State University
marsed.asu.edu/mep/craters/rampart-craters

Wikipedia: Water on Mars
wikipedia.org/wiki/Water_on_Mars

Presenting Your Work:

For our presentation this month we'll focus on an activity. Think about the main points of this month's models. We worked on understanding the logical sequence of geological events – crater, streamline, fault, smooth terrain. What kind of an activity could you use to help explain these concepts? How about the formation of the streamline in Athabasca by flowing water? Can you come up with an activity to help show that? Mudflows around Davies crater? How about the general differences between craters on the Moon and those we studied on Mars? Whatever the main point you want to get across is, design an activity that will help present this to your audience

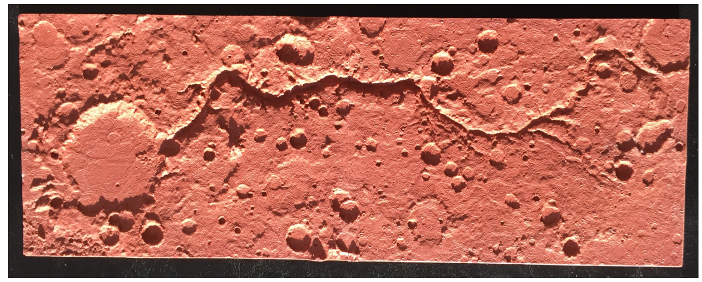
13) Using your activity, practice giving a 3- to 5-minute presentation about what you've learned about from these Martian craters. You can practice it with a friend or a family member. While you are practicing, ask questions of any people helping you. For example, is their activity going as you had planned? Are they noticing the things you want them to notice? It might take a few attempts to get the kinks worked out of your planned activity.

14) When you are comfortable with your presentation, record yourself giving it and share the recording with your University Mentor. Also ask them for comments to help you improve your presentation skills.

15) Give your presentation to your industry mentor and then have a conversation about the project and what each of you have learned about water on Mars.

16) The last step is to share the video recording of your presentation with Tasnim XXXX and XXXX so that we can follow your progress. Some people have been sharing their presentations using a private YouTube channel or a Google Drive account. Find what works best for you.

Segment #9
Grand Canyon Crater



Tactile Tools:

Gusev Crater on Mars
(Braille label is on South edge)

Special Note:

Many of us are feeling overwhelmed with the coronavirus situation. It can be a struggle to keep up with our remote learning and teaching from school. To help make our lives a little easier, <u>we're **not** going to do presentations in Activities 9 or 10</u>. Hopefully you can have some fun exploring Mars and learning some wonderful things.

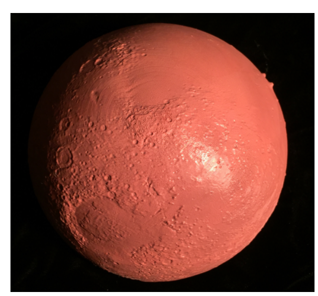
Brief Introduction:

The search for life on Mars has inspired people for over a hundred years. Since we know there is life on Earth we look for ways that Mars is similar to Earth to understand if it does, or did, support life. Both Earth and Mars have an atmosphere. An atmosphere can mean clouds, wind and rain. An atmosphere can also allow a planet to have lakes, rivers, and oceans. Life on Earth requires this water, so looking for signs of life on Mars often means searching for evidence of water. Last month we used the Davies and Athabasca impact craters to help us explore the evidence for water on Mars in the past. Our next stop is Gusev crater.

Your List of Wonders:

1) There are two defining features of this month's Martian model. First is Gusev crater itself, which is the large crater near the Northern end of the model (the braille label is on the Southern end). Find Gusev on your model and use this as a reference point. The second feature is connected to Gusev and wanders back and forth across the model as it extends away from Gusev towards the South. While you explore this second feature think about things on Earth that might be similar to it. What could have caused this long winding channel to form on Mars? As we explore our Gusev crater model let's start adding things to our List of Wonders. Remember that wonders can pop into our minds at any time during our exploration, so keep your list handy. Ask your university mentor what they are wondering about while exploring Gusev crater.

Gathering Your Data:



2) Gusev crater on Mars is at latitude 14 degrees South and longitude 175 degrees East. This places it in the Eastern Hemisphere. It is near the equator and near the cut edge of the hemisphere model you have from Activity #6. On the inside of this hemisphere the marker shaped like a tadpole indicates where Gusev is located. Once you find Gusev on the East hemisphere model, describe the region around it. Use our terms for Northern and Southern areas of Mars from Activity #6. Does the orientation of the channel flowing into Gusev make more sense now?

3) Let's use the size of Gusev crater to find the scale of our 3D model. According to NASA measurements from orbiting spacecraft, the real Gusev crater is about 160 kolometers in diameter. To make a scale from this information we need to measure how many centimeters across Gusev crater is in our model.

4) You can find the scale of your model by dividing the real diameter of Gusev by the diameter of the model crater. The answer will tell you how many kilometers on Mars are represented for each centimeter in our model. What is your scale? If it helps you understand better you can use miles instead of kilometers.

5) The long meandering channel connected to Gusev crater was formed by an ancient river. It may be difficult to measure this channel directly with a ruler because it has a lot of twists and turns in it. Can you think of a way to measure it better? You can ask a friend or your university mentor for ideas. When you have a plan, go ahead and measure the length of the river channel, starting at Gusev crater and going all the way to the farthest southern end where you can still notice the channel. How many centimeters long is the river channel? Use the scale of your model to find out how long the real channel is on Mars, in kilometers or miles. What length do you get?

6) Now that you have the length of this river channel on Mars we can compare it to a familiar river channel on Earth – Arizona's Grand Canyon. Find the length of the Grand Canyon (can you ask Siri, Alexa, or Google Assistant?). Is it bigger or smaller than the Gusev river channel? Do you need to add anything to your List of Wonders after making this comparison?

7) Using your models can you think of a way to identify which direction water was flowing in the Martian river channel? Was the water flowing out of Gusev crater into the channel, or was it flowing from the channel into Gusev crater? What would Gusev crater have been like when the water was flowing?

8) Gusev crater is so interesting that NASA sent its Mars rover Spirit to explore the crater. In the next activity you'll get a 3D model of the Spirit rover to build. Do some online research to learn more about what Spirt found in Gusev crater and try to answer at least two things from your List of Wonders. Remember, there may not be answers for everything on your list. Describe what you find in your journal, along with other interesting information you learn. Your university mentor can help you find resources. Here are a few places to start your research:

   Wikipedia:
      https://en.wikipedia.org/wiki/Gusev_(Martian_crater)
      https://en.wikipedia.org/wiki/Spirit_(rover)

   In the News:
      https://www.space.com/18766-spirit-rover.html
      https://www.iflscience.com/space/gusev-crater-mars-was-once-lake/

Discussing and Sharing Your Work:

9) Discuss your exploration of Gusev crater with your industry and university mentors. Ask what things they have on their own Lists of Wonders.

10) Share your List of Wonders for this activity with XXXX and XXXX so they can follow your progress.

Segment #10 – Wheels on the Ground

Tactile Tools:

Model of NASA's Mars Exploration Rover named Spirit
Diagrams of primary spacecraft components with assembly instructions

Special Note:

Many of us are feeling overwhelmed with the coronavirus situation. It can be a struggle to keep up with our remote learning and teaching. To help make our lives a little easier, we're **not** going to do presentations in Activities 9 or 10. Hopefully you can have some fun exploring Mars and learning some wonderful things.

Brief Introduction:

People on Earth can explore the surface of Mars using robots that drive around on the red planet. So far, four of these rovers have been sent to the planet, and a fifth is heading there this summer. The model in this activity is a rover named Spirit. Spirit is a twin to another rover named Opportunity. They each landed on Mars in 2004. Spirit was sent to explore Gusev crater, the model from last month.

Your List of Wonders:

1) Carefully unpack the individual parts of Spirit from the box. There are 15 different pieces. The smallest pieces are together in a small zip-loc bag so they won't get lost. A small tube of super glue is also included so that you don't have to leave home to get your own. Along with the different rover pieces there are two pages of diagrams. These diagrams label important components and indicate where some of the different parts attach together. Organize the two diagrams and 15 parts so you can easily locate each component of Spirit. If you are curious about any of the parts or instruments add your thoughts to your List of Wonders.

Assembling Your Rover:

2) Spirit's largest part is its equipment deck. The entire wing-shaped equipment deck is a solar power array used to charge the rover's internal batteries. Spirit's deck holds three different antennae and a tall mast with cameras. During launch from Earth and the cruise through space to Mars the mast and antennae were stowed flat and the equipment deck was folded up. Study the equipment deck and see if you notice the six individual solar panels that make up the deck. These panels folded along the raised hinges to form a pyramid shape over the stowed mast and antennae. The engineers who developed this folding solar power deck must have had some training with folding origami. Lay out the deck, antennae, and camera mast in the arrangement of the first diagram. Get the tube of superglue ready.

3) First, we will dry-fit the parts on Spirit's deck, to make sure they all are correct. Then we can glue them if needed. You may want to leave the mast unglued so that is can rotate. Find the three round holes and one square hole in the top of the equipment deck. The square hole marks the left side of the deck and is where the high-gain antenna goes. Slip the high-gain antenna into the square hole. Do you remember what a high-gain antenna is used for? This is the primary antenna used to communicate with Earth. On the real Spirit rover the high-gain can rotate around horizontally and the small radio dish sticking out the side of it can rotate vertically. The rover keeps the high-gain antenna pointed towards Earth whenever Earth is above the horizon. But for this simple model the high-gain can't turn.

4) Right next to the high-gain square hole is the round hole where the omni-directional low-gain antenna goes. Do you remember how an omni-directional antenna works? The LRO and MRO spacecraft we built each had one of these. They are back-up devices in case the high-gain has problems. Slip the low-gain antenna into its round hole next to the high-gain. You may need to turn the high-gain antenna 90 degrees one way or another so the dish doesn't interfere with the low-gain antenna.

5) The Spirit and Opportunity missions each cost about $800 million. At this price NASA was extra careful about making sure there were backup systems of communication. In fact, there is a backup for the backup! Engineers at NASA gave the rovers a third way to communicate. This is by using an Ultra High Frequency antenna, or UHF antenna. UHF is the frequency range we use for small hand-held radios on Earth, like walkie-talkies. They only work over short distances. Spirit can use its UHF walkie-talkie to communicate with other spacecraft orbiting Mars, like MRO. Then those orbiters can relay the communication back to Earth. This method can be used if the other systems fail, or when Earth is not above the horizon, so the low-gain and high-gain antenna won't work. Find the round hole on the right side of Spirit's equipment deck and slip in the UHF antenna.

6) Finally, we need to install the mast. Study the mast and find the two eye-like cameras at the top of it. Slip the mast into the round hole at the front of the equipment deck. Once upright like this, Spirit's mast reaches about 5 feet above the ground (about 1.5 meters). That should give you a good idea of how big Spirit is. You would be literally eye-to-eye with Spirit if the two of you were facing each other. The cameras on the mast are designed to resemble the height and spacing of human eyes so that Spirit can mimic the experience a human might have while standing on Mars. The images from these two mast cameras are combined together to give people on Earth three-dimensional depth perception of Mars. People on Earth wear 3D glasses when they study the images. This allows them to program Spirit to drive around obstacles and to investigate interesting rocks lying on the surface.

7) Once you have the mast in place and the three antennae dry-fitted correctly you can reinstall the antenna with a teeny tiny drop of glue in each of their holes. Be very careful with the glue so you don't get any excess on Spirit's deck. <u>One trick</u>

you may want to try is putting a drop or two of glue in a bottlecap and then using a toothpick to apply a tiny amount into each hole. You can glue the mast if you want, or leave it loose so it can be rotated.

8) Spirit's solar panel equipment deck should now be complete. We'll move on to the underside of Spirit next. Before start that, there's one fascinating thing to share about the twin rovers Spirit and Opportunity. Engineers at NASA only thought the rovers would survive for about 90 days on Mars. After those three months the engineers thought so much dust would have built up on the solar panels that it would starve the rovers of sunlight and thus electricity. Spirit ended up surviving for over 6 years, and Opportunity for almost 15 years. Do you wonder how they could survive that long?

9) Turn your attention to the second diagram. Let's build the suspension system first. Notice that there are two seemingly identical parts in the suspension system. They are actually left-handed and right-handed components, like mirror images of each other. Each of these suspension pieces has a square bracket at one end and a small pin at the end of each of three struts. Lay each suspension piece flat so that the small pins stick up. Pick up one of the wheels and find the flat side with a tiny hole in the center. The holes are probably too small to feel, so you may need to use a small probe to find them. Something like a toothpick will work. First dry-fit the wheels onto the pins to make sure everything fits. Then, place a tiny drop of superglue next to each pin and press the wheels into place. The superglue should dry in about 60 seconds, but maybe give it a bit longer just in case. On the real rover each wheel has its own electric motor, like the wheels on a Tesla electric car. That means Spirit is a 6-wheel drive electric rover! The top speed of a 4-wheel drive Tesla Model S is about 155 miles per hour. What do you think the top speed of Spirit is?

10) After the glue has dried on the wheels it is time to attach the suspension system to the rover body. Notice that each side of the body has square pegs where the suspension attaches. The tricky part is making sure you have the left on the left and the right on the right. The front of the body is narrower than the rear. There are two small hazard-avoidance cameras at the very front of body. Can you find them? There are also two hazard-avoidance cameras on the wider rear. These are for the times when Spirit drives in reverse. Line up the front left wheel with the front left of the body and dry-fit the square bracket over the square peg. It should fit snuggly and may not need glue at first. Do the same with the right-side suspension.

11) Before gluing the suspension onto the body be sure to double and triple check that you have the right and left side correct. Notice that each suspension piece has two wheels together and one wheel by itself. That wheel by itself is the front wheel on each side. If you've got it correct, then place tiny drops of glue on each edge of the square peg and gently press and hold the square suspension bracket onto the peg. This is where you may get superglue on your skin, so have a plan ready for how to avoid that!

12) Once the glue dries on the suspension system, the rover body should stand on it own. Holding the robot arm, gently press the round end of the arm into the space just below the hazard-avoidance cameras on the front of the body. The round end of the arm has been slightly tapered to slip into the space and then onto a round peg. A very small amount of force might be needed to slip the arm into this gap. Don't glue the arm in place. It should pop onto the peg and then move freely. The most interesting instrument on the end of the robot arm is called the RAT! Do you wonder what that is? Your job is to find out what the RAT is and how it is used!

13) We're finally ready to join Spirit's deck and body. Notice on the top of the body there is a triangular hole and on the underside of the deck there is a matching triangular peg. Dry-fit these together to make sure the deck will lay completely flat on the top of the body. If the suspension pieces stick up a bit too high you may need to sand them down with a nail file. Once the deck is laying flat on the body you can place a couple drops of superglue on top of the body and hold the deck in place until the glue dries.

14) Your model of Spirit should now be complete. Do you need to add anything to your List of Wonders after completing the model? Review your List of Wonders and ask your University Mentor what they have on their list. Then, pick two items from the Lists and conduct some research to look for answers. For more information about Spirt and its twin Opportunity try these sources:

    Wikipedia:
        https://en.wikipedia.org/wiki/Spirit_(rover)
        https://en.wikipedia.org/wiki/Opportunity_(rover)

    Space.com story on Spirit:
        https://www.space.com/18766-spirit-rover.html

    National Geographic story on Opportunity:
        https://on.natgeo.com/2ZGx8TY

    NASA – Why have the rovers lasted so long?
        https://mars.nasa.gov/mer/highlights/why-have-the-rovers-lasted-so-long/

Discussing and Sharing Your Work:

15) Discuss your work with Spirit with your industry and university mentors. Ask what things they have on their own Lists of Wonders.

16) Share your List of Wonders for this activity with XXXX and XXXX so they can follow your progress.