Lunar Surface Curriculum Pack

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The ***Astronomy For Educators Workshop*** will be held on December 2nd (Elliptical Orbits), December 9th (Exploring Lunar Phases), and December 16th (Exploring the Lunar Surface).

The workshop focuses on Dr. Barth's ***Low-Cost Science*** methods for teaching astronomy and space science. The intent of Low-Cost methodology is to enable every school, teacher, and student to enjoy a quality astronomy education without significant expense. Dr. Barth believes that a quality STEM education is the right of every child – and that no one should lack a powerful STEM experience because funding for expensive lab equipment is lacking.

Comments, and reviews of these materials may be posted on social media, or emailed directly to Dr. Barth. Questions about the activities may be addressed to Dr. Barth at: AstronomyForEducators@gmail.com

About the Author:

Dr. Daniel E. Barth is Assistant Professor of STEM Education at the University of Arkansas, USA. Dr. Barth has more than 40 years of experience teaching astronomy and physics at secondary and university levels, and training STEM educators in the United States. Dr. Barth has been a Reagan Scholar, Research Corporation Fellow, and Science is for Kids Foundation Fellow. Dr. Barth's work has been recognized by UNESCO, the Amgen Award for Science Teaching Excellence, the Global Campus Award, and more. Published works include:

Science Texts:

Astronomy for Educators

Observational Astronomy

Teaching Science Through Literature

Fiction:

Maurice on the Moon

The Doomed Colony of Mars

Crisis on the Far Side

Revolt in Volkov Crater

Modeling the Moon's Surface in Clay

Modeling the lunar surface in clay seems like a very tall order for younger children. I've often had my education students (and experienced teachers!) scoff at this activity and claim that such an art project is much too hard for students younger than high school age. These people couldn't be more wrong.

When making a scientific model it is important to remember that we are not striving to create great art, or even mediocre art! Instead, we are striving to create an understandable representation; something that helps show what we know about a particular part of Nature, in this case, the lunar surface.

We help students achieve this by guiding them step by step to create their own models. The idea is to get them to put into physical form something they have learned about the lunar surface, such as the large mountains that exist at the center of large craters! We do not have to produce great art in order to produce better understanding and comprehension for our students!

Academic Standards

Science and Engineering Practices

Developing and using models
Analyzing and interpreting data
Constructing explanations
Obtain, evaluate, and communicate information

Crosscutting Concepts

Cause and effect
Systems and system models
Stability and change

Next Generation Science Standards

Space systems (K-5, 6-8, 9-12)
Earth shaping processes (K-5, 6-8, 9-12)
The Earth-Moon system (6-8, 9-12)

For the Educator

Facts you need to know

1. Planets and moons are formed by a process called ***accretion***. Basically, small pieces collide and stick together making larger pieces. Gravity (and other forces) help speed the process and the larger a piece is, the faster it tends to grow.

2. The smaller, free orbiting pieces that haven't become planets or moons yet are called ***meteoroids*** and ***asteroids***[1]. Meteoroids are anywhere from the size of a grain of dust up the size of a large car or truck. Asteroids range from the size of a small building, to hundreds of miles wide; these meteoroids and asteroids are the basic building blocks from which planets are assembled – and the building process still continues today.

   The word ***asteroid*** means "star-like". When the largest of these bodies were discovered in the early 1800's, they appeared as small drifting stars in the telescopes of astronomers.

3. When a small piece of material such as an asteroid collides with a planet or a moon, it is referred to as an ***impactor***. These impactors strike at tens of thousands of miles per hour and can hit the surface with tremendous energy, enough energy to reshape the very surface (and interiors!) of worlds as large as the Earth.

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[1] Astronomy is rife with interesting names and nomenclature and there is much debate over what does and does not qualify as a planet. Large objects (more than 50 miles across) are sometimes called *protoplanets*, *planetessimals*, or even *planetoids*. In order to keep things simple, I have restricted myself to meteoroid (small rock invisible from Earth) and asteroid (large enough to be seen with a telescope). An object becomes a *planet* when it is large enough to become spherical in shape.

Conducting the Activity

Materials

1. A large block of light-colored modeling clay, enough to make a slab that is 6-inches square and ½-inch thick.
2. A smaller block of dark-colored modeling clay. (The exact color will not matter, as long as the colors contrast well.)
3. A piece of aluminum foil large enough for your slab of clay. Oil-based, non-drying clays can stain table tops, clothing, or papers with oily residue in a matter of hours if left in place.
4. Various size marbles and beads.
5. Some larger, smooth-surfaced balls such as baseballs, hard rubber handballs, etc. These should be between two and six inches in diameter.
6. One 12-inch piece of string per group
7. Construction paper and markers.

Building the Lunar Surface Model

1. Begin by flattening out the large block of clay into an even layer in a paper plate, or on a baking pan. School clay is typically oil-based, leaving it on a wooden, cloth, or leather surface is likely to leave an oily stain. When the layer is relatively flat, turn the pan over and tap the layer of clay out onto a sheet of construction paper. When turned upside down and dropped onto the construction paper, the surface of the clay may settle and will likely not be perfectly flat – don't worry, that won't affect our model at all.
2. Now take the largest ball you have (large marble or ping-pong ball works well) and press it firmly into down into the surface, you may even want to rock it back and forth just a bit. When you take it away, you should have a nice depression, perhaps with the edges raised just a bit. Roll this depression out until it is 2-3 inches wide. This will be a ***maria*** – but we aren't done with it yet!
3. Move to the next size smaller balls and make one or two more large craters. Be sure you press them firmly into the surface so that they are deep enough. You may notice that these depressions even overlap a bit – don't worry, craters tend to do that!

4. Now it is time to fill in your maria. Take the dark colored clay and roll out a 2-inch ball, then flatten it out to make it nice and thin. Make sure the piece you have is pressed out large enough to cover one of your large depressions all the way to the edges; if you don't have enough clay, start again with a larger ball!
5. Lay this thin piece of dark clay into the depression and press it in place. If it goes beyond the edges at some point, you can either trim the extra away with a plastic knife, or smooth it onto the surface – lava flows from maria do sometimes overflow their crater and flow out onto the lunar surface!
6. ***Lunar mountains*** are actually huge pieces of stone that have been blasted out of a maria basin. Pinch off small pieces of dark clay, about 2-3 mm wide (half the size of a pea) and place them in a curved line around a maria basin. The arc of mountains usually extends no more than $1/10^{th}$ the circumference of the maria basin.
7. Now you can start with marbles and beads, pressing small ***craters*** into the surface as you like, remember to start with the larger marbles and work your way down to the smaller sizes. Make lots of medium and small craters and don't worry about creating them in any order – just tell the kids to have fun with this. Remind the students that it is perfectly alright for craters to overlap! Does anyone notice that new craters sometimes wipe out older ones? Don't ignore the dark maria surface! Maria have almost as many craters covering them as the rest of the Moon does!
8. Choose a few scattered craters to be "new" (no more than 100 million years old!). Use a pencil to lightly scratch 'splatter marks' – lines leading directly out from the edge of the crater like a sunburst. These lines are called ***rays*** and are actually made of powdered material blasted out of the crater when it was made.

9. Some larger craters have ***central mounts***, essentially mountains centered in the crater. Take a pinch of light clay and form mountains to place in one or two of your larger craters.

10. Now you can create an ***ejecta blanket*** around some of your larger craters. Ejecta is the rock and dust ejected when a crater is made. You can model ejecta by scratching around a crater with a nail or golf tee. Your scratches shouldn't be too deep, and make sure all of them radiate outward from the crater's rim like the spokes on a wheel. The ejecta blanket is typically 2-3 times wider than the crater itself.

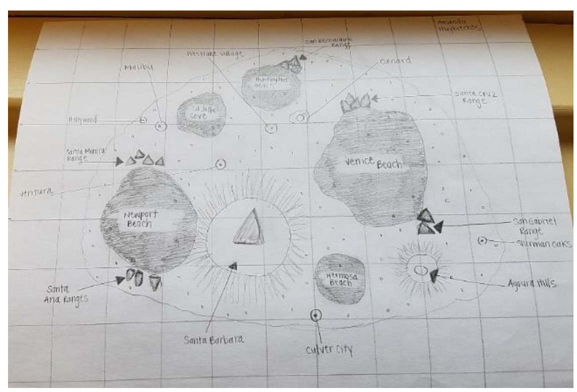
11. One or two of your craters may have ***rays***. Rays are thin layers of dust that may stretch for hundreds of miles away from a new crater. Use a nail or golf tee to lightly scratch marks extending 5-6 times as far as the crater is wide. A large crater will usually have just 5-8 major rays.

12. Finally, you can add one or two ***rilles***. Rilles are dry river basins formed from flowing lava (the Moon has never had liquid water on its surface!) Rilles typically appear on maria, and wind their way across the surface. Scratch them in lightly with a nail or golf tee.

Exploring the Lunar Surface Model

1. Have the students use string to mark lines of latitude and longitude on the model; this works best if students work in pairs. Have one student stretch the string horizontally across the model while the other presses it lightly into the surface. Make these latitude lines one inch apart across the model. Now make an identical series of lines running vertically, again one inch apart. When finished, you should have a grid of latitude and longitude lines on your lunar landscape!

2. Have the students use construction paper and markers to make a map of the landscape they have made. Start with a series of latitude and longitude lines drawn in pencil with a ruler, then use the lines on the lunar landscape to map out the craters and maria you have made in colorful markers.



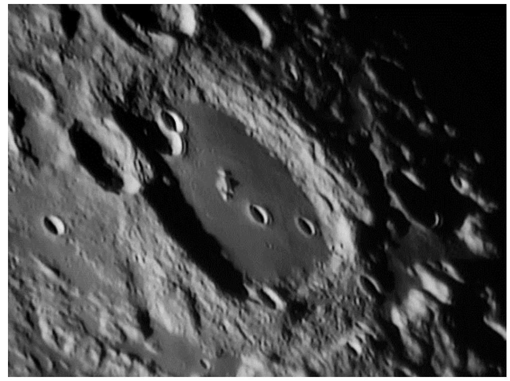
   Have the students name the larger craters on their maps using a theme. Will they choose U.S. Presidents? Rock bands? Favorite cartoon characters? Have fun with this!

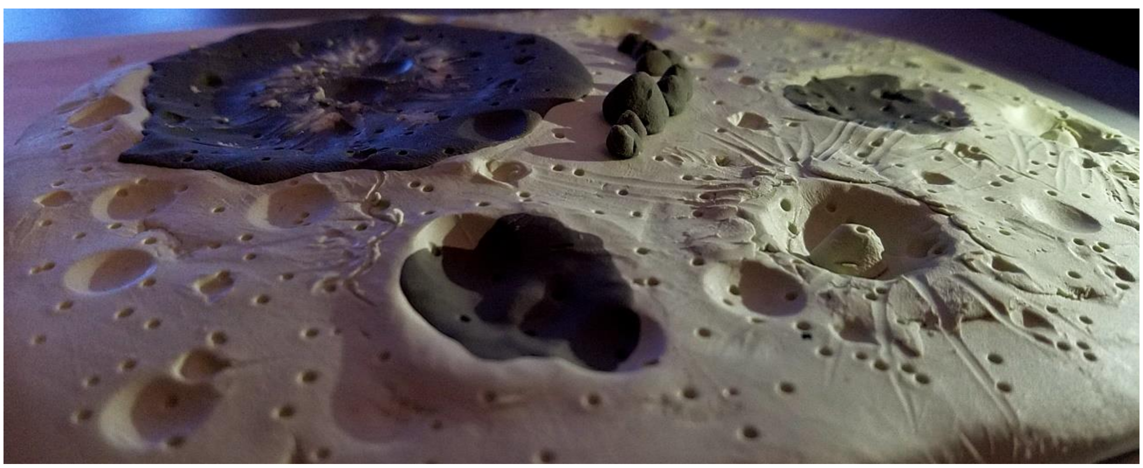
3. Crater diameter is a good rough indicator of impact energy. Generally speaking, when a crater doubles in size, the impact energy needed to create it is ten times as great. If you have craters 1cm, 2cm, and 4cm in size; the 2cm crater required 10 times the energy of

the 1cm crater, while the 4cm crater needed 100 times the energy of the smallest crater! Rank your craters by size and make a bar graph of the impact energy needed to create them.

4. The crater we see is usually ten times larger than the asteroid that created it. Choose the largest maria on your model and create a model asteroid that would be large enough to make such an impact. Display this giant impactor with your model.

5. Dim the room lights, then try using a small flashlight to illuminate your model. Shine the light from the side and take a photo of your clay model this way. Can you see shadows filling craters? Are there long shadows from mountains reaching across the surface? Compare your model to a photo of the Moon taken near the ***terminator*** (the line separating light from darkness.) You will see many similarities between your photo of your model and the real Moon – this is one way that we know our model / hypothesis is accurate, because we use it to predict what we find in Nature!





Exploring with Math:

Once you have marked off your model with latitude and longitude lines, it is time to set the ***scale*** of your model. Decide how far apart these horizontal and vertical lines are! It is typical to set your scale so that lines are 100 km apart.

Once you have a scale, be sure to reproduce these longitude (vertical), and latitude (horizontal) lines on your map. If your lines are 100 km apart, calculate the scale by dividing 100 km by the distance in mm separating your map lines. This is the ***scale*** in km/mm. Measure any distance and multiply it by your scale to get the ***true distance*** on your map or model.

Using the Distance (mm) x Scale formula, you can also measure crater diameters, ejecta blankets, rays and other features. Have students explore their model with math and get a true feeling for the size of various features. You can take your rectangular area of your model and sketch it onto a map of your state or the United States to get a feeling for the size of these features in real life!

You can measure the perimeter of a crater or maria by pressing string into the surface. Once you have pressed the string all the way around a feature, measure the string in mm and multiply by your scale to get the true circumference of a feature. You can also estimate the area of a feature in a number of ways – have students think about this and document their solutions!

Filling a crater with water gives a good estimate of volume – and the volume of a crater is a good measure of the energy used to create it. Remember that all the rock ***inside the crater***, was blasted out in just a few seconds by the impact that created it! Use an eyedropper and see how many drops it takes to fill small craters. For larger craters, use a small graduated cylinder. Typically, 1 mL or water = 20 drops. Compare the energy required to make craters of various sizes!

Being an Astronomer

One of the best features of making a model of the lunar surface is ***bringing that knowledge to the eyepiece!*** It is a sad truth that just showing someone the Moon through a telescope can be disappointing for the student. It is common to hear: “Yeah, sure, it’s the Moon. I’ve seen that before!”

The key to taking real knowledge and value away from an observing experience lies in bringing knowledge to the eyepiece! When your students have modeled the Moon’s surface in clay, explored the features by making a model for themselves and learning how these features are made, the observing experience becomes far more meaningful!

Time for another look at the Moon? Sure, why not, it’s always exciting! Whether you are looking at high-resolution photos from NASA, or through the eyepiece of a telescope, you can see a lot of detail on the lunar surface. Examine the areas near the ***terminator*** (the dividing line between light and darkness) to see the most detail. Can you find a maria region? These areas are distinctly darker than the surrounding highland regions of the Moon, and their smooth surfaces shows off later craters with great effect.

Can you see an area where lava has broken out of a crater and spilled across the lunar surface? If the telescope or photo is good enough, you can sometimes even see waves and ripples in the maria surface, frozen in place as the lava solidified billions of years ago. Small craters on the surface of the maria are also good candidates for showing off ***rays***. The best way to find these features is to look at the lunar surface with low power (40-60x) and try to spot a bright 'splash mark'. Zoom in on one of these 'splash' features at 80-150x and you will see a crater surrounded by rays of powdery and bright lunar dust blasted out of the crater by the enormous energy of the asteroid impact.

Another thing to look for is ***overlapping features***. Can you see craters on top of a lava flow? Which came first!? Can you see small craters inside larger ones? This takes a good eye and some patience, but you can begin to see a timeline of events, carved out of the lunar surface by giant rocks, falling from space.

Key terms:

Asteroid: A large, irregular piece of rock, often containing bits of ice or metal. Asteroids orbit the Sun and are large enough to be seen from Earth with a telescope. Asteroids differ from ***planets***, because they are not large enough to be spherical in shape.

Craters: These are impact basins. Deep, circular depressions that are blasted out when an asteroid or meteoroid slams into the surface of the Moon. Craters come in all sizes, from maria hundreds of km wide, down to microscopic pits in small rocks formed by dust and sand grains.

Ejecta: Material blasted out of a crater during an asteroid impact.

Ejecta blanket: A layer of pulverized rock and dust that lies around an impact crater.

Lunar Mountains: Unlike Earth where mountains are produced over millions of years from tectonic forces in Earth's crust, lunar mountains are huge pieces of stone, often miles wide, that have been blasted out of a maria basin. These huge chunks landed in their present locations creating mountains over a period of just seconds rather than millions of years.

Maria: A large impact basin, typically hundreds of km wide. These giant impact sites were so deep, that the interiors filled with dark colored, iron-rich lava. These basins are typically 2.5-3 billion years old and can be seen with your naked eye as the darker colored marks on the Moon's surface. *Maria* is Latin for 'sea'. These dark areas were mistaken for ocean basins, but astronomers quickly realized there was no liquid water or air on the Moon.

Meteorite: A fragment of rock, metal, or carbon from a meteoroid or asteroid that has survived to land safely on the surface of the Earth.

Meteoroid: A bit of rock, metal, or carbon drifting in space. Meteoroids are too small to be seen from Earth, even with a telescope. If a meteoroid collides with the Earth and a fragment survives on the surface, we call this fragment a ***meteorite.***

Rays: Thin streaks of dusty material that are blasted out of a crater. These streaks, usually just a thin layer of dust, can stretch for hundreds of kilometers from large impacts on airless worlds like the Moon.

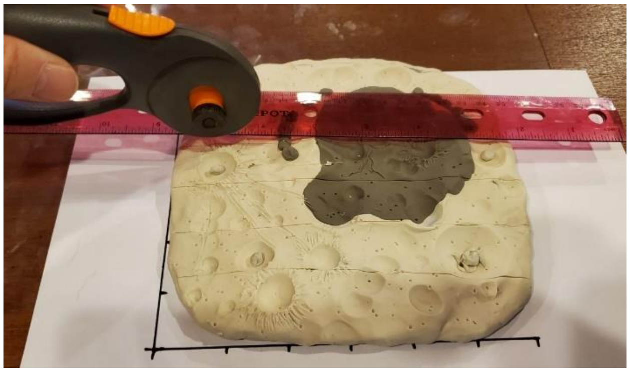
Rilles: Volcanic lava flows on the Moon left dry 'river beds'. These 'rivers' of lava are long dry and cold, but can still be seen from Earth when viewing the Moon with a powerful telescope.

Mapping the Lunar Surface:

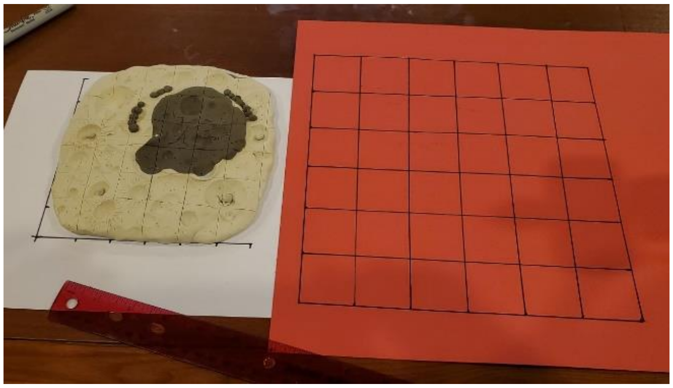
This activity is intended to be a follow on for the ***Modeling the Moon's Surface in Clay*** activity. If you do not have this activity, you can download a free copy of my book: ***Astronomy for Educators*** at this web address: https://scholarworks.uark.edu/oer/2

When we seek to bring a student to the eyepiece to view the Moon, there is often a problem – for many children, the image in the eyepiece becomes just one more image in a sea of thousands of images seen every day on the internet, on the smart phone or tablet, and on the television. In a high tech society, the image in the eyepiece loses its impact!

In order for students to take value ***away from the eyepiece****, they must* ***bring more knowledge to the eyepiece.*** My solution to that problem is to have the students model the lunar surface in clay (See: Activity 25: Modeling the Moon's Surface in Clay in *Astronomy for Educators.*) This activity allows students to model maria, craters, ejecta, rays, lava flows, rilles and more. Once the model is made, what more can we do with it? In fact, there are many cross curricular opportunities here!



Begin by having students make a 2-axis grid on plain white paper, make marks on the paper every 2 cm (1-inch). Place the clay moon model on the paper, the marks will give you guidelines for latitude and longitude lines on your model. Use a ruler and a butter or putty knife to cut the lines of longitude (vertical) and latitude (horizontal). In the picture below, I am using a wheel-cutter, but any dull knife will work as well. If you do not have tools like this (or do not feel that cutting tools are appropriate for your students,) you can use thread or dental floss to cut the lines into the clay surface.



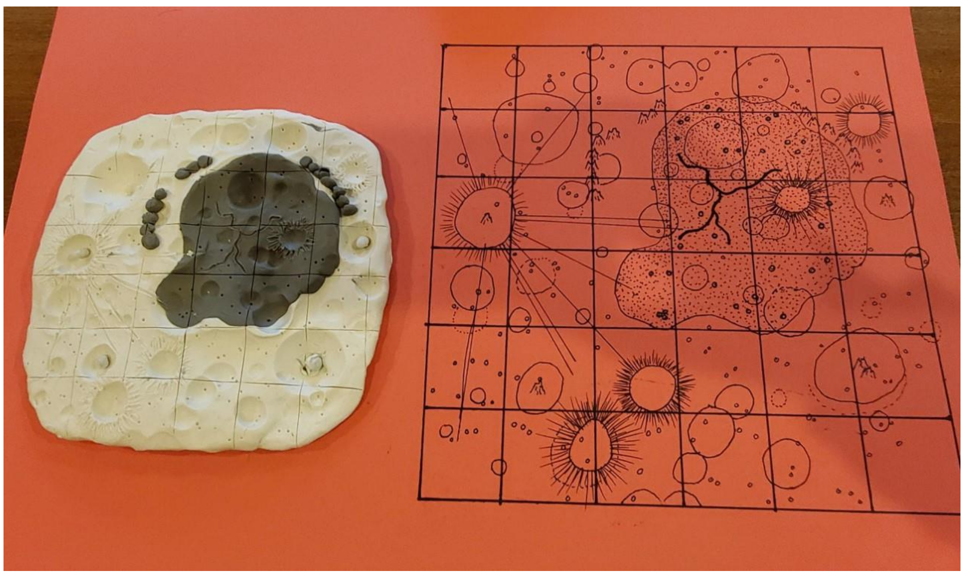
Once you have cut the lines into the model, it is time to decide on the ***scale*** that you will use for your model. Keep in mind that ***maria*** (the dark area of the model) are often 100, 500 km or even larger. For the model shown here, I have set the scale to ***2cm = 100km.*** This means that the lines on the model are 100 km apart, and the entire model represents an area of 600 km^2 on the lunar surface.

With the model's longitude and latitude lines cut, now it is time to make a map of the surface. You can create a map that is the same physical size as the model (12x12 cm), but for older students I often increase the challenge by requiring them to make a map which differs in size from the model by at least 50%. In the photo below, I have laid out a grid that is 30x30 cm on construction paper.

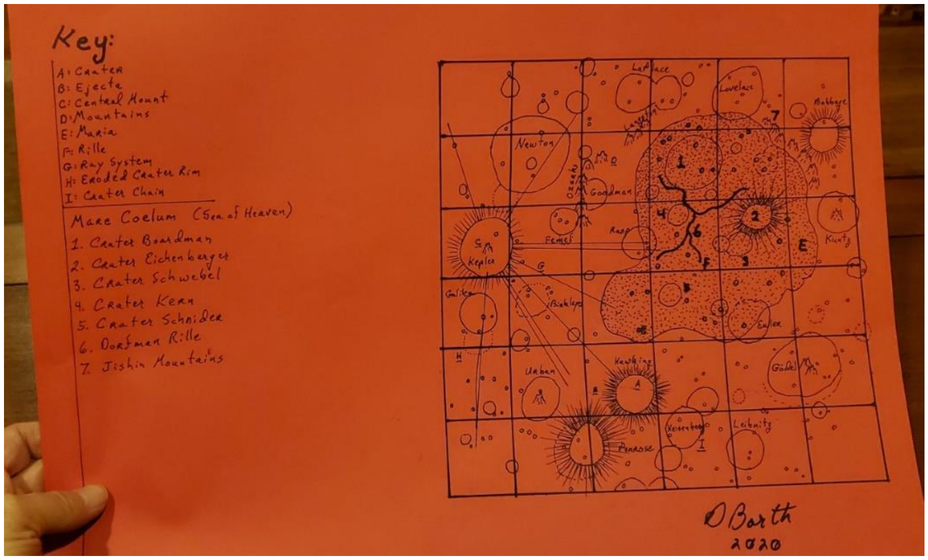
Now it is time to start mapping your surface! I generally tell students to begin by placing the largest features, and then work their way down to smaller and smaller objects. Using the grid for a guide, sketch the outline of your maria, then start placing in your largest craters. Pay attention to where the boundaries of craters are, where they cross the lines of the grid, how much of a single square a crater fills, etc.

After mapping the maria and large craters, go on to secondary features such as mountains. Mountain chains bordering the maria and central mounts found in craters. Move on to ejecta blankets surrounding some of the newest craters, and then ray systems. Last of all, proceed square by square and fill in the smaller craters. Work your way down from larger to smaller objects again, being careful to place each small crater in its proper location. For shallow or faint craters, I use broken outlines to show that the crater is eroded (and very old!) Finally, you can shade in the maria and add in any rilles you have made.

I use pencil to outline the drawing first, then follow on with pen and ink, using stipling (dots) for shading in the maria region. Rilles are hard to draw, so I put them in with a black marker that gives a bold line.



Finally, it is time to make the ***Map Key***. I usually divide the key into two parts: geological surface features (examples of a maria, crater, ray, etc.) and named features. I number examples of surface features so that anyone reading the map will know what they look like.



Named features are more numerous. Most major craters and all maria have proper names. On the Moon, such features are named for scientists, philosophers, or famous explorers. Most things in astronomy have a naming theme, moons of Neptune are named for Shakespeare characters, surface features on Venus are named for women in various mythologies. Have your students choose a naming theme, characters from a book or a movie are favorites, cartoon heroes and figures from history are also popular. Not all craters are named, small craters surrounding a major crater are usually given letters of the alphabet – start with the first small crater due north as 'A', then proceed clockwise. For a crater named: Cicero, sub-craters would be Cicero-A, Cicero-B, etc.

Adding the Math!

Now that the map and the key is made, you can pursue some mathematics! We will add things in from simpler to more complex. Let's get started!

Coordinates: Once you have put the Latitude and Longitude lines on the clay, you basically have an x,y coordinate system. In its simplest form, students can label the lines 1-6 on both axes with the lower left corner being 0,0. Students can find location coordinates for different craters and other locations. This fits in very well with 5^{th}-6^{th} grade math where these coordinate systems are first introduced.

For more advanced students, using the scale of 50-100 km between lines, students can find more precise locations and use the Pythagorean theorem to find distances between locations.

If you have an astronomy class, try setting the lines to be 10 degrees apart, and find locations in terms of degrees and minutes of longitude and latitude. Using the Pythagorean theorem in this way adds significant challenge because the angular measurements must be converted to decimal format before the calculations. The most advanced students may want to use the circumference of the Moon to determine a conversion from degrees to kilometers!

Perimeters and Areas:

Finding the perimeter of a crater or maria can easily be done by carefully placing a piece of thread or dental floss around the crater and then measuring it. Students may want to try placing pins or toothpicks around a crater and then carefully stretching a string to get a more accurate measurement.

Areas can be calculated in a number of ways. For a circular crater, the old standby formula: Area = πR^2 can be used. For irregular areas, students can estimate the percentage of a square that is covered, and use ratios from there. For instance, if your scale is 100 km per division on your model, one square is 100 km^2, so a figure that covers 60% of that square would be 60 km^2! More advanced students may wish to make a transparency that divides a single square on your map into 10x10 lines. Placing the transparency over the map can allow students to carefully measure how much of the square is filled by the crater or object of interest.

Exploring Tycho's Rays

Materials: Telescope capable of 50-80x, Pencil and Paper

Time Required: 15-20 minutes

Lab Availability: Tycho's rays are visible only within ±24 hours of the full moon.

NOTE: It ***is possible*** to do this activity using a high resolution photo of the Moon from the web. It works on desktop computers and tablets, but more fun to do if you can project the image on a larger screen. As always, a computer screen is ***no substitute*** to actual observing, but this method makes this activity ***remote teaching friendly!***

Scoring rubric:

For full credit, students must prepare a proper circle to represent the Lunar disk (see below). Crater Tycho must be drawn in the correct position and size. Crater rays must be accurately traced and drawn on the surface of the disk. Student must use ratio & proportion math to estimate the length of the rays.

Introduction:

With any large ***explosion crater***, material from inside the crater is blasted out onto the surrounding surface – this material is called ***Ejecta***. On a world with an atmosphere, such as Earth or Mars, much of the vaporized rock, dust and ash are suspended in the atmosphere as smoke and dust particles. If enough vaporized rock dust is suspended in the upper atmosphere, the amount of sunlight reaching the surface is reduced dramatically, creating a ***Cosmic Winter*** scenario. It is this phenomenon which killed the dinosaurs 65 million years ago.

Craters on an airless world like Luna are entirely different! With no atmosphere, any particle from dust grains to boulders all fall at the same speed – there is no 'suspension' effect, even for the smallest particles. Material which blasts away horizontally is strongly affected by the shape of the crater rim. Where the rim is high, less material is blasted out; but where the rim is lower or notched, huge amounts of ejecta may spray out like water from a fire hose! The result is that long, straight lines of ejecta called ***Rays*** are created, each leading away from the central crater rim. These rays give newer craters their typical 'splattered' look. With major craters like Tycho, the rays may extend across much of the lunar disk.

In spite of the great volume of material ejected from a crater the size of Tycho, the long rays are extremely thin. A typical ray may be hundreds of kilometers long, but only 2-3 cm thick. As a result, ***rays have no shadows.*** Except for the fact that rays are usually lighter in color than the surrounding surface, we might not see them at all. In fact, rays on Luna are only visible when the Sun is directly overhead – at full moon. This means that except for the 24 hours immediately preceding and following full moon, the rays are almost invisible. You can only do this lab at full moon – usually 6-7 times per school year.

Procedure:

1. Use a blank sheet of paper and trace a circle using a CD – mark the center point of the circle.

2. Draw ‘cross hairs’ on the circle and mark 12, 3, 6, and 9 ‘o clock hours. Mark in points for the other hours without labels.
3. Remember to look for ***Hour Angle***, and then ***Radial Distance*** for every feature to place it correctly on your sketch. (See: Sketching with the Clock Method for details!)
4. Use the size of the radius to estimate the size of the feature – students commonly draw features ***bigger*** than they really are – try to be accurate about size!
5. Draw in the crater first, then sketch in the ejecta blanket.
6. Now add the rays of the crater – remember, depending on your perspective, some may appear straight, others (especially longer rays) may appear curved. Label the rays A through ?
7. Use ***ratio and proportion*** to estimate the length of each ray. Show one calculation, put other results in a data table.
8. Record the ***Time***, and ***Date***, on your observation sheet. The ***Location*** should be recorded THS if you observe at the school, otherwise use Hemet, (or the city you happen to be in.) ***Weather*** should be clear, hazy, windy, etc. **Remember: No data - no credit - no exceptions.**

Bonus #1: Lunar astrophoto – +50 max

Use a cell phone camera to take a photo of the Moon. (set camera to ***daylight***, remember to use the ***timer***, and turn off the flash.

The use of the camera’s zoom may be needed to get a photo of the Moon that fills the frame.

Print out the photo and label features 1, 2, 3, etc. Then use ***https://fullmoonatlas.com/atlas*** and the lunar atlas to identify as many features as you can.

Bonus #2: Ray Length Calculation – +50 max

Our ratio & proportion method assumes that the Moon we view is ***flat!*** The rays we see actually curve around the surface of the Moon – this means the actual length of the rays is ***longer*** than our original estimate. Do some research and consult with your math teacher about how to calculate the length of a curved ray from a flat photo! (Mercator originally did this with maps in the 1500’s!).

Document your calculation method and recalculate the length of your labeled rays. Show one sample calculation and put the rest of the data in table form.