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Astronomy for Educators

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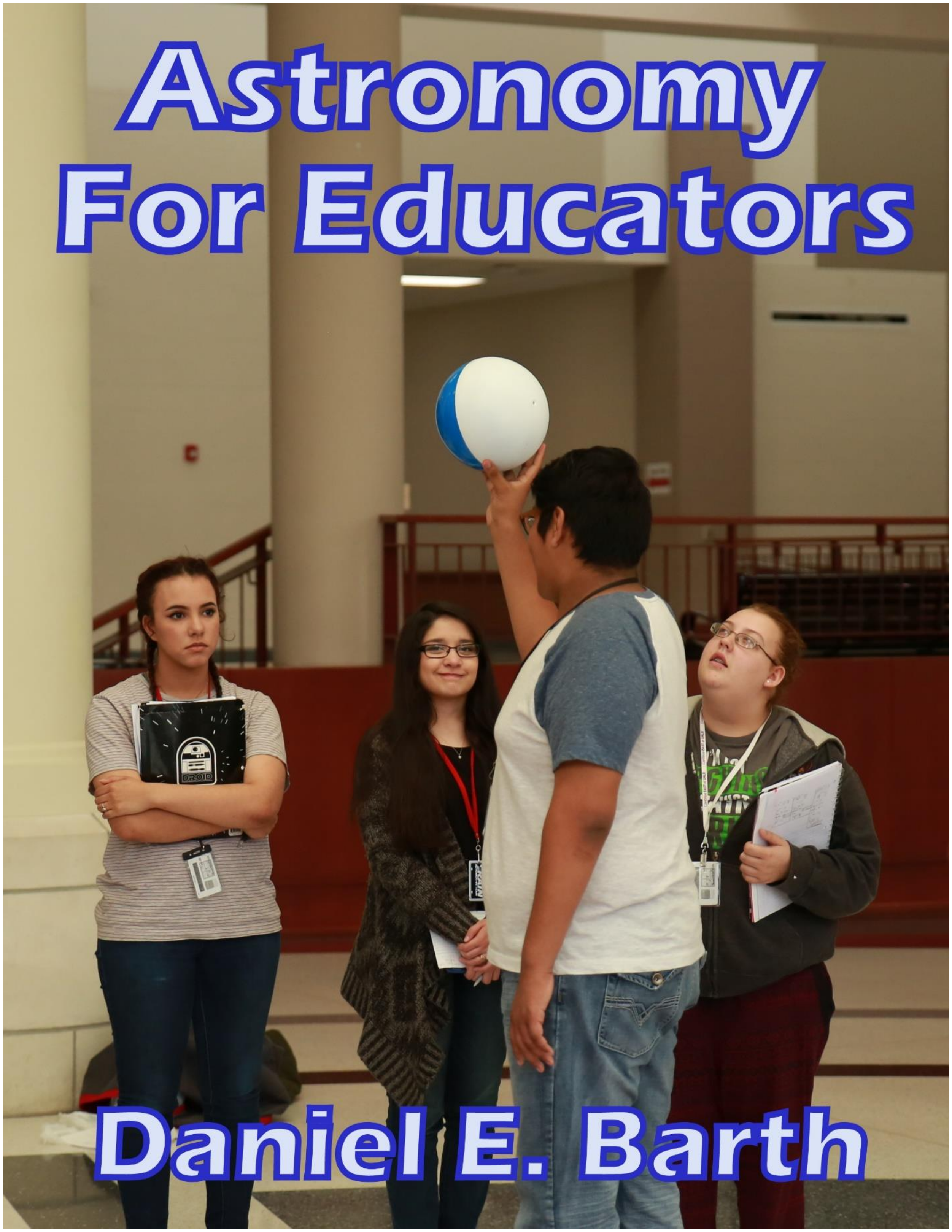

Daniel E. Barth

Astronomy for Educators

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Table of Contents:

Introduction:

Transitioning from being a science teacher to a professor of education who trained new teachers was one of the greatest challenges in my career. I opened my first Astronomy for Educators class by telling the students that I had been an astronomy teacher for more than 30 years; a student in the class immediately raised her hand and said: "I haven't." That blunt comment convinced me I needed to change my priorities for my class; I wasn't there to teach pre-service teachers science, rather I was there to convince them that they ***could teach science***, and then give them the tools to do so. My state, like many nation-wide, was mandating new initiatives for STEM science from elementary through high school – and my pre-service elementary teachers were worried about achieving these goals in their classrooms.

Most of the young teachers in my class were more than worried about this, many were actually afraid of teaching science. "I'm not a science person!", "I don't do math!", and "I've avoided taking any science class since freshman biology in high school!" were all typical comments. I told the teachers in my class that I was sure that they could teach science in the K-8 classroom. I told my young teachers that they knew almost everything they needed already, and the rest they would discover along the way with the children in their classrooms. The same is true for you!

You don't have to be a math whiz, or have a science degree to teach STEM activities – and you don't have to have deep pockets either. I taught in high-poverty districts for many years, my district could not afford expensive equipment, and neither could I; my students and I built our own models and equipment for pennies, often using materials scrounged from around the house or garage. I know many teachers supply materials and equipment in their classrooms out of their own pockets – all of the activities in this book cost less than $1 per student to set up and perform.

Making your own models and then working with them in the classroom brings a hands-on authenticity to your classroom that engages almost everyone. These hands-on projects have proven very effective with ESL students, helping them to acquire vocabulary and fluency in a natural, conceptual way that has been substantially more effective than worksheets or vocabulary exercises. Special needs children also often find the hands-on classroom to be more congenial than a traditional educational environment. I have often seen special needs students begin to learn about astronomy conceptually, and demonstrate their knowledge physically with simple models long before they acquired the vocabulary skills to express what they knew.

Our students need to be prepared to take on the challenges of a technology-rich and science-dependent 21st century economy. If we are to empower them to address these future challenges, it is time we began to change the way we teach science starting in elementary school. We have spent years teaching science as a collection of facts, teaching children what we know instead of allowing them to discover things for themselves. It is critical that the children in our classes understand how science works, both its strengths, and its weaknesses. I believe that children can only do this effectively by participating in science activities, getting their hands dirty and seeing how science works, and why science sometimes fails.

None of this needs to be complex or expensive – you can do it in your classroom too! Each unit of this book is centered on fundamental science concepts. The learning process is based around activities. I'll show you what you need to know, and help guide you through each activity, explaining not only what you and your students will learn about the Earth, Moon, stars and planets, but explaining what each model we will make teaches us about the strengths and weaknesses of science itself. Each activity is easily scalable, younger children can explore the activity conceptually while older or more advanced children can add math and dig deeper into the topic with additional activities.

I am a firm believer in the ***Constructivist*** school of thought; I discovered in my own classroom that hands-on, open ended activities where students discover concepts and facts for themselves have been more effective in terms of teaching academic content than reading textbooks or doing worksheet activities. Students find these activities more engaging, memorable, and enjoyable as well. Even in high-poverty schools, I never had a problem filling my activity-based classes, not even for subjects like physics and astronomy. Students took these classes because they were fun and exciting. As a professor of STEM Education, I still train my pre-service teachers this way; the method is just as effective with adults as it was with my middle and high school students years ago!

I have avoided filling up this book with quizzes or multiple-choice assessments. Instead, I have included discussion questions after the activities as a guide for you. Discussion after the fact helps students learn to express what they have learned, increases fluency both in English as well as STEM vocabulary. Expressing what we know or have learned is also a powerful educational tool, it helps cement and integrate concepts into our thinking.

How This Book is Organized:

As educational professionals, we all need to be able to show in our lesson plans that we are meeting expectations. Many of us do this by citing which standards or which part of a science framework our lesson is addressing. To help with this, I have listed the connections to the ***K-12 Framework for Science Education*** published by the National Academies' National Research Council, and to the ***Next Generation Science Standards***. The K-12 Framework for Science Education focuses on three principal dimensions: ***Science and Engineering Practices, Crosscutting Concepts,*** and ***Core Ideas in Science***. The Next Generation Science Standards are a set of academic content standards broken down by grade level. I will identify each applicable dimension and content standard at the start of each activity.

Throughout the book you will find that I use ***Bold Italics*** regularly. These words are often vocabulary terms that you will find in the glossary, other times they are points that I wish to emphasize based upon my experiences teaching the Astronomy for Educators class at my university. The ***bold text*** helps to call attention to terms and ideas that will help you focus on the essentials and understand the instructions in the activities better.

Although the activities follow a well-defined sequence, each activity in the book is essentially independent – you can thumb through and pick and choose whatever you feel will work in your classroom.

After the standards, each activity begins with ***Facts You Need to Know***. Most of this really is common knowledge (I don't expect to surprise anyone by telling them that the Moon orbits the Earth!) I also limit this section to no more than three to four basic facts. I don't want to overwhelm you with minute details, and I've made a real effort to stick to the essentials here.

After the essential facts, we discuss ***Teaching and Pedagogy***. I have strived not to be heavy handed, but tried not to assume too much about your prior knowledge of science in general (or astronomy in particular!) I have based these sections upon the lectures and classroom discussions with my Education students who take the Astronomy for Educators class here at the University of Arkansas. They are wonderfully bright young people, but as they often remind me, almost universally not 'science people' or 'math whizzes'. As one student told me: "You have to bring the science to us where we are now, you cannot expect us all to be astro-geeks like you!" That got a good laugh all around, but the point was very well taken! I'm going to guide you through these activities as I do my own students – I'm sure you will be as successful as they have been!

Next comes ***Student Outcomes***, beginning with ***What Will Your Students Discover?*** Although this section addresses what your students will achieve, this discovery piece often includes the teacher as well! While we all know such things as 'The Moon orbits the Earth', we don't really know how that fits with other simple facts to make a coherent scientific model or theory. The STEM activities you and your students will create together will help you see how these facts fit into scientific models, and how these models lead us to new knowledge.

If this is your first time dabbling in STEM education, you're going to learn a lot! You will also be learning all this science stuff by building and playing with models such as toy planets and moons – and who doesn't enjoy playing with exciting toys?

What Will Your Students Learn about Science? This section addresses a critical part of STEM education that is often neglected. What do we know about science as a process, and as a human activity? Science in the media, in the classroom, even in semi-professional science publications like Scientific American and National Geographic rarely deal with science as a process. I believe very strongly that STEM activities should not just teach us facts, but about science itself. I want to help your students understand why, how, and when we decide to put our trust in a scientific theory or model – and just how far that trust should go.

How do we know what we know? Why do we accept this theory but not that one? Why do scientists sometimes change their minds about things? Should we believe a particular theory or idea just because "over 99% of the world's leading scientists agree"? Is belief appropriate in a discussion of science at all?

Your students will explore (and recreate!) some of the most famous scientific debates in history; we'll see by experiment and data not only who won, but how and why the new scientific model was accepted and why the old model was discarded. Your students will learn that science is a glorious human activity, sometimes prone to error, but always self-correcting in the long run.

Now that you are thoroughly prepared, we move on to ***Conducting the Activity***. Much as you would expect, this begins with the materials you will need, then moves on to ***Building your model***. Once the model is built, we move on to ***Exploring your model***, a step-by-step to using your model as an experiment, and gathering information from it. The next step is often the most fun – going outside and observing the sky to see if our model actually reflects what we see in Nature!

After building and exploring your model in the activity section, we have ***Discussion Questions***. These questions are essential to helping your students learn to think about what they have done in class. A playful spirit of exploration in the classroom is fine, but we also need to help children think about what they have learned. Don't worry – I have included all the answers to the discussion questions to help you out!

After the activity, I have put in a variety of ***Supplemental Materials***.

Going Deeper is a section especially for the Gifted and Talented student – or anyone who shows an exceptional interest in the subject of the activity. This section usually contains either an additional project to work on or an investigation that can further the students' knowledge and interests.

While there is a great national awareness of the needs of special education and ESL students, the gifted and talented children in our schools are often ignored. "She's really smart, she will get along fine," is a common sentiment – but not an effective pedagogy to help these children reach their potential. The Going Deeper section gives you activities and explorations that you can offer to your gifted students to challenge and encourage them. Don't be shy with these activities, you will be surprised when you focus on STEM activities in your classroom, just how many 'gifted' students you have!

Being an Astronomer is a section designed to get your students out and observing nature on their own. Not only is this an opportunity for them to confirm what we have learned in the classroom, it encourages students to actively compare what a scientific model or theory tells them with what they see for themselves in nature. Comparing the predictions of a theory with the actual experimental data and observations we make is a fundamental part of the scientific process. This is also an excellent way to increase family involvement with your student's science education.

Parents and children observing the Moon together in the back yard on a clear and pleasant evening can be a wonderful bonding experience. Parents who are involved with their child's science education are going to become your biggest fans; they will see the good that you – and your school – are doing for their children. This sort of parent involvement transcends cultural and linguistic barriers in a marvelous way; it engages the ESL student and parent in a way few other activities ever do!

I also understand that most families and schools do not have their own binoculars and telescopes. There are sections where I urge you to seek out a local astronomy club; as a member of such clubs for over 40 years, I can tell you that amateur astronomers are almost universally friendly folks who enjoy sharing their equipment and knowledge with members of the community. My own club, the ***Sugar Creek Astronomical Society*** not only holds bi-monthly public star parties, we also go to local schools quite regularly to help students, teachers, and parents discover the wonders of the night sky. Clubs do almost all this work free of charge as a public service (and because we love this stuff!) Contact your local club today – you will be glad that you did!

Being a Scientist is a section for the mathematically inclined. This is both for the K-8 educator who wants to put a little more math in to STEM, but also for the secondary educator who would like to attempt these activities. I have tried to make every activity in this book scalable, that is, to make it applicable for a wide variety of grade levels. One of the ways that we do that is to help teachers and students transition from a conceptual exploration of a topic to a mathematical exploration and understanding. Mathematics is the universal language of scientific all scientific models, and developing a mathematical understanding of an idea is one of the key elements of a sound scientific model of Nature.

Following Up is the final supplemental section. This section is devoted to the enthusiast in all of us. Each teacher has found in their own student experience that one area where their enthusiasm and imagination was ignited by a teacher's lesson. We remember that day, that lesson, that teacher – and the effect it had on us. Many of us remember asking: 'Can we learn some more about that?' For a teacher, this is a golden moment – but also a tremendous challenge. The ***Following Up*** section is my attempt to prepare you to take advantage of one of those precious moments in the life of a child.

Unit 1:

Starting our Journey of Discovery

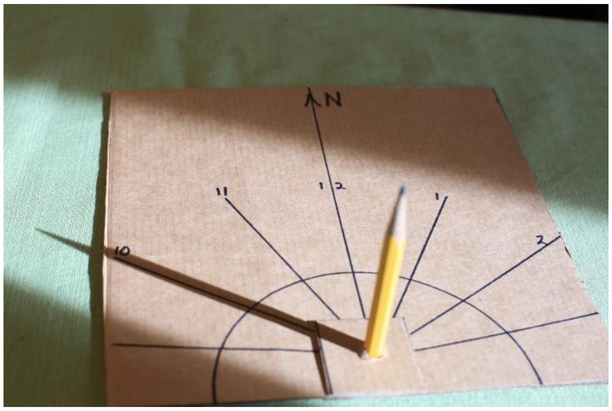
We will begin our journey in the same place that the ancient astronomers of Greece, Persia, China, and other cultures did – we will take a look at the most obvious objects in the sky, the Sun and the Moon.

The Sun and Moon are not only the brightest objects in the sky, they give us our first calendar and helped early cultures to measure and record the passage of time. So much of our modern society is linked to the precise measurement of time. From the school bell which regulates the day in millions of classrooms around the world, to the ultra-precise clocks that are essential to smart phone and GPS technology.

By creating a clock, calendar, and lunar phase map in our classrooms, we will join our students in walking in the footsteps of our ancestors around the world. We will begin to understand and measure the passage of time for ourselves.

Activity 1:

Building a Solar Clock and Calendar



This first unit may not seem very significant, but the activities contain pieces that take extended periods of time to appreciate, so we will start them off now, in the early part of the school year. In this way, they will be prepared and ready when we want them later! Two of the most basic facts in astronomy are that we have the Sun crossing the sky during the day and the stars crossing the sky at night. In this unit, we will focus on the Sun and its movements, both daily, and over the weeks as the school year passes.

Academic Standards

Science and Engineering Practices

Developing and using models
Obtain, evaluate, and communicate information

Crosscutting Concepts

Patterns in nature
Cause and effect
Structure and function
Stability and change

Next Generation Science Standards

Space systems (K-5, 6-8, 9-12)

Structure and function (K-5)

Waves and electromagnetic radiation (6-8, 9-12)

For the Educator

Facts you need to know

1. The Sun rises in the east and crosses the sky each day. Okay, this seems almost too basic, but then one has to start somewhere, doesn't one?
2. The Sun changes it rising position on the eastern horizon and its highest altitude each day as you move through the school year.
3. We can measure these hourly and daily changes easily enough with very simple materials.

Teaching and Pedagogy

The idea that a simple vertical stick or ***gnomon*** can tell the time and date is astonishing to most children. They are used to the idea that technology either involves a great many moving parts such as in an automobile, or almost magical electronics with function inside a smartphone or a DVD player. The fact that something so simple can function as a clock and a calendar is a revelation. The idea of ancient people as 'primitive' or even 'stupid' is easily and often promulgated in popular children's entertainment and even sometimes in textbooks. Nothing could be further from the truth! As we will discover in various activities through the course of this book, ancient peoples the world over participated in astronomy and were able to do amazing things both scientifically and mathematically. By following in their footsteps, we will learn a great deal about how science discovers the truth about nature, and how science corrects itself when it wanders down the wrong path.

One interesting fact your students may have discovered with their sundials is that the shadow from the gnomon always travels ***clockwise*** around the paper! When the first mechanical clocks were made, it would have been just as easy to construct them to run around to the left as to the right, but these clocks were modeled on the ***sundial***, and so they all moved clockwise! Inventors from many different countries and cultures developed clocks, and all of them modeled their inventions in the same way – after nature itself! In our next unit, we will investigate another way to tell time in the heavens – with the phases of the Moon!

Student Outcomes

What will the student discover?

1. The Sun's motion through the sky is regular and predictable. Again, this may seem simple to you, but for young children, the idea that nature is regular and predictable is a powerful one. Recognition of the cycles of nature was one of the foundational ideas that helped develop calendars, timekeeping, and our modern civilization! Once we recognize the regular patterns in nature, we are on the high road to harnessing nature's power for our benefit and comfort!

2. The first clocks were based upon the regular movement of the Sun across the sky (and actually upon the regular rotation of the Earth on its axis!) Have you ever wondered why clocks go clockwise? This activity will easily answer that question for you – and your students!

What will your students learn about science?

1. Science is based first and foremost upon recognizing patterns. We want to identify these patterns, discover how they change over time, and find out what factors influence and control them. These activities will likely be the first introduction for many young students that ***science is based upon patterns***, and we can all look for them, and learn to recognize them!

2. Timekeeping, both clocks and calendars, are also fundamental to science. Patterns are after all, regular events that recur over ***time***. To study science, we must be aware of the passing of time; both in small increments like seconds, as well as longer units like days, months, even years.

Conducting the Activity

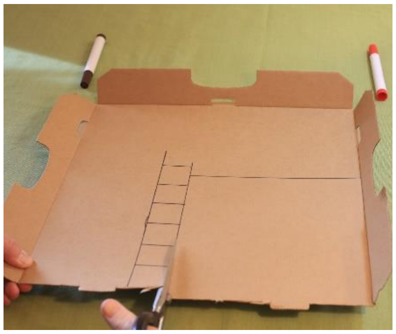
Materials

1. One 12-inch square of cardboard (Old copy paper boxes or pizza boxes can be cut apart to make these easily and cheaply!)
2. Construction paper (Lighter colors work best)
3. A drawing compass
4. Waxed paper (Two six-inch squares is sufficient)
5. A small compass (A free compass app on the teacher's smartphone will do for this.)
6. Glue stick or white glue
7. Superglue. White glue isn't strong enough for every part of our project – Teachers will have to handle the superglue part of the project, of course!
8. One half-used pencil – about 5-6 inches long works best
9. Two metal washers [Optional] Washers that fit snugly around the pencil make our solar clock sturdier. You can also use small squares of cardboard as washers. If you want the metal kind, your local home improvement center will be able to help you out.

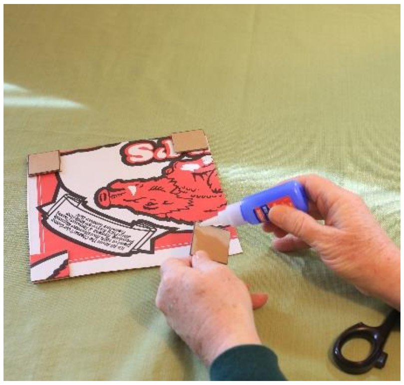
Pro Tip!

When you go shopping for materials, you might want to take this book along and ask to speak to the manager at your local home improvement store - you'll be seeing a lot of each other as you work through the projects in this book! Many such stores are locally owned, and if you ask nicely (and have your school ID!), you may be able to get a 'school discount' on the materials for your class all year long. If you do get a discount, remember to tell all your parents that your classroom is 'Sponsored by Bob's Hardware'; turnabout is fair play, after all!

Building the Solar Clock & Calendar



1. Use a glue stick to secure the construction paper to the cardboard. [Optional]
2. Draw a line dividing the paper in half. Start your compass at a point about 1 inch in from the edge and draw a circle with a 3-inch radius. The entire circle will not fit on the paper, that's perfectly alright for our purposes.
3. Carefully use the pencil to carefully punch a hole through the cardboard where the center of your circle is.
4. Use a ruler to draw a pencil line across the paper from the hole to the opposite side. Label the side opposite the hole ***North***.



5. Starting at the back side of the cardboard, push the pointed end of the pencil through the hole until it is almost all the way through.
6. Have your square of waxed paper ready on the desk and put a generous bead of superglue on the cardboard around the hole and the pencil. Slip the first washer over the pencil, then press the cardboard flat to the table on the waxed paper. The pencil and washer should now be glued in flush with the back of the cardboard!

7. Put another generous bead of glue around the pencil on the front side and slide the second washer down over the pencil. Push the second wax paper square down over the pencil and use this to press the washer down firmly for 5-10 seconds, keeping the pencil as vertical as you can while the glue dries. The wax paper should keep you from getting any glue on your hands! Leave the wax paper in place for the remainder of the day to insure the glue is cured completely and protect both hands and surfaces!
8. Once the glue is completely dry, remove the wax paper from both sides. If a little clings to the project, don't worry – that won't affect how it works!

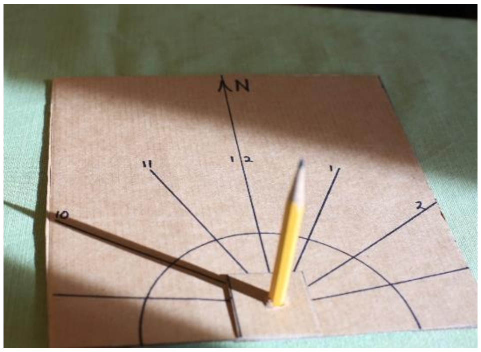
Exploring the Solar Clock & Calendar

1. We will begin by setting our sundials out on a sunny morning when school is just starting. Use your compass to be sure that everyone's sundial is pointing correctly north. Many school buildings are constructed to be well-aligned to the cardinal directions of the compass. If this is true for your building, then the wall of a building or the direction of a sidewalk may help you to easily set up the sundials in the correct direction; if not, use your compass to help you.

2. With the sundials set up in the proper direction at the start of the school day, mark the point where the tip of the shadow lies. Next, mark where the shadow crosses the circle – this point can labeled this as 8:00 (or whenever you start school.

3. For this first day, bring the sundials out several times during the school day on the hour and mark these times as well. You should now have several different hours marked on your sundial.

4. With the hours marked, use a ruler to draw straight lines from the pencil out to the time marks. Older students will easily be able to fill in the missing hours and make a more complete clock face.

   There is however, no real need to mark your clock with numbers. You can mark the clock with the start of the subjects that you teach. Your first mark might be "Home Room", the next might be "Math", then "English", etc. Children will no doubt enjoy this more whimsical clock, but this is actually a very old tradition. Medieval monks marked the hours with the names of the prayers that they recited at various times of day, other ancient societies did similar things.

5. So much for our sundial, but how do we make a calendar? For this, we need to have our sundials out at least once a week (preferably more) at the same time each day. If you have a midday recess or lunch period, this is a perfect time to do this; the closer to noon you are, the better this will work.

6. At the noon hour, set your sundial out and mark the point where the tip of the shadow falls on that day with a small, neat dot. Do this with a colorful marker or pen, and remember to use the same color each day for the best effect. You don't always have sunny weather, of course, but if you can manage two sunny days a week, you will have excellent results.

Keep in mind that when we shift our clocks to and from ***daylight savings time***, you will have to adjust your routine. Your sundial does not function in daylight savings time! For instance, let's say that you mark your calendar dot at noon each day when you begin recording data in the Fall Semester. When you ***fall back*** to Standard time in October, you will have to record your calendar dot at 11:00 am until you ***spring ahead*** to Daylight Savings time again in April, when you will resume plotting your dots at noon.

7. On the 1st and 15th of each month, make the dots a bit larger, and label them with the date. Continue to do this without fail and you will begin to see a pattern emerge – your dots do not fall in the same place each day, but begin to trace out a complex and beautiful figure. When complete, this shape is called an ***analemma,*** you will complete a little over three quarters of it during a typical school year. Your solar clock and calendar will continue to trace out the time and day each year without fail!

8. If you have a tether ball in your playground area, you have the perfect setup for creating a solar calendar outdoors on the playground area. Just as you did with the student's sundials, mark a dot on the ground where the tip of the pole's shadow falls each day at noon. You can use a circular cardboard stencil and some bright colored spray paint to mark the dots. For the 1st and 15th of the month, use a larger circle stencil and cut out a date stencil from a manila folder. By the end of the school year you will have an analemma calendar marked on the ground that will accurately show the date each day at noon.

   Remember to keep these solar clocks and calendars around – we will be using them later in the year to help us make some important decisions!

Discussion Questions

1. Why do clocks go clockwise?

   Answer: Because the Sun travels across the southern sky from east to west – the shadow it projects travels around the post from west to east – clockwise! When mechanical clocks were developed in the 1400's, inventors sought to make them move as "conventional" sundials did, so they made the hands rotate to the right.

2. What are some limitations to our solar clocks?

   Answer: They can't show the time after sunset!

   Answer: No minute or second hand!

   Answer: They need to be adjusted from summer to winter as the angle of the Sun changes.

3. How would having an accurate clock improve people's lives?

   Answer: It gives us the ability to measure time for appointments, school classes, etc.

   Answer: Accurate timekeeping is important for science and astronomy!

Supplemental Materials

Going Deeper

A very interesting bit of sculpture can be created by constructing a medium size solar calendar. Use a half-sheet of plywood and a 2-foot long broomstick or 1-inch dowel rod for a gnomon. You may want to use some copper wire as guy-wires to make sure the gnomon stays perfectly straight all year. It also helps to extend the gnomon with a 3-inch piece of coat-hanger wire so you have a precise point to mark.

Mark the point of the shadow each day at the same time as you did with your other model, but this time drill a small 1/8th inch hole where the tip of the shadow falls. When you have marked a month out on your calendar, take a spool of yellow nylon builder's twine and tie if off at the top of the gnomon. Run the twine down through the first hole, then back up through the second and back to the top of the gnomon again and so on until you have threaded all the holes you made that month.

When you have completed the next month, do the same thing with another color of thread and continue alternating the colors through the year. You will end up with a 3-D sculpture that shows how the Sun travels through the sky as our Earth orbits the Sun. Each line shows the precise angle and direction to the Sun at noon on that day!

Being an Astronomer:

We know that days are shorter in the winter and longer in the summer, but as astronomers, we can investigate this ourselves. A permanently mounted pole such as a flagpole or a tether ball pole works well, but even a fence post can be used for this investigation.

The shortest day of the year is the Winter Solstice which falls on December 21st each year. On that day, the Sun is at its lowest point in the sky. By contrast, the longest day of the year is the Summer Solstice (June 21st) when the Sun is at its highest point in the sky. If we measure the shadow of a fixed pole once a week, we will see the length of the shadow change as we move through the year.

If you have a tether ball pole in your school yard, draw a line on the ground that starts at the base of the pole and travels due north (use a compass to help you find north!) One day each week, when the shadow of the pole lies along this line, mark the end of the shadow. Use paint so that the marks will not wash away easily!

By marking the shadow one day each week, you will see that in the fall semester, the shadow gets longer each week because the Sun is lower in the sky! During the spring semester, the shadow lengthens again as the Sun travels higher in the sky and the days get longer. By marking a simple shadow, you have measured the path of the Sun across the sky as the Earth travels around its orbit!

Being an Astronomer

Not every planet has a 24-hour day! Mars is the closest to Earth with a day of 24 hours, 37 minutes. The Moon is very different from Earth, the lunar day is 655 hours long – that's almost 28 days! Since the Moon spins so slowly, the Sun will rise and then stay in the sky for two weeks before setting; the lunar night is also two weeks long.

How would a solar clock behave if you had one on the Moon? Could you use it every day? How would you have to mark the dial differently to make it work there? Think about this with your student group and see what suggestions you can come up with!

Being a Scientist

Measuring time is always important in science. We have succeeded in making a working clock, but how accurate is it? Try measuring the angles for the marked hours, are they all the same size? Time the progress of the shadow on your clock as it moves and mark the progress in 15-minute intervals. Does your clock's shadow always move at the same speed? Can you explain your result?

Following Up:

There are many different types of clocks. Do some research on the internet and see how many different types you can find. What type of clock do scientists use most often? What is the most accurate clock in the world?

Unit 2:

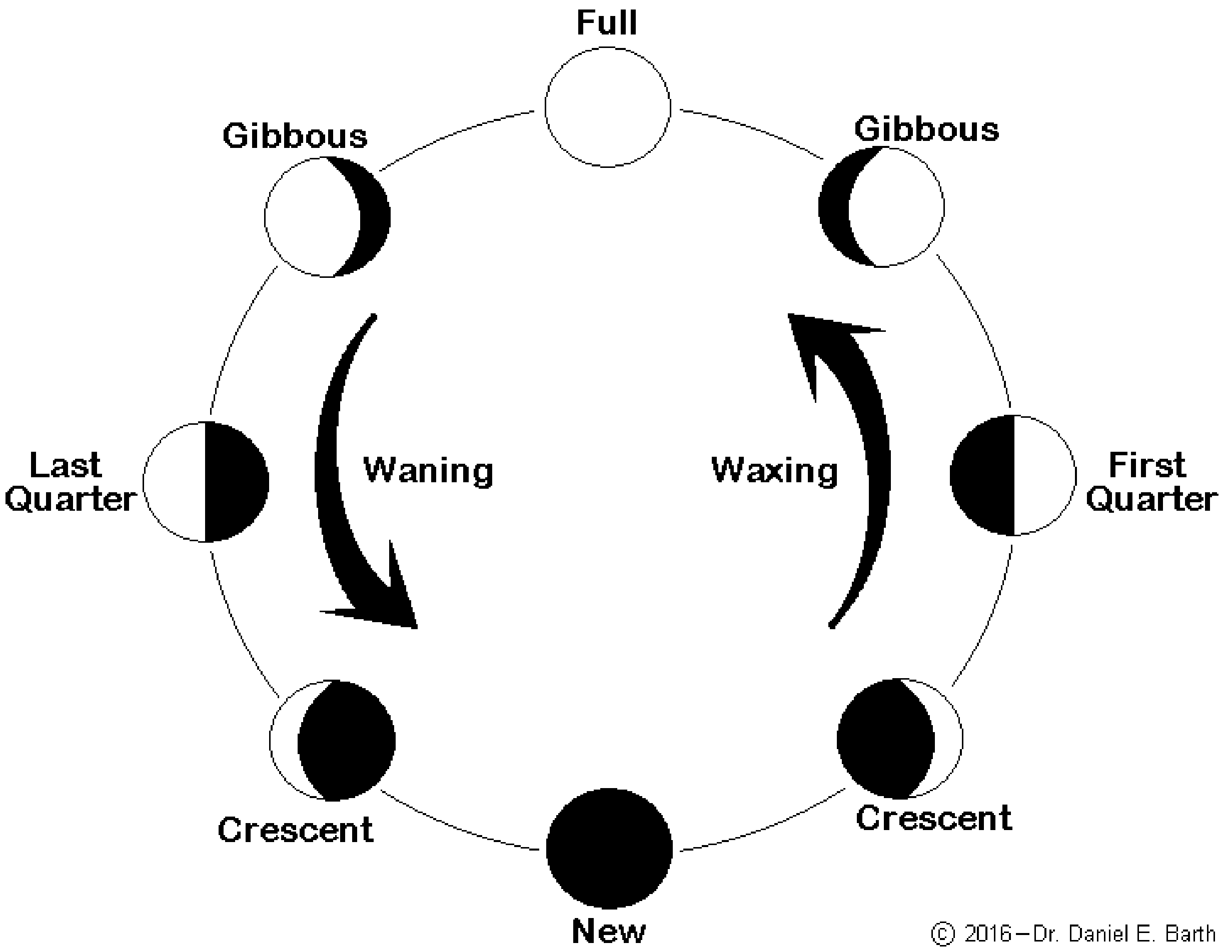
Lunar Phases – A Simple Scientific Model

Astronomy is sometimes called ‘the oldest science’, certainly it is a natural focus for children of all ages. The sky is always above us, and children point up asking, ‘What’s it made of?’, ‘How far away is it?’, ‘Where does the Sun go at night?’, and a host of other questions. Parents are sometimes overwhelmed or frustrated by these questions, but as teachers, we must welcome them.

For young children, the Moon is an excellent place to begin. Even very young children are attracted to the Moon because it is the largest, brightest object in the night sky and immediately draws everyone’s attention; not only because it is bright and beautiful, but also because it changes shape. These changes in shape are called ***Lunar Phases***, and you can see them listed in the illustration below.

Activity 2:

Making a Moon Phase Map



Some teachers worry about doing STEM activities in class and fear that they will not have all the answers when children start to ask more interesting questions – instead, take this as an opportunity! A piece of poster board or just an area of the class whiteboard can be used to write down questions to be answered. For younger children, the teacher can later research the answer and report back to the class. For older children, supervised web searches can provide a wealth of information. If your classroom has the ability to use a projector with a computer, this can be an exciting learning and exploring activity to follow up a STEM activity. Occasionally, students ask questions that science has not yet answered – this is not a problem! Students can, and should learn that science is not perfect or all knowing. Science has its limits, and unanswered questions are not failure, they are opportunities for future exploration!

Our next student activity will be constructing a model of the lunar phases, but before we do this, let's review the scientific facts you need to know in order to run this successful STEM activity in your classroom. As I mentioned in the introduction, you don't need a vast knowledge of facts at your disposal to teach astronomy successfully as a STEM activity in any elementary classroom. You probably already know most of these things, but it is helpful to review them before we begin.

Academic Standards

Science and Engineering Practices

Developing and using models
Constructing explanations

Crosscutting Concepts

Patterns in nature
Systems and system models
Stability and change

Next Generation Science Standards

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

For the Educator

Facts you need to know

1. Lunar phases (the shape of the Moon we see in the sky) change slowly over a period of days. Each of the eight distinct lunar phases lasts 3-4 days, this means we must be patient as lunar observers!
2. An entire series of lunar phases from one full Moon to the next is called a ***lunation***, and takes about just over 29 days[1]. This regular change was one of humanity's first calendars and gives us the modern concept of the ***month***.

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[1] While a ***lunation*** takes 29.5 days, a lunar orbit is shorter at 28.3 days. The difference between the two times is due to the Earth's own motion around the Sun. We will ignore this small difference in our activities for simplicity's sake.

3. Each complete set of lunar phases coincides with the Moon making a complete trip around the Earth; this is called a ***lunar orbit***. Interestingly, the Moon travels ***West to East*** as it orbits the Earth, this is something we will see for ourselves later as we begin observing the Moon outdoors!

Teaching and Pedagogy

When we start students off on a project like this one, they get very involved in the project as art without giving a thought to what it means. That's okay! We want them to have fun and enjoy the creative aspects of building this lunar phase model as they learn the basic vocabulary and names of the lunar phases. It is also less than helpful for a teacher to try to push students to perform creatively while building a model, plus learning the vocabulary, and then trying to understand the concept of changing lunar phases all at the same time. I suspect that most adults would balk at that much complexity, and it certainly isn't a recipe for academic success with young children either.

Although I fully understand that the pedagogy we are discussing certainly isn't a one-day lesson, I've resisted breaking this down into lessons for you. ***You*** know your class best, the pace at which they can absorb new material – and this will differ quite a bit depending on what age group you are working with. If you are teaching a STEM activity-based unit for the first time, you may have to feel your way forward, have material on hand, and proceed as you feel best by ending lessons early, or extending them into the next topic if you feel your students are energized and ready for the challenge. Those of you teaching in a home school environment may be teaching children of several different ages at one time; the open-ended nature of these lessons will work particularly well for you, with the younger children gaining inspiration and knowledge from their older siblings.

A teacher can help the process along by posting photographs of different lunar phases around the room and labeling them with cards – or even challenging students to use their new lunar phase model to help name the phase shown in the photo once it has been created. Given the piece-meal style of much science curriculum, many older students may expect the learning to end once we've finished and labeled the model – far from it, we're just getting started!

Once your students have finished the model and are ready for the next step, have them start at the bottom of the diagram and label the new moon phase as ***#1.*** Proceed anti-clockwise around the diagram, labeling the waxing crescent as #2 and so on until all eight phases are numbered. Starting at the bottom and working around to the left may seem odd to you, but there are very good physical reasons for this. If we were able to stand very high above the North Pole in space and watch the Moon orbit the Earth, we would see that it travels anti-clockwise around the our planet.

As we proceed around the diagram rising ***up*** the page to the left, the phases get larger (they are ***waxing***), and when they descend down the page again the phases get smaller (they are ***waning***). Once you explain this to students, there is a very satisfying logic to it all. If they don't quite see it, and you have a 12 to 15-inch standard globe in your classroom, a Moon can be made from a tennis ball and a small child's action figure can stand in for our observer so that you can show them how this works.

At the end of this lesson, step back and congratulate yourself! Something marvelous has just happened in your classroom, your students have constructed a scientifically accurate model, compared it to what they know of nature, and learned something profound and important about how it works.

Clever students will probably already be picking up on the idea that the Moon's position in orbit around the Earth has something to do with which lunar phase we can see in the sky. Excellent! Assure them there will be more to learn about this later!

It's now time to sprinkle in a few additional facts to add to what we've already learned. ***The Moon takes 28 days to orbit the Earth.*** So what? Let's try a little math; division for the older students, counting for the younger ones will quickly bring them to the fact that each quarter of an orbit (from new moon to first quarter for instance) takes ***7 days***.

"Hey! That's a week!" Exactly! The Moon was humanity's first clock and calendar, NASA scientists have found carvings representing the lunar phases dating back over 30,000 years. The word ***moon*** is the origin for our word ***month***, and the cycle of lunar phases is the origin for the 4-week long month that we see on our calendar.

Ancient carven lunar calendar, c. 30,000 BC, courtesy of NASA.

By this time, your students may be spinning off questions faster than you can write them down – what an excellent outcome! Everyone engaged and excited about learning! If you have a skeptical administrator in your building, this period at the end of a project will be an excellent time to invite them to visit your classroom – they are sure to be impressed by what they see!

Student Outcomes

What will the student discover?

1. Lunar phases change in predictable ways.

The idea that we can predict nature is a powerful idea for children, who often see the ability to predict the future as nothing short of magical. But it is not magic that gives us this ability, it is instead careful observation and the use of the scientific method; it is important for children to understand where this powerful ability comes from!

2. The Moon orbits the Earth in 28 days.

While the model created in this activity has its limitations (more on this later!), you should put forward the idea that the ***lunar phases*** are linked to the ***lunar orbit***. Regular cycles in nature is a key theme in all fields of science, and this introduction to the idea in elementary school is foundational to a child's later understanding of science and nature.

3. The lunar phases are divided into ***waxing*** and ***waning*** phases.

Waxing phases occur when the Moon grows larger each day until it is full. Waxing phases are easily seen just after sunset on any clear night.

Waning phases occur when the Moon shrinks each day until New Moon, when it is not visible in the sky at all. Waning phases are easily seen at dawn or in the early morning while the sky is still a bit dim.

4. The lunar phases are named: New, Crescent, Quarter, Gibbous, and Full.

What will your students learn about science?

1. Scientific models explain some facts, but not others.

The knowledge that science is not omnipotent is important. Children (and sometimes adults!) put too much faith in power of science to know all and do all. Teaching young children that science (like all human endeavors) has its limits is important, and it helps combat misconceptions later!

2. Scientific models are creations of the human mind, and people are always changing them.

No scientific model is perfect, no model explains everything. Even if we are satisfied with a scientific model today, someone may discover a new fact tomorrow that challenges what we think we know and must be explained. Science is ***never finished***.

3. Scientific models are ***fun!*** We learn about nature by making – and playing with – scientific models.

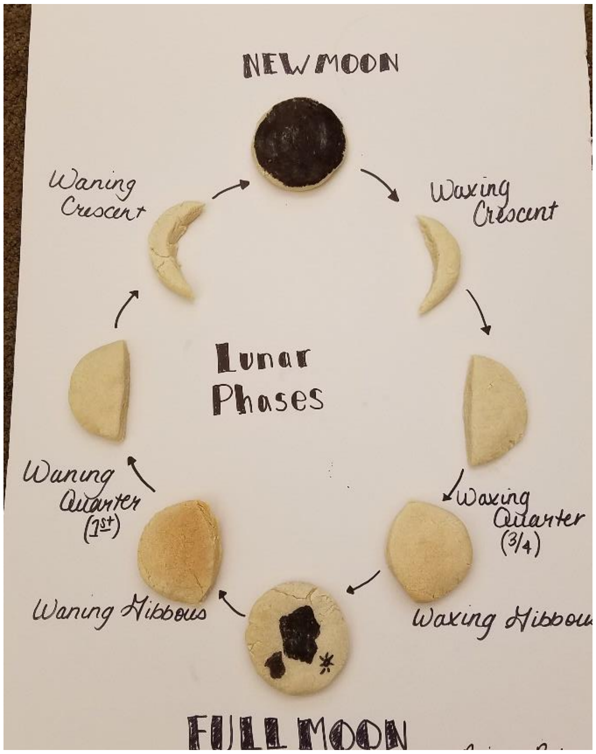
The job of scientist can be one of the most joyful occupations! Spending your days building models, playing with them to see what happens, and then comparing what you have learned from your model to what you see in nature can be very exciting. Many scientists I have known would cheerfully admit that they never really grew up, they just found a job where they could play with the best toys ever! As a former research scientist and science teacher, I must agree, science is fun!

Conducting the Activity

Materials

1. Modeling clay – enough for each student to make 6 balls about the size of a large marble (¾-inch each).
2. Plastic knife
3. Flattener – this can be a water glass, jar lid, any flat and rigid object can be used to flatten balls of clay into neat disks.
4. Wax paper
5. Construction paper and pencils or markers

Building the Lunar Phase Model



Now it is time to make a lunar phase map. This activity is a simple one, and students will probably not see the significance of it immediately. This is not a flaw, rather consider that student inquiry and discovery are built into these activities from the start. Often, it is helpful to record questions, but not answer them immediately. As science teachers, we do not want to build an expectation that the teacher is the fount of wisdom, but instead create the expectation that looking for, and finding answers is well within the student's capability!

1. Have each student divide their clay and make six balls of roughly equal size. Exact size is not important here, as long as they are roughly the same.
2. Place the first ball between two 4-inch squares of wax paper and use the flattener to press it into a disk at least 1/8th inch thick (3-4 mm). This first disk will be the full Moon, peel it carefully from the wax paper and place it at the top of the construction paper as shown below.
3. Repeat the process with another ball of clay and make a second disk. Making the disk the exact same size is not critical, but if you are particular, you may wish to use a circular cookie cutter to make all the disks identical.
4. We now use the plastic knife to create a gibbous shape by trimming away the clay as shown below. Proceeding counter-clockwise around the diagram, place the waning gibbous shape on the diagram in the next spot to the left of the full moon shape. Create a second identical gibbous shape and fill in the waxing gibbous position on your diagram. When placed correctly, the gibbous shapes should be on the right and left of the full moon shape.

Note that the cut begins at the north pole and ends at the 6 o'clock position (south pole). This will produce the most accurate phase diagrams!

5. For our next step, we will make a new clay disk and cut it in half; this will create both the waning and waxing quarter phases. These are then placed on the diagram as shown.
6. Next, we will create our crescent phases. Older children may be able to cut both the waning and waxing shape from one disk, younger children will probably need to do these one at a time. Place them on the diagram as shown.
7. Finally, we will color in a dark circle on our diagram to represent the new moon phase. If you've used a cookie cutter for making every phase the same size, you can now use it as a stencil to make a dark circle. Otherwise, just trace a circle from a sports-drink bottle top and you've got it. Take a marker or pencil and carefully label each phase with its correct name, add some arrows to show the direction in which the diagram runs and our scientifically accurate model of the lunar phases is now complete!

Exploring the Lunar Phase Model

1. If you have older students (4th grade & up), you may want to avoid showing them how the phases fit together. Give the students a circle with eight places marked around the circumference, and challenge them to place the phases in order. Be careful, not all the lunar phase models you see on line are correct!
2. Once you have your phases in order, a natural question is 'Where is our Moon now?' and 'Which phase is coming next?' While this is a simple question to answer – go outside tonight and look! The question of what comes next requires patience – it takes several days for one phase to change into another, and an entire month to see the entire cycle of phases.
3. Making a calendar. It is easy to find printable calendars online, or to make one with construction paper, a marker, and a ruler. Record the days of the month, and record the changing phases on the appropriate days of the month. Can your students use one month's calendar to make a prediction about when phases will be visible *next month?*

Discussion Questions

1. How did making this model help you learn about the Moon and its phases?

   Answer: Most students (most people!) see the Moon but do not regularly observe it and pay attention to the changing phases. Increasing awareness of nature is the first step of building STEM thinking!

2. How is this model like the Moon?

   Answer: It shows the changing phases of the Moon.

3. How is this model NOT like the Moon?

   Answer: Our model of the Moon is flat – not round!

   Answer: There is no motion in our model – the real Moon moves across the sky and orbits the Earth!

Supplemental Materials

Going Deeper

Lunar phases are interesting, but we can look closer! The line that divides light from darkness on the Moon is called the ***terminator***. If you were standing along this line on the Moon, you would see either a sunrise (waxing moon) or a sunset (waning moon.)

Challenge your students to look up photos of the different phases of the Moon online. Look along the terminator and you will see dramatic shadows cast by mountains and craters. Look farther away from the terminator and the Moon appears much more flat, few shadows are to be seen. Can your students explain why this is so?

Hint: Near the terminator, the Sun appears low in the lunar sky. Like sunrise here on Earth, the shadows are long and dramatic. Farther away from the terminator, the Sun is well overhead. Like noon time here on Earth, shadows are shorter and less noticeable. Go outside in the early morning – and again at noon time – your students will easily see the difference!

Being an Astronomer

Being an astronomer means first being a careful observer. It works best if you can consult a lunar calendar. Many calendars have little symbols on them indicating full, new, and quarter phases, there are also a variety of free apps for your smartphone that will do the same thing. Plan this initial observation for the time of the first quarter moon phase; the Moon will be easily visible at sunset (students won't have to stay up late!) and remain in the sky for a few hours making it an easy target for everyone.

Have students trace a circle on a piece of paper and draw a horizontal line below it like the one shown here. Ask them to go out in the back yard with a parent after sunset and sketch the Moon's appearance inside the circle. Hold the paper up so that the horizontal line matches the horizon before they draw to get the orientation correct if they can. (Some teachers may wish to simplify the activity by eliminating this step for younger children.) Emphasize to the students that all they need to observer is the shape of the lighted portion of the Moon's surface (just the phase). Understandably, some children may wish to sketch or color in some of the light and dark regions of the lighted portion of the Moon – don't discourage this, but emphasize that an accurate sketch of the Moon's shape is the first priority.

If you have older students who have access to smart phones, some of them may wish to try and capture a photograph of the Moon with their phone camera. Don't discourage them from trying, this is perfectly safe, but far more difficult than it may at first appear. The Moon is a tiny target, smaller than a typical aspirin tablet held at arm's length! It is also very bright, and on a dark background, making it difficult for most cameras to focus on. Street lights and lights from nearby autos will make it even more difficult, and just holding your hand steady enough to capture this tiny target may well be beyond the skills of most elementary age children. Although it may seem strange, sketching by hand is in this case, much easier than taking a photo!

Once your students have made a single sketch of the Moon at night, ask them to match it to the lunar phase model they have created. Once they have done this, ask them to ***predict*** which phase will come next, and how many days this may take to happen.

One of the most powerful things about a scientific model of theory is that it gives us the ability to ***predict what will happen*** in nature. This model will give your students the ability to predict the behavior of the Moon, and then the skill set needed to observe and verify their prediction. This is extremely powerful! Your students, even very young children, can learn to function as scientists by observing nature, constructing models, and then making and verifying their predictions.

In spite of the low cost and simple methods used in this activity, the outcomes are sophisticated and powerful. Our students have become scientists. They have the power to predict nature, and the ability to frame and ask even more complex and profound questions. When we, as teachers, highlight and celebrate their achievements in STEM science by doing activities like this, we not only initiate them into the sciences, but armor them against misconceptions later in life.

1 Time: Date:	2 Time: Date:	3 Time: Date:	4 Time: Date:
5 Time: Date:	6 Time: Date:	7 Time: Date:	8 Time: Date:

Being a Scientist

Making a scientific model and exploring it in the classroom is a wonderful activity, but this is only half of what a scientist does. After making a shiny new model and playing with it for a while and thinking up lots of new ideas and questions, it is time to take this baby out for a spin! Let's compare what the model tells us to what we see in nature! This critical step, which we call an ***experiment***, will tell us if our model is any good or not. A good model is sometimes called a ***theory***, and it will do two important things. First, our model will be able to predict the behavior of nature and help us to know what happens next. Second, our model will point us toward new knowledge by helping us to ask clever questions that lead to further discoveries. Now, it's time to get started!

Following Up:

Ask your students what is good or powerful about this model we have created? You are likely to get a variety of answers, but sooner or later a student will zero in on the idea that this model allows us to predict the behavior of the Moon as it orbits the Earth and to measure time without a clock or calendar. Point out to them that the ability to predict the lunar phases and keep a calendar was a major accomplishment for ancient societies, and that most modern people can't do it without help either!

Playing with and exploring the lunar phase model has no doubt inspired many questions among your students. If you have written down and answered some of them, this is the time to go back and draw your student's attention to the fact that playing with the model inspired both questions and learning! Real scientists value scientific models for just this reason!

Now ask your students what is weak or wrong about this model? Where does it fail? This may be a difficult question for young children; they are not used to considering where or how something fails in a dispassionate way. Failure is synonymous with BAD! Not so for the scientist!

Lead them to consider questions like ***What? When? Where? Why? How?*** Our model tells us ***what*** will happen next, but it does not tell us ***why it happens***, or ***how it works***. It is true that our model ***fails*** to give us all the answers we desire, but this is a ***fundamental truth*** about all scientific models. Many students hear the word "science" and they begin to think of a great, all-knowing body of knowledge or an omniscient scientist figure. Nothing could be further from the truth!

Every scientific model explains some things, but not others. A model or theory may answer some questions (What lunar phase comes next?), but will likely fail to answer others (How do lunar phases work?). Students need to learn that science is not infallible! For instance: it is ***incorrect*** to say that science has ***proven*** something. Scientific models ***never*** answer all of our questions – there is always something new to learn or discover, even about the things we've known the longest.

The Moon is an excellent example of this; humans have been wondering about, theorizing about and exploring the Moon for millennia, and we are still learning new things today! In fact, men and women working in the sciences all over the world are working to improve and refine even the oldest scientific models as we learn more about them. Point out to your students that by creating and exploring their lunar phase model, they are participating in this process in the classroom today. Many important scientific questions were first asked by children – and then answered as they grew into adults! The best scientific models help us think of new questions to ask, and point us to where the answers may be hidden and waiting to be discovered; science is an adventure that never ends!

Unit 3:

Modeling Earth and Moon Together

Our first model of the lunar phases is an easy and exciting place to start, but there is something missing – the Earth! Whenever we talk about a moon in orbit, we automatically assume that there is a planet for the moon to circle around. Early lunar models had the same problem that our model did, they failed to account for the Earth. Rather like a fish ignoring the water that they swim in every day, it is easy for us to ignore the Earth; in spite of it being so large, it is all around us and under our feet every day. People often forget to consider the obvious!

Gravity will also emerge as a major theme of this unit. Most of my astronomy students are astonished at how much gravity affects everything in the cosmos – and the Earth-Moon system is their first introduction to that concept. Although the activities in this unit seem to address many separate facets of the Earth and Moon, gravity unites them all!

Our new models will help students understand that the Earth and Moon are a system – two planet-sized objects bound forever together in space by their mutual gravity. If we wish to understand how the Moon works and how the lunar phases we see every night are produced, then we must take into account the Earth beneath our feet. In fact, because the Earth and Moon are bound together, we cannot understand one without studying both of them together. While it may seem incredible to you, this fundamental scientific truth was not discovered until the late 1960's when we first began to send men and robotic craft out into space to explore the Moon for the first time.

This new model will also begin to take into account the ***physical scale*** of the Earth-Moon system. The Moon is about ¼ the size of the Earth, but very far away – about 30 Earth diameters away. Both the large size of the Moon relative to the Earth and the great distance from the Earth is seldom appreciated. Our new classroom model will be quite large and is best explored outdoors or perhaps in a gymnasium-sized space. Because it is accurate both in terms of ***size and distance***, it will correct common errors seen in most models and diagrams of the Earth-Moon system – it is almost certain to surprise and delight your students.

Activity 3:

Making a Scale Model of the Earth-Moon System

Because this model is both larger, and more complex that what we have done before, we will divide up the construction of the model, and exploring it scientifically into two separate activities. It is assumed that Activity 3 and Activity 4 will be done sequentially with one following close upon the other.

Academic Standards

Science and Engineering Practices

Developing and using models
Using mathematics

Crosscutting Concepts

Scale, proportion, and quantity
Systems and system models

Next Generation Science Standards

Space systems (K-5, 6-8, 9-12)
The Earth-Moon system (6-8, 9-12)
Gravitation and orbits (6-8, 9-12)

For the Educator

Facts you need to know

1. The Moon is about ¼ the size of the Earth (when you compare diameters).
2. The Moon is about 385,000 km (250,000 miles) from Earth (average distance). This is about 30x farther than the Earth is wide.
3. The Moon orbits the Earth in about 28 days.

4. One side of the Moon always faces the Earth, we call this the ***near side***; the side we never see from Earth is called the ***far side***.

Teaching and Pedagogy

This model of the Earth-Moon system is one of the largest models we will construct in this book – in fact, the completed model is approximately 60 feet in diameter, perfect for an outdoor activity!

In spite of the model being of great size, the materials for the model will fit into a single grocery bag – it turns out that the Earth-Moon system is mostly empty space! This vast amount of space compared to the relatively small Earth and Moon is one of the main things that your students will learn about.

Diagrams of the Earth and Moon in a textbook have to be compressed to fit on a single page. Physical models of the Earth and Moon system have to be made compact enough to fit on a desk top. You could draw or construct such models to correct scale, but the drawing on your page would show an Earth no larger than a BB, and the Moon would be a single speck on the page.

Your first reaction might be: “Those models lie!” In fact, almost every scientific model makes many compromises and simplifications. Some of these compromises are deliberate, others are out of ignorance. Unfortunately, when we become used to the compromises – and no one tells us about them – we come to think of these things as facts.

This will certainly be the first true-to-scale model of the Earth-Moon system your students have seen. It is a wonderful experience to introduce the student to the vastness of space, but just as importantly, we must dig deeper and draw the student’s attention to the compromises that scientific models make. Awareness of how scientists present models will help your students interpret, and understand these models better!

Student Outcomes

What will the student discover?

1. The scale of the Earth-Moon system is enormous!

   Almost every diagram of the Earth and Moon depicted in textbooks is wildly out of scale. When we use a 12-inch vinyl playball as the Earth and a rubber T-ball as the Moon, the diameter of the lunar orbit is 60 feet!

2. The Moon crosses the sky from ***East to West*** each night.

   This east to west motion is called ***apparent motion***, it is caused by the speedy rotation of the Earth on its axis and it is not actually how the Moon moves through space as it orbits the Earth.

3. The Moon moves from ***West to East*** as it orbits the Earth in space.

   This is the Moon's ***true orbital motion*** which is in the ***opposite direction*** of the east to west apparent motion that we see each night. We ***can*** see this eastward movement of the Moon from here on Earth, but we must watch the Moon carefully over several nights to observe it!

4. Unlike our consistent sunrise and sunset, the time of moonrise and moonset changes by about an hour each night.

   Because the Earth is spinning as the Moon orbits our planet, our Earth must turn more than 360° each day before we can see the Moon again. This means it takes ***more than 24-hours*** from one moonrise to the next, and the Moon rises about 50 minutes later each day. Be patient, this fact will be much easier to see in one of our later activities than it is to explain now!

5. We can only see one side of the Moon from Earth (the ***near side***), in order to see the ***far side***, we must physically travel through space.

   This unique fact will be explored in several upcoming activities. We will discover both that it ***is true***, and more importantly, ***why it happens***.

What will your students learn about science?

1. We will learn that by ***improving a scientific model***, we can begin to answer the ***Why does that happen?*** and ***How does it work?*** questions – not just the ***What happens next?*** questions.

   When we build on and improve a scientific model, we partake in a tradition of scientific inquiry that is literally thousands of years old. Science has no sacred ideas that cannot be challenged. In fact, to be good scientists, we ***must challenge*** every idea and scientific model. If the model is robust, it will be able to answer questions and respond to challenges; if it is not, then it must be changed, or even discarded all together!

2. Playing with scientific models is important. It helps us ask (and answer!) questions in a kinesthetic way – even before we have the vocabulary and conceptual understanding to frame these questions properly in English!

Understanding a scientific model physically and kinesthetically often comes before a proper description exists in the language of mathematics or English. ESL students often respond particularly well to a good scientific model and demonstration because they can frame the ideas mentally in their native language first, then acquire the proper English vocabulary right along with everyone else in the classroom. Scientists often ***invent new vocabulary*** to describe their discoveries, these terms are generally adopted in almost all languages ***without translation.*** Science and mathematics are truly the universal languages of humanity!

3. Science lets us explore the shape and structure of things – even when they are too far away for us to actually touch and explore personally.

   By making models of faraway things like the Moon here on Earth, we can begin to understand how they are put together and how they work as they do. Of course, models are just scientific theories made flesh, so to speak; they aren't perfect and never tell us everything we wish to know – but they do help us frame the next question and point us toward where we may find the answer!

   In this unit, we will also make comparisons between common things like rain drops and distant things like the Moon. Comparing the structure of these things can help us see the themes in nature and how simple forces like gravity shape almost everything around us!

Conducting the Activity

This activity involves making a true-scale model of the Earth – Moon system, and this baby is gonna be BIG! Large scale things delight children, and this model is large enough that you will need extra space just to play with it and explore; unless you teach in a gymnasium, this model won't fit in your classroom. Don't worry though, the pieces to this model can fit in a plastic grocery bag – you'll see what I mean as we start constructing the model! The preliminary construction of the model using glue and sharp instruments should probably be carried out by the teacher, especially with younger students; use your own judgement here! Students can decorate and operate the model after it is built.

Materials

1. Classroom paints and brushes, or permanent markers
2. Sidewalk chalk
3. One 12-inch vinyl playball (blue is highly preferred)
4. One light-colored, 4-inch rubber balls (I used a rubber T-ball baseball)
5. 50 ft of stout, non-stretchable cord (clothesline or pull-cord for blinds works well)
6. Duct tape (blue is preferred)

Building the Earth-Moon Model

1. The larger vinyl play ball will be our Earth, the T-ball will be our Moon. Note that the 4:1 size ratio between these balls reflects the true scale of the size of the Earth and Moon in space!
2. [**Teacher**] Tie a knot in one end of the cord and use an 'X' of tape to secure it to the vinyl playball. Alternatively, you can use a suction cup such as those used to hold a soap dish to the shower wall. These vinyl balls usually have a dimple where they are inflated, you will want to keep this clear so the ball can be reinflated if needed. Tape your line to the opposite side of the ball.
3. [**Teacher**] Measure out 30 feet of cord, plus an extra few inches. Cut the cord and save the remainder.
4. [**Teacher**] From the remainder of the cord, tie two knots 6'-10" apart, secure the knots with a few drops of white glue and allow to dry completely. Trim off any extra cord and discard. This cord-measure will show us how far the Moon moves each day as it orbits the Earth!

5. [**Teacher**] Put a knot in the end of the cord. (Optional: secure the knot with a drop of white glue and allow to dry completely before proceeding.)
6. [**Teacher**] Secure the knot to the rubber T-ball Moon. The best way to do this is to take a sharp knife (a hobby knife works well) and cut a deep, ½ inch slot in the T-ball. Force the knot into the slot with a screwdriver and seal the slot shut with a few drops of superglue and pinch shut; hot glue also works well.

Now that the model is built, it can be decorated by students. Remind them that the two pieces are tied together and to be careful of pulling or tripping! The Moon should be painted white if possible – the teacher can do this with spray paint before allowing the students to decorate the Moon if you wish.

7. Think of the place where the cord is attached to the Moon as a 'South Pole'. Draw a bold red 'equator' line on the Moon.
8. This line is not actually an equator; instead, it will separate the ***near side*** from the ***far side***! Label the near side and far side neatly in red.
9. Use dark-colored markers or paints to add ***craters***, ***rays*** (faint splash marks leading away from a crater in all directions!), and ***maria*** (dark-colored seas of frozen lava, usually round or oval in shape.) Some students will wish to be very artistic and use photos of the Moon to make the model look more accurate. But don't worry if your Moon doesn't look like the real one in the sky – our model will work just fine the same!
10. Now it's time to decorate the Earth. Consider the place where the knot is attached to the ball to be somewhere along the equator, perhaps out in the Atlantic or Pacific oceans. Once again, some students will want to be very accurate and artistic, others may wish to make a wildly imaginative planet that exists only in their imagination; either way, our model will work just fine!

Exploring the Earth-Moon Model

Now that our model is built, we can do several activities with it, most of these work best outside on the playground area. Although I do not recommend this as a first choice, you can build a smaller, ‘inside the classroom’ model if you wish. If you teach in a school with little play area outside, of if you just wish to conduct the activities inside, this smaller model works just fine. For the smaller model, use the rubber T-ball as the Earth and a glass marble as the Moon. To keep the Earth-Moon distance to scale, remember to make the string connecting them shorter, just 7.5-ft long, and make your measuring string just 2’-4” long. This smaller (and less impressive) model will fit in most classrooms, but at 20 feet wide, it will still cramp you for space in most standard classrooms!

Activity 4:

Exploring the Moon's Orbit

The Moon's orbit is wonderfully complex, and yet the youngest child in your classroom can understand the essentials of how the Moon moves through space. One of the essential skills of successful STEM teaching is to be able to break down complex things into small components that are simple to understand. Once your students complete these simple activities, they will be building the pieces of a conceptual model of the Moon and its orbital motion around the Earth.

Academic Standards

Science and Engineering Practices

Asking questions and defining problems

Developing and using models

Using mathematics

Obtain, evaluate, and communicate information

Crosscutting Concepts

Scale, proportion, and quantity

Systems and system models

Next Generation Science Standards

Space systems (K-5, 6-8, 9-12)

The Earth-Moon system (6-8, 9-12)

Gravitation and orbits (6-8, 9-12)

For the Educator

Facts you need to know

1. The Moon's diameter is ¼ that of the Earth, about the same ratio as a small marble to a baseball. The Moon is a much smaller world than Earth is!
2. The Moon's orbit is 60 times wider than the Earth itself. This 60:1 ratio demonstrates the vastness of space, but obviously makes it difficult (but not impossible!) to show an accurate model in the classroom.
3. The Moon orbits the Earth approximately every 28 days (moon and month are related words!) Each week the Moon travels ¼ the way around its orbit.

Teaching and Pedagogy

Now that we have built and decorated our Earth-Moon system model, let's have some fun with it! These next four mini-activities can each be done in 20-30 minutes, perfect for a single class period. Because the model is so large (sixty feet in diameter!), these will obviously be outdoor activities. I strongly suggest that you try them on a paved playground area where you can use sidewalk chalk to mark things out. The distance scale we are working with is something that really has to be experienced directly to allow students to gain a substantive cognitive understanding. One can talk about dinosaurs for days and look at all the photos on the internet you like, but there is no substitute for going to a museum and standing next to a life-size model or a real fossilized skeleton to give one an appreciation of the size of the creature.

These activities strike to the very core of constructivist pedagogy. During these activities, students construct their own meaning and create their own (hopefully accurate!) mental models of the Earth-Moon system. You may see this as simply "play time" rather than real science – don't be fooled! The cognitive work the students are doing as they play with these models is substantial! Your students are constructing mental models and maps of things like size, scale, orbits, planetary motion, rotation and revolution, space travel, and much more. We will be building on these ideas as we continue to build and refine scientific models throughout this book!

Conducting the Activity

Mini-Activity #1

Take your Earth-Moon model outside to the playground with some sidewalk chalk. Use the model as a giant string-compass and draw the lunar orbit out in chalk. Use chalk to draw in the Earth and Moon in their correct sizes on your diagram. Draw the student's attention to the sheer size of the Earth-Moon system compared to the relatively small sizes of the Earth and Moon themselves! Interestingly, the planet Saturn and its ring system would just fit inside the distance between the Earth and the Moon!

Try and use some sidewalk chalk to draw Saturn and its rings on the playground. The planet is a circle ten feet in diameter, the outermost rings make a circle fifteen feet in diameter! The great difference in scale between the tiniest and largest planets is one of the things that makes modeling the solar system so challenging.

How about the Sun in our model? To be in scale, our Sun would be a 100-ft ball (as large as a ten-story building.) We would have to place this giant Sun model 2.1 miles away; from that distance, it would appear to be almost exactly the size of our T-ball moon!

Mini-Activity #2

Ask the students to try drawing their model Moon while standing in the Earth's position. The apparent size of the 4-inch rubber ball from 30 feet is about the same size as the Moon appears in the night sky! Although our Moon looks large because it is a bright object on a dark background, it is really quite small! If you have decorated your Moon with maria and craters with rays, ask students if they can make them out when standing where the Earth is. If they cannot, this is an excellent time to offer them a chance to try out a pair of binoculars if you have one. Students will quickly see that binoculars do bring things closer, but holding them steady and drawing what you see in the eyepiece is still quite challenging!

Mini-Activity #3

Use the 6'-10" measuring cord to mark out the distance that the Moon moves each day. Number these daily positions of the Moon for one entire orbit. How many days does it take for the Moon to orbit the Earth? Surprise! It takes about 28 days (one month) for the Moon to orbit the Earth. Use your sidewalk chalk to draw in the lunar phases as we see them from Earth around your lunar orbit. Use your Lunar phase map from Activity #1 to help you!

Mini-Activity #4

Try for a moon shot! Use marbles or ping-pong balls as 'spacecraft' and try to roll your craft all the way from the Earth to the Moon! Alternatively, have everyone make a paper airplane and try 'flying' to the Moon as someone walks slowly around the lunar orbit representing the orbital motion. Getting from the Earth to the Moon is hard!

Discussion Questions

Now that your students have had a chance to play with this model of the Earth-Moon system, they should have a much better cognitive grasp of how large the system is, and what the relative size of the two bodies are and how they are related in space. Almost all drawings and illustrations from textbooks or internet sites are horribly distorted in this way. Artists invariably show the Moon being far too close to the Earth, and often much larger than it actually is in comparison to the Earth. There are good reasons for this of course, try to draw an accurate scale picture and most of the space on the page is not only empty, but the Earth and especially the Moon are really too small to show any detail at all! Never-the-less, these drawings encourage gross misconceptions about our planet and its nearest companion in space.

1. Show your students a drawing or illustration of the Earth and Moon in orbit taken from any textbook or website. Ask them what is wrong with this drawing as a scientific model?

   Answer: There are likely to be a great many things wrong with these illustrations! The relative size of Earth and Moon and the scale of the distance between them just for starters!

2. Ask your students to hold up their drawings of the Moon made from inside the circle at Earth's position. Ask them why observing and drawing the Moon is so difficult!

   Answer: This question will help you see how far your students – and their cognitive models of the Earth-Moon system – have progressed. No doubt they will now realize that drawing small features on a small lunar globe from very far away is quite challenging – even when they originally drew the features themselves and know just what they look like!

3. Show a photo or some video of the Apollo astronauts flying to, and landing on the Moon. Ask your students what they think of these explorers and the journey that they made!

   Answer: To understand an achievement, you must first know something about the challenge that it represents. If I told you I had built and learned to play a Theremin, this might not mean much to you unless you first knew that a Theremin is an electronic musical instrument that one plays *without touching it*. Your students are likely to find the Apollo voyages much more exciting now that they understand a bit more about the Earth-Moon system!

Supplemental Materials

Going Deeper

The average distance to the Moon is 385,000 kilometers – compare this to a trip from New York City to Los Angeles which is just 4490 km! That trip would take you 41 hours by car (without stopping for gas of food!) The Moon is about 90 times farther away than our imaginary cross-country trip!

Apollo astronauts traveled at an average speed of 5500 kilometers per hour (kph). Imagine you were going to travel this great distance – 770,000 km, all the way to the Moon and back - in a very small car with two of your best friends. Remember that this is a spacecraft and that you ***can not stop or get out!*** Work together with your two traveling companions to answer these questions.

1. How long would this journey take you? (Show your work!)
2. What things would you want to take with you? Space is very limited, so divide your items up into a ***Must Have*** and ***Want to Have*** lists.
3. Being in the car for this long without being able to stop or even open a window presents some very special problems; eating, washing, and going to the bathroom come to mind! What would you do to handle living in this very compact space for so long?
4. If your compact car got very good mileage, say 65 km per gallon, how much fuel would you need for the entire trip? Find a 5-gallon gas can and measure it; use this to estimate the size of fuel tank you would need for this trip!

Being an Astronomer

Observing the Moon's ***apparent motion*** is much easier than observing its ***orbital motion*** around the Earth – but both take some patience and clear weather! The best time to do this is in the two weeks after ***New Moon***. With your teacher or parent's help, use the internet to find the date for the next new moon, your observations will begin about 3 days after this.

Three days after the new moon, you should see a thin ***crescent moon*** in the western sky just after sunset as the sky gets dark. Watch the Moon for an hour or so starting at sunset and notice the motion of the Moon as it sinks into the west. If the weather is nice, a good way to do this is to have a Moon Picnic in the back yard with your parents and eat dinner as you watch the Moon! This ***east to west*** motion that you see is the Moon's ***apparent motion.*** What we are really watching is ***the Earth spinning on its axis***.

Being a Scientist

The Moon's ***orbital motion*** is harder to see, and you must watch the Moon carefully several days in a row to see it. Begin by going out on a clear night about three days after new moon. Look for the crescent moon low in the western sky right at sunset and make a note of the Moon's position. An easy way to do this is to notice where the Moon is compared to trees or buildings in your back yard. Take careful notes of what you see!

For the next 3-4 nights, go out again just at sunset and notice the Moon's position. You will notice that the Moon appears ***farther east*** each night. This ***west to east motion*** is the Moon's true orbital motion. We don't notice it on one night because the Moon takes 29 days to make a complete revolution around the Earth – it doesn't move much in just an hour or two!

Calculate the ***circumference*** of the Moon's orbit. Circumference = 2 π r (your teacher can help you with this!) The ***radius*** of the Moon's orbit is just the distance between the Earth and the Moon – 385,000 km. Use what you have learned to answer these questions:

1. How far does the Moon travel in each orbit?
2. How far does the Moon travel in just one day?
3. How fast is the Moon moving in orbit in kph?

Following Up

Think about how challenging space travel is! To be an astronaut and travel to the Moon requires great planning, scientific knowledge, and tremendous courage! We will explore these ideas further in later activities in this book.

Activity 5:

Rotation and Revolution

We are going to use the Earth-Moon system model once again, but this activity gets the children thinking about our scientific model in a different way; it also helps students understand the difference between ***rotation*** (a body spinning around on an internal axis), and ***revolution*** (one body circling around another)***.*** These two motions are generally independent of each other; our Earth, for instance, rotates 365.25 times (days) for each single revolution around the Sun (year); this is not a whole-number ratio. Planets are generally not ***synchronized***, that is to say their rotation time and revolution time do not divide evenly into one another. Our Moon (indeed most moons) are exceptions to this and have ***synchronized orbits***, as we shall see.

Academic Standards

Science and Engineering Practices

Asking questions and defining problems

Developing and using models

Planning and carrying out investigations

Analyzing and interpreting data

Using mathematics

Constructing explanations

Argument from evidence

Crosscutting Concepts

Systems and system models

Next Generation Science Standards

Forces and interactions (K-5, 6-8, 9-12)

Space systems (K-5, 6-8, 9-12)

The Earth-Moon system (6-8, 9-12)

Gravitation and orbits (6-8, 9-12)

For the Educator

Facts you need to know

1. From here on Earth, we only see one side of the Moon, commonly called the ***near side***. The only way to see the Moon's ***far side***, is to fly there in a space craft and take photos!
2. ***Rotation*** and ***Revolution*** are different! Things ***rotate*** on their axis the way a carousel spins on its central axis. To ***revolve***, you must circle around a point outside your body. A tetherball revolves around the pole and the Earth revolves around the Sun.
3. All planets and moons both rotate ***and*** revolve; just as the Earth rotates on its axis once a day, and revolves around the Sun once a year.
4. The Moon is interesting because it rotates only once on its axis each time it revolves around the Earth. ***Rotation*** and ***Revolution*** take the same amount of time – about 28 days. This is called ***synchronous rotation***, and it is the reason that we only see one side of the Moon from Earth!

Teaching and Pedagogy

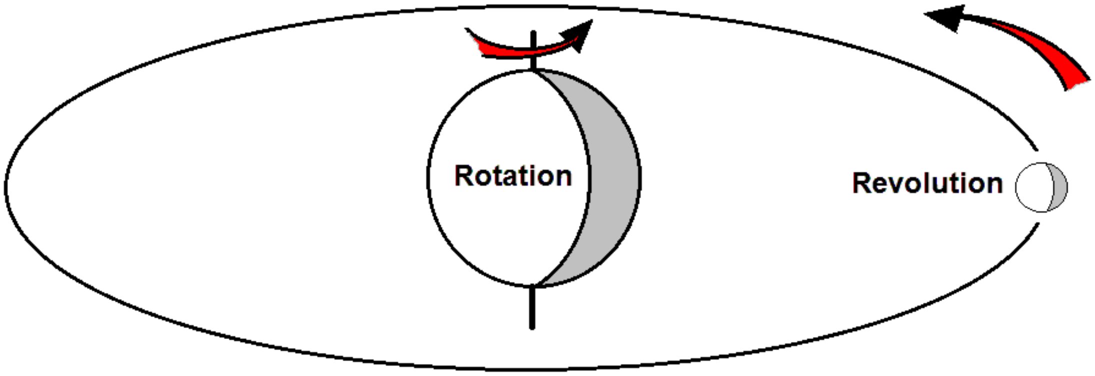
The concepts of rotation and revolution are often difficult, not just children, but adults often struggle with them. It is not that the concepts are inherently difficult, but I suspect that because we fail to introduce children to them at all, this sets them up to struggle later in life. Studies show that we must be exposed to novel concepts several times before we begin to internalize them; even more exposure and practice is needed to master a concept. These early exposures to the ideas of rotation and revolution will be critical for your student's later success in science. In keeping with the philosophy of many exposures to achieve mastery, we will return to these ideas again as you work through this book.

We are going to use the Earth and Moon model we built in Activity #3. You can use either the larger or smaller size model, but this activity generally works better outside using the larger size model

It may help your students visualize what is going on if you color your moon model before you work with it. Hang the moon model from the string (it should look like you are hanging it from the North Pole.) Draw a line where the equator should be and color the southern hemisphere dark grey, and the northern hemisphere white. The white half will represent the near side of the Moon, and the darker half represents the Moon's far side.

With the model in place in the playground, ask the students what the cord between the model Earth and model Moon represents? The cord represents the force of gravity that holds the Moon in orbit of course, but the students may need to be guided to this idea. In general, if the students can stand 5-10 meters (15-30 ft.) away from the model, it will be easier to see what is happening.

As you can see in the illustration below, ***rotation*** occurs when a body such as the Earth spins around an internal axis. Virtually all objects in space spin around their own internal axis; for the Earth, this creates the night and day cycle. ***Revolution*** occurs when one object orbits around another. The Moon for instance, ***revolves*** around the Earth once per month.



Student Outcomes

What will the student discover?

1. One side of the Moon always faces the Earth.

   Students may decide that this is caused ***by the string*** which attaches the Earth and Moon models together. Remind the students that it is actually the ***Force of Gravity*** which locks the Moon in a 1:1 ***synchronous orbit*** around the Earth.

2. The Moon ***rotates*** or spins on its axis just once for each rotation around the Earth.

   It is sometimes helpful to have a student hold the Moon over their head and walk the Moon model around the Earth. You will clearly see that the student faces a different direction each time they move ¼ the way around the orbit!

3. The Moon's ratio of rotations : revolutions = 1:1.

   This 1:1 ratio is typical of very large planets with relatively small moons. This is more common than you might think! The moon Charon always faces the same side toward it planet Pluto! Several moons of Jupiter and Saturn are locked in orbit in this same way.

What will your students learn about science?

1. Playing with models and exploring what they can tell you about the world around you is powerful science!

   Working with models is very powerful. The famous scientists James Watson and Frances Crick used models to discover the shape of the DNA molecule – and won a Nobel Prize for their efforts.!

2. Models can help explain what we see in Nature.

   Sometimes we see something, but we don't understand how it works. Always seeing the same side of the Moon is like that – we've all looked at the Moon in the sky hundreds of times, but few people wonder ***why do we always see the same side?***

   Playing with models can help us understand what is happening, and help us plan new experiments!

3. Models can help show us where to look for new ideas, and help us form good questions to ask as we continue exploring!

   Once we see the same side of the Moon always faces us, we begin to ask other questions. Is it always ***exactly the same?*** Can we see the Moon tip or wobble at all?

   We will deal with these, and other questions, as we move through this book!

Conducting the Activity

Materials

We will use the Earth-Moon model that we constructed in Activity #3. It should be modified as discussed in the ***Teaching and Pedagogy*** section above.

Exploring the Earth-Moon Model

With the model in place in the playground, ask the students what the cord between the model Earth and model Moon represents? The cord represents the force of gravity that holds the Moon in orbit of course, but the students may need to be guided to this idea.

1. Explore how the cord in our model is similar to gravity – and different from it. This is another way to help children realize the difference between a scientific model or theory and nature itself. Our model has several difference and similarities to nature – how many can you find?

2. Gravity is not a physical cord of course; it is a force, similar to magnetic force. We can feel gravity, and like a magnet, the force gets stronger as we get closer to Earth (Most of us never get far enough away from the planet to notice this, however!) Gravity is also elastic! Unlike our cord, gravity can stretch to hold a moon in orbit at almost any distance around a planet. (Use orbiting satellites to give students a sense of this. Most satellites orbit much closer to the Earth than the Moon is, but some orbit much farther away!)
3. After moving the Moon in orbit around the Earth one or two times, ask the students if the Moon ***rotates*** on its axis as it ***revolves*** around the Earth in space. Two points of view are helpful here.
4. Ask some students to stand close to the Earth's position as someone moves the Moon around its orbit – can they ever see the far side?
5. Ask other students to stand well outside the Moon's orbit as it moves around the Earth – can ***they*** see the far side?
6. If the students are having difficulty with this, try moving this indoors onto a table-top. Prepare a T-ball or tennis ball colored black on one side and white on the other. Set a globe, or even a soccer ball or basketball on the center of the table – this is the Earth. The smaller black and white ball will be the Moon, keep the white side always facing the Earth – this is the near side of the Moon which we always see; the far side which we never see is black in this model.
7. Slowly move the Moon around the Earth, keeping the white side facing Earth at all times. Students will quickly see that the Moon ***must revolve*** on its axis once per orbit. To drive the point home, keep the white face pointed toward one particular wall at all times and orbit the Earth again – both the near and far sides would visible from Earth if the Moon didn't rotate at all! This 1 rotation per orbit motion is called a ***synchronous orbit*** – it is caused by the strong gravity of the planet. Many moons in our solar system have this interesting feature! We will explore how and why this works in our next activity!

Discussion Questions

1. We know that one side of the Moon forever faces the Earth. Is there any other speed the Moon could spin on its axis and still have this be true?

   Answer: No. Try this with your table top model. Spin the Moon just a bit faster than one rotation per revolution and we begin to see some of the far side. Spin the Moon slower and the same thing happens! Only by spinning exactly once around its axis for every one orbit around the Earth can the Moon keep its near side facing Earth and the far side forever hidden!

2. How does this exact one to one ratio work? Is it all coincidence or is there something causing it and controlling the Moon's rate of spin upon its axis?

   Answer: In fact, this deep scientific question plagued men and women of science for centuries. The answer was only discovered after we traveled to the Moon and sent explorers there to observe and gather data! We will see exactly what they discovered, and how this works, in our next activity!

Supplemental Materials

Going Deeper

If your students are studying ratios, the orbits of the planets provide wonderful material for this. If you use a search engine (Google, Yahoo, etc.) and type in: "What is the rotation and revolution period for the Earth," you will find what you are looking for.

Try dividing the revolution time by the rotation time. For Earth this will give you 365.26 days / 1 day for a ratio of 365.26: 1. If you do this, you must be sure the numbers are in the ***same units.***

Example: Jupiter's revolution time is given as 11.86 ***years***, while its rotation time is given as 0.41 ***days***.

To make the units the same, multiply 11.86 years by 365.26 (the number of days in a year.) This gives Jupiter's revolution time as 4,332 ***days.***

Now divide revolution by rotation: 4332 / 0.41 = 10,566 : 1

In other words, Jupiter has 10,566 'days' per year! Look up the facts for other planets and moons in our solar system, you will be astonished at what you learn!

Being an Astronomer

Our model has told us something about the Moon, but is it really true? This idea given to us by the model (one side of the Moon always faces the Earth) is called an ***hypothesis***. An hypothesis is an idea that we use to try to understand how the universe works – but it ***must be tested!***

Astronomers test ideas like this by ***making observations***. Observations can be made by looking at the sky with just your eye, or by looking through a telescope or pair of binoculars; some scientists even use cameras to take accurate photographs which can be studied later!

Try observing the Moon for a month! If you start after new moon, you will find the Moon in the sky just after sunset. After the full moon passes, the Moon is best observed in the early morning sky. Winter is a good time to do this because the Sun does not rise too early in the morning, and the sky gets dark early in the evening.

Look at the Moon's surface every chance you get. Can you verify that you ***always see the same side?*** How can you be sure? Write your ideas down in a journal, then make sketches of what you see.

Teacher's Note: Help the students by showing them a globe. The globe has many features, but they are always in the same places – the continents never move around! The Moon has regular features too, some are bright and others are dark. If students look for these familiar features, they should be able to verify that they see only one side of the Moon.

Following Up

There is more than one way to observe the Moon! Do an internet search for images of the Moon. Look at each one and see if you can find common features to verify our hypothesis.

You can also search for images of the ***far side of the Moon***. The far side looks nothing like the familiar near side. A comparison of the two images side by side should convince even the most skeptical student that they have never seen the Moon's far side!

Activity 6:

The Lop-Sided Moon

The mystery of the Moon's synchronous orbit is very profound, it has puzzled astronomers and scientists for thousands of years. Even today, when you point out that we only ever see the near side of the Moon, many people will insist that this means that the Moon does not rotate on its axis. The precise match of rotation time to revolution time seems almost miraculous; in fact, it is no such thing. Although the mechanism remained mysterious until the 1970's, it is quite simple – the Earth's gravity controls the Moon's rotation and keeps one side forever pointed toward our planet, and one side forever hidden from us. This activity will show your students both clearly and simply how this works.

Academic Standards

Science and Engineering Practices:

Asking questions and defining problems

Developing and using models

Planning and carrying out investigations

Constructing explanations

Crosscutting Concepts

Cause and effect

Systems and system models

Structure and function

Next Generation Science Standards

Forces and interactions (K-5, 6-8, 9-12)

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)

Gravitation and orbits (6-8, 9-12)

For the Educator

Facts you need to know

1. Like the Earth, the Moon has a dense core of metal and rock.
2. The Moon's core ***is not centered***, Earth's gravitational pull has shifted the lunar core so that it is off-center and closer to the Earth.
3. The Moon's off-center core locks the Moon into a ***synchronous orbit***, causing one side of the Moon to always face the Earth.

Equipment you will need:

1. A rubber T-ball
2. A hobby knife
3. Fishing weights
4. Instant glue

Teaching and Pedagogy

This series of activities begins to explore gravity as a fundamental force that shapes our universe. The shape of the Moon, how it moves in orbit, the way one side always faces our planet, even the peculiar 1:1 ratio of rotation and revolution that we call a ***synchronous orbit*** – none of these things can be understood without understanding gravity first!

The first person to understand the intimate relationship between gravity and the motion of the Moon was ***Isaac Newton***. The famous story of Newton being struck on the head by a falling apple was actually the moment he discovered that the Moon and the apple both fall because of the same force – gravity! Newton was the first to realize that gravitational force extends far out into space and effectively rules the cosmos!

Newton was perhaps the smartest man ever to have lived; he invented the mathematics we call ***calculus*** to help him understand the action of gravity and the motion of the Moon in orbit around the Earth. But we needn't dive deep into mathematics to understand the fundamental action of gravity and how it controls the Earth-Moon system; this activity will give students a powerful, conceptual knowledge that will serve them well as they begin to explore mathematics later in life!

You will need several items for this activity – some of the model building must be done by an adult, or by older students with professional adult

Student Outcomes

What will the student discover?

1. The Moon is not a uniform body – its core is not located at the center of the Moon.
2. Earth's gravity affects the Moon in more ways than one. The Moon's rotation on its axis is powerfully affected as well as the Moon's orbit.
3. The Moon's ***synchronous orbit*** causes the ***near side*** to continuously face the Earth while the ***far side*** always faces away from us.

What will your students learn about science?

1. The universe is a complex place, there is always something new to learn and to explore. Even so, just a few fundamental forces and principles such as gravity control virtually everything there is! Because this is true, models (and other objects!) here on Earth are controlled by, and function much the same as distant objects across the solar system.
2. The idea of ***fundamental forces*** makes it possible for us to make models on Earth that can tell us about the structure, motion, and function of objects so far away we may never be able to reach them. It also gives us confidence that when we make a scientific model here on Earth, the same fundamental forces and processes are at work in the classroom or the laboratory as they are in deepest space. While our models (and our understanding of them!) aren't always correct, we can have confidence in the scientific process in general.
3. We also learn that the universe and our solar system is a complex place! It often takes more than one scientific model to understand something as complex and wonderful as the Earth-Moon system. Science always welcomes new models, new ideas, and new questions. Even so, no one will believe you just because you are smart, or famous, from a big important country, or because you have lots of friends who all think you are right! Science tells us that only ***experiments*** can tell us which idea is right. Men and women make models and theories, but Nature decides which ideas are correct.

Conducting the Activity

Materials

1. A 4-inch, light colored rubber ball (Yes, another T-ball baseball!) – $3
2. A ½-inch lead fishing weight
3. An eye dropper (For older students, one eye dropper per group works well)
4. Red food coloring (Optional – red drink mix powder or any red drink works for this.)
5. 4-inch square of aluminum foil
6. A clear piece of plastic (an overhead transparency works well) or 12-inch square of clear plastic wrap.
7. Kitchen hot pad
8. Hobby knife
9. Classroom paints and markers

This activity requires some preparation by the teacher beforehand, as in our other activities, students will paint and decorate the model before working with it. Depending on the age of your students, you may wish to make more than one lop-sided Moon model. For children in grades 3-6, this works well as a group activity with 2-3 students per group. This is also a discovery type activity, you should not share your preparation of the materials with the students before they begin – they will figure things out soon enough!

Building the Lop-Sided Moon Model

How much your students can do assembling this model is up to the instructor's individual judgement, your class's age, familiarity with tools, and maturity must be taken into account. I have taken a conservative approach and reserved all tasks with tools for the teacher.

1. **[Teacher]** Take the hobby knife and carefully cut out a hollow in the rubber ball just large enough to completely hide the lead fishing weight. If you cannot find any fishing weights, a stack of three 3/8" nuts from any hardware store will do.

2. **[Teacher]** Our next step is to use hot glue to secure the weight inside the ball. Have the square of foil and the kitchen hot pad ready – you may wish to coat the foil with butter, Vaseline, or non-stick cooking spray before you begin!

[Teacher] Put a little hot glue in the bottom of the cavity and carefully press the weight inside – the weight must be completely ***inside the ball*** for this to work properly. Add more hot glue until the cavity is completely full, then put the square of foil on top and press it down with the kitchen hot pad for a minute or two until the glue hardens completely. You should now have a smooth spot that matches the curvature of the ball quite well, and the weight is sealed inside where the students cannot touch it.

Safety Note: Don't ignore the hot pad! Hot glue can easily burn you and the foil will not protect your hand from the heat!

3. **[Teacher]** I recommend painting the ball flat-white before giving it to the students to decorate. Mark a dot where the weight is as one 'pole', place another mark on the opposite side. These points are not poles per se, rather they are ***antipodes***; one marks the point on the Moon closest to the Earth on the near side, the other marks the point on the Moon farthest from the Earth on the far side.

4. Have the students draw a bold, red 'equator' line halfway between the two antipodes you have marked. This will represent the boundary between the near and far sides of the Moon.

5. Students can then decorate their Moon with craters, rays, and maria as they did before. The exact pattern of craters does not matter – let them be as creative as they wish!

Exploring the Lop-Sided Moon Model

1. Now it's time to play! Students will quickly notice that there is something odd about the new Moon model. It doesn't roll straight, and it wobbles when

bounced or thrown! Ask them what is wrong with the model and they will quickly tell you that the ball is lop-sided or off balance!

2. Now ask everyone to roll the Moon model gently on the floor or a table top, you can even try spinning it like a top if you wish. Each time the Moon model will stop in roughly the same position – heavy side down! Have the students label the weighted (downward) side as the ***near side***, and the upward facing side as the ***far side.***

Ask the students which way the near side faces, and they will quickly say "Down!" But what is ***down***? You may point out to them that the ***near side always faces the Earth*** – just as with our real Moon. Why does this happen, children? "Gravity!" Because the Moon model is lop-sided, one side is heavier than the other and the pull of gravity causes this side to always face the Earth. A fact we discovered with an earlier model ***is now explained*** with our new model!

3. Now it is time for the eye droppers and colored water. Since you will be using food coloring, plenty of newspapers to cover the desks will be in order! Have the students take up some of the colored water and try to hang the biggest droplet they can without letting it fall. What shape is this? A tear drop shape, of course – no one will likely be surprised by this. Now ask them ***why*** the water drop isn't round? The answer is gravity once again – gravity stretches the drop from a perfectly round shape into the familiar tear drop shape. Why does the droplet's shape always point the same direction? The answer of course is: ***heavy side down***, just like our model of the Moon.
4. A clever student may point out that the Moon doesn't look like a tear drop! Quite right! Now it's time to use the sheet of plastic (an overhead transparency works very well for this.) Have one student look upward through the plastic sheet while another student makes a hanging droplet of colored water above their head. What shape does the droplet look now? Round! We are now looking up at the droplet exactly as we look up at the Moon far above our heads in the sky![2]

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[2] In fact, the distortion of the Moon's shape is quite small. The near side does indeed bulge and 'hang down' toward the Earth, but only by a few kilometers. This distortion is so small that it took painstaking radar measurements from lunar orbit to detect it! Even so, the distortion is large enough for Earth's gravity to be able to control the Moon's rotation.

Discussion Questions

1. If the Earth's moon is locked into a synchronous orbit by gravity, what do you think we will find when we look closely at other moons in our solar system?

   Answer: Gravity works the same for all things and in all places! NASA has sent long-duration space probes to Mars, Jupiter, Saturn; keeping these spacecraft in orbit around these planets long enough to make detailed studies of their many moons. Every moon in our solar system has its rotational motion controlled by the gravitation of its planet! Although we haven't seen every moon in our solar system, from what we know today this seems to be a universal effect.

2. What would it look like if you were an astronaut on the Moon, looking back at the Earth in the night time sky?

   Answer: Since the near side of the Moon always faces the Earth, any observer on the Moon would simply see the Earth hanging in one place in the sky. It would spin on its axis and change phases every month just as our Moon does, but it would ***never move*** across the sky! The Earth is also four times larger than the Moon, so it would appear 4x larger than the Moon does to us. It would be easy to see oceans, continents, and weather patterns spinning across the globe!

Supplemental Materials

Going Deeper

The idea that just one side of the Moon always faces the Earth is sometimes hard for children to accept. The Earth spins on its axis every day, shouldn't the Moon do the same? One way for children to see for themselves is to observe the Moon carefully over time. The pattern of dark spots or ***maria*** on the lunar surface gives us a clue to what we are actually seeing. If students take a look at a globe of the Earth, it becomes clear that Earth looks very different depending on which side of the globe we are looking at. The same is true of the Moon!

Have students look carefully at the pattern of maria on the Moon as it runs from new moon to full moon. Although the Moon crosses the sky, the pattern of marks and dark maria we see ***never changes***; we never see the far side at all. You can do this with a globe in the classroom – point the Americas toward the students, no matter how you tilt the globe from side to side, the pattern of continents and oceans always remains the same – you are not showing them the opposite side of the globe! Their own observations of the lunar surface should convince them that they never actually see the far side of the Moon.

You can go farther and look up images of the Moon's far side on the internet. It looks quite different! There are very few dark maria on the lunar far side, and the four that are there are quite small and unlike the extensive seas of frozen lava that create the dark markings on the lunar near side!

Being an Astronomer

This is an interesting activity for older, or more advanced students. While a telescope is quite useful, this activity can actually be done by exploring photographs of the Moon on the internet!

Let's explore the idea of ***Libration*** – the slight wobble that the Moon experiences as it orbits the Earth. You might think that since one side of the Moon always faces the Earth, you could only see 50% of the lunar surface. In fact, because of the ***libration*** or wobble of the Moon, you can see almost 60% of the Moon if you are a careful and patient observer.

1. Begin with your lop-sided Moon model and a cafeteria tray (you can also use a cookie sheet for this). Place the Moon on the tray, and gently shake the tray back and forth as you watch the Moon from directly above.
2. If you wish, a classmate can take a video with a smart phone while you shake the tray. As you watch, you will notice that the wobble in your model allows you to see ***past the line*** dividing the near side from the far side from time to time.
3. If you have access to a telescope, take a look at the Moon at 50-100x magnification and pay particular attention to the edges of the lunar disk – even a very small and modest telescope will work for this. Some of the terrain you see at the very edge of the Moon is likely to be part of the Moon's far side!
4. If you do not have a telescope that you can use, check on the internet to see if there is an astronomy club in your area. These clubs often have observing nights that are open to the public. Club members all bring their own telescopes and binoculars, and almost everyone will be happy to point the telescope toward the Moon and show you the lunar surface! Some members may even have lunar maps with them that will tell you the names of some features! Remember to say 'Thank you!' after you've had your turn at the telescope!

Unit 4:

Measuring Time in the Sky

Time is one of the slipperiest concepts in all of science. Everyone feels that they know what time is, but when we try to measure it, we quickly run into difficulties. For early scientists and astronomers, the sky itself served as the first clock and calendar.

The sky above us is constantly changing and full of wonderful objects that never stop moving! As scientists and astronomers, one of our first tasks is to be able to say when and where something interesting happened. The ability to locate things in time and space, both in an absolute sense, and in relation to one another, is a fundamental skill. In this unit, we will explore measuring the Earth-Moon system with time, and then move on to show how science can accommodate different ideas and explanations for the same observations! Only experiments can tell us which model is correct!

Activity 7:

The Earth Clock

The concept of time is intimately connected with astronomy, and more particularly with the spinning Earth. We divide the Earth into 24 time zones, it takes the Sun one hour to move across each one of these zones.

The motion of the sundial's shadow around the gnomon gives is the 'clockwise' direction (turning to the right). This motion is also intimately related to the Earth's spinning motion on its axis.

In today's world of digital clocks and cell phones, the concept of a 24 hour day being related to the rotation of the Earth has become more remote. This activity will bring home to your very modern students that the old fashioned idea of the sundial and the spinning Earth are closely connected with the time we keep.

Academic Standards

Science and Engineering Practices:

Developing and using models

Constructing explanations

Crosscutting Concepts

Patterns in nature

Systems and system models

Next Generation Science Standards

Space systems (K-5, 6-8, 9-12)

The Earth-Moon system (6-8, 9-12)

For the Educator

Facts you need to know

1. The Earth is both our oldest, and one of the most accurate clocks, spinning each day in exactly 24 hours (86,400 seconds!)
2. ***Diurnal motion*** is the daily motion we see as the Sun and Moon rise in the east and cross the sky to set in the west. This is also ***apparent motion***, caused by the rapid spinning of the Earth on its axis – not by any actual movement of the Sun or Moon in space.
3. Unlike our Sun which rises consistently at about the same time each day, the Moon's rising and setting time changes, rising and setting by almost an hour later each day.
4. The time of moonrise and moonset are intimately tied to the Moon's orbital motion around the Earth.

Teaching and Pedagogy

The concept that the measurement of time is linked to the daily motion of the Sun across the sky is a very ancient one. The Sun and Moon are the brightest and most obvious things in our sky and their regular motions and changes make them a natural focus for time keeping. Civilizations around the world have universally developed solar and lunar calendars in their earliest pre-history.

More than 2,200 years ago, a Greek named ***Aristarchus of Samos*** came up with the first known ***heliocentric model of the solar system***. In a time when most educated people believed that the Sun revolved around the Earth every day, Aristarchus theorized that a spinning Earth and a stationary Sun would explain the same ***diurnal motion*** we see in the sky each day as the Sun rises, crosses the sky from east to west, and then sets again.

Most people see, but do not reflect upon the diurnal motions of the Sun and Moon. It is a difficult thing at first, to lift your perception from off the surface of the Earth and envision the motion of the Earth as it spins upon its axis and revolves in orbit around the Sun. The best thing about this activity is that it helps the student extend their perception and envision our world as a planet in orbit around a star.

When we teach these activities to our students, we must take care to help the student see the larger picture. When we help students see beyond the ball and string of the model and make a connection to our solar system and how it works, these changes in perception can be both effective and lasting.

Sometimes in science, we have ***competing theories*** that both try to explain the same thing. We can argue if we wish, but only time, and careful experiments, can settle the issue for good! For older students in 5th grade and up, you may wish to show both theories with your activity. First have the Sun orbit slowly around the Earth which stands still. From the point of view of our Earth observer, the Sun will still rise in the East and set in the West at the correct times each day. After that, do the activity as described above – the Earth observer will see the same motion of the Sun across the sky!

I do not recommend showing competing theories to younger students however, as it can promote misconceptions and be confusing to them!

Student Outcomes

What will the student discover?

1. There is more than one model which can explain why the Sun and Moon rise in the east and set in the west each day. Our experiments with our models will help us decide which theory is best!
2. A common misconception is that the Sun and Moon rise and set at about the same time every day (This is true for the Sun, but not the Moon!) Your students will learn that the Moon's rising and setting time are tied to the Moon's orbital motion and change in a predictable way.
3. Seeing the Moon in the early morning sky is a surprising event that many people find inexplicable. Your students will learn that the ***waxing moon*** is visible in the early evening, while the ***waning moon*** is visible in the early morning – and why this is true!

What will your students learn about science?

Sometimes in science, we have ***competing theories*** that both try to explain the same thing. We can argue if we wish, but only time, and careful experiments, can settle the issue for good! For older students in 5th grade and up, you may wish to show both theories with your activity. First have the Sun orbit slowly around the Earth which stands still. From the point of view of our Earth observer, the Sun will still rise in the East and set in the West at the correct times each day. After that, do the activity as described above – the Earth observer will see the same motion of the Sun across the sky!

I do not recommend showing competing theories to younger students however, as it can promote misconceptions and be confusing to them!

1. ***Competing theories*** sometimes exist in science, sometimes for hundreds of years before the issue is decided. Science has room for more than one idea at a time, and more than one explanation of what we see in nature. Only experiments and data can solve these dilemmas – arguing, or asking 'Which theory do you believe in?' is pointless.
2. Standing on a moving platform (the spinning Earth) can make it difficult to sort out what we see. The spinning Earth creates the ***apparent motion*** of the Sun and Moon crossing the sky each day (also called ***diurnal motion***). Only careful experiments with different scientific models can help us sort out apparent motion from the actual motion of the Sun and Moon in space!
3. The measurement of time is critical to all science. Although the spinning Earth and orbiting Moon made humanity's first clocks, they are by no means our last! Learning about measuring time and motion is a key scientific idea.

Conducting the Activity

Materials

1. A large (3-ft) piece of cardboard – a science fair poster board works well for this.
2. A set of irrigation flags
3. An old baseball cap (adjustable size works best.)
4. Wooden yardstick
5. A large ball to serve as the Sun
6. A yellow vinyl play ball is preferred, but a basketball or soccer ball may be used easily enough.
7. Several 2-ft pieces of rope or strong cord (clothesline cord works well)
8. Markers or paints
9. Construction paper – various colors (optional)
10. Hot glue gun

Building the Earth Clock Model

1. **[Teacher]** Begin by hot gluing the yardstick horizontally across the back of the large piece of cardboard. This keeps the cardboard ridged and makes it more durable. If you

are using a folding piece of cardboard such as a science fair poster board, you can attach the yardsticks with Velcro. This will insure the cardboard piece is still foldable and stores more easily.

2. **[Teacher]** Using a screwdriver, punch two holes in the cardboard (one above the yardstick, one below) at each end of the yardstick. Thread a 2-ft piece of rope or cord through the holes and knot it securely on the yardstick side. Use hot glue to secure the rope in place. This creates handle loops to help students hold onto the device.
3. Take two irrigation flags and mark them as ***East*** and ***West*** (you may also use index cards for this.) Use duct tape to attach them firmly to the back of the artificial horizon so the flag sticks up over the edge of the cardboard and is visible to everyone. When looking at the front (smooth side) of the artificial horizon, the East flag goes on the right side, while the West flag goes on the left side.
4. **[Optional]** Students can decorate the horizon by adding a skyline at the eastern and western edges. These can be drawn on poster board and then cut out and taped or glued in place. This allows the person using the horizon to see the Moon in relation to houses, mountains, etc.
5. Make a 'Time Hat' by cutting out a long arrow (12-15 inches long) from poster board and taping or gluing it to the top of the hat so that the arrow points straight out past the center of the bill of the hat.
6. Mark 12 irrigation flags as follows: 2 am, 4 am, 6 am, 8 am, 10 am, Noon, 2 pm, 4 pm, 6 pm, 8 pm, 10 pm, and Midnight. If you have different color flags, use one color for am and another color for pm. Alternatively, you can staple two different colors of construction paper to the flags and mark them that way. The flags work well in any grassy area.

   Optional: If you do not have a large grassy area to work in, you can cut 4-inch long pieces of 2x4 lumber, drill small holes in them, and hot glue the flags in place. These inexpensive wooden stands will allow the flags to be placed on any floor or hard outdoor surface.
7. Place an irrigation flag in the grass to mark the center of your clock face. Use a cord as a compass (the 7-ft cord from the Earth-Moon system model works well) and mark out a clock face on the ground using the labeled irrigation flags to show the hours. Remember that you are marking a ***24-hour*** clock, so instead of having 12, 3, 6, and 9 at the cardinal points like a standard clock face, you will have Noon, 6 pm, Midnight, and 6 am. Place the other hour markers appropriately.

Exploring the Earth Clock Model

1. With your clock face marked out, half of the circle represents AM (daytime) and half of the circle represents PM (night time). Have a student hold the Sun ball at the Noon position. All is now ready!
2. The student playing Earth must hold the artificial horizon cardboard steadily across their shoulders (rather like a backpack!). The horizon limits their view to 180 degrees (just like the real horizon does) and prevents them from looking behind themselves (we cannot see 'behind' the planet, either!)

   Begin standing facing the Sun, and the Noon flag. Whichever flag they are facing tells the time (they ***are*** the hour hand on our clock!) The first 'day' begins at noon with the Sun directly overhead!
3. The Earth student now spins slowly to the left (anti-clockwise) – this represents the Earth's ***daily rotation*** on its axis. As they turn slowly, they will see the Sun move slowly westward, and finally disappear over the western horizon! What time is it? The Earth clock will say approximately 6 pm. The student may object that they are moving, not the Sun – ***Exactly!***
4. Continuing to spin to the left, the student will see the Sun rise again over the eastern horizon – they will now be facing the 6 am flag – sunrise! Have each student spin through several days so that everyone gets the concept of the ***diurnal motion*** of the Sun – and understands that it is caused by the spinning motion of the Earth and that the Sun does not actually move at all!

Discussion Questions

1. How many hours are there in a day? Is this a natural number (based on some observation) or a human invention?

   Answer: There are 24 hours in the day, but this is purely a human invention. The Babylonians were the first society to divide a circle into 360 degrees, 24 divides neatly into 360, making the hours of reasonable length and easy to measure throughout the day.
2. Imagine that the Earth spun four times faster, spinning on its axis every six hours instead of a leisurely 24 hours. How would things be different for you on this fast-spinning planet?

   Answer: This is a wonderful question for stimulating a child's imagination. In fact, our early Earth did spin 4-5 times faster than it does today, the Moon slowed

Earth's rotation down over billions of years and continues to slow us down today!

3. What would the world be like if the Earth didn't spin at all?

   Answer: This seems like a strange question, but it is a good lead in to ideas we will explore in further units and activities. Before 1600, most astronomers believed that the Earth did not spin and did not orbit the Sun. This idea, called the ***geocentric theory***, was developed by a Greek thinker named Aristotle almost 2,500 years ago. Aristotle proposed that the Earth was ***fixed***, or unmoving and was the center of the solar system

Supplemental Materials

Going Deeper:

We are all familiar with the idea of the ***leap year***, when we add a day to the calendar every four years. We add this extra day because the Earth's orbit around the Sun takes **365.26** days. We have to deal with the extra quarter day by adding a day to our calendar every four years. In effect, we use the leap year to clean up messy fractions that wouldn't work in our calendar!

An interesting variation on this idea is the ***leap second.*** Like the leap year, this idea is used to clean up messy fractions. We say that the Earth's day is ***exactly 24 hours or 84,600 seconds***, but in fact this is not true! Like the Earth's rotation around the Sun, the Earth's spin on its axis does not match our clocks and calendars precisely.

Explore the idea of the leap second; search the internet and see what you find.

1. Is the Earth rotation time shorter or longer than 84,600 seconds? By how much?
2. Is there a regular schedule for adding a leap second? (Remember the leap year happens on a regular schedule every four years.)

Being an Astronomer

Timing the rising of the Sun or Moon can be a reasonable way to time the Earth's rotation! This works best when sunrise or moonrise is straight up off the horizon; for this reason you will get the most accurate results timing the sunrise in June, and the moonrise in December. All this requires is a stopwatch!

Position yourself to see the Sun or Moon rise over a flat edge – the edge of a building works well, students can watch the Sun come up over the roof of their own house on a clear morning!

Start timing when you can first see the edge of the Sun's disk, and stop when the disk is ***completely*** over the edge and clear of the building; this will take about two minutes. Remember that the Sun is blindingly bright – don't stare at the solar disk the whole time, just glance at it occasionally so you know when to stop your timer!

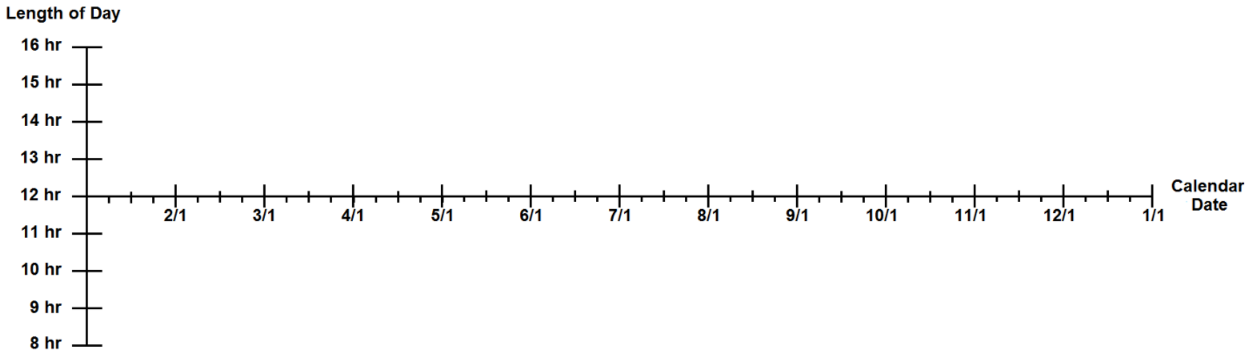
Take the time ***in seconds*** and multiply by 720[3]. The Earth's actual rotation period is 86,400 seconds (24 hours) – how close did you get?

Being a Scientist:

When we think about what a day is, most people think about the time between sunrise and sunset. The problem is that the number of hours of daylight we have changes throughout the year, this is also part of our ***Earth Clock***.

An interesting investigation can be made by graphing the number of hours of daylight for every day of the year. Students can do this by using an app or website to tell them how many hours of daylight each day; or by using a weather website to find the time of sunrise and sunset and working out how many hours each day and then plotting the results on a daily graph.

The graph should look something like this:



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[3] The Moon and Sun are both ½ degree wide. Since there are 360° in a circle, we divide 360 by 0.5 and get 720; in other words, the complete circle is 720x wider that the angular diameter of the Sun or Moon. We take the time of sunrise and multiply by 720 to get the time for a complete rotation of the Earth.

Plot the length of the day in hours on the 1st, 7th, 14th, and 21st of each month. Over the length of the year you should see a beautiful curve formed by the points on your graph. 12 hours is used as the center point of the graph because that represents a day perfectly divided with equal hours of daylight and darkness. These days are called the ***equinoxes***; the name comes from the Latin language, meaning *equal night.* *S*ee how many equinox days you can find in a year.

There are also days when we have the longest and shortest day; these days are called ***solstices.*** The word solstice also comes from the Latin, meaning *Sun stands still.* Can you find the longest and shortest days of the year on the graph? How do these days relate to the seasons? How can we explain these slow and steady changes of daylight and darkness? We will explore these ideas further later in the book!

Following Up

Having a regular place in your classroom where you record days of the week or showing the month and date is fairly common in a classroom. These things help students develop their sense of time, seasons, weeks, semesters, etc. Consider adding some astronomical features to your daily calendar such as the phase of the Moon, the length of the day, or noting equinox and solstice days!

Activity 8:

Moonrise and Moonset

This is a fascinating activity for young and old alike. Everyone is aware that the Sun rises early each morning, the time changes a bit from season to season, but sunrise is remarkably consistent. Moonrise is no such thing! Many people know that the Moon is sometimes visible in the early morning sky, but few people take note that the Moon rises about an hour later each day. If the time of sunrise is so consistent, why is the time of moonrise so variable? This activity answers this question with an exciting ballet of planetary and orbital motion that is sure to inspire everyone in your class!

Academic Standards

Science and Engineering Practices

Asking questions and defining problems

Developing and using models

Planning and carrying out investigations

Analyzing and interpreting data

Constructing explanations

Argument from evidence

Crosscutting Concepts

Patterns in nature

Cause and effect

Systems and system models

Stability and change

Next Generation Science Standards

Space systems (K-5, 6-8, 9-12)

Structure and function (K-5, 6-8, 9-12)

Waves and electromagnetic radiation (6-8, 9-12)

The Earth-Moon system (6-8, 9-12)

Gravitation and orbits (6-8, 9-12)

For the Educator

Facts you need to know

1. We all know that the Earth spins on its axis and the Moon orbits the Earth – but most people don't think about these two motions ***occurring at the same time.***
2. Each time the Earth turns once on its axis (one day), the Moon has moved in its orbit.
3. Because of the Moon's motion, the Earth has to turn a bit more than 360 degrees to see the Moon rise over the horizon each day. This change accounts for the changing times of moonrise each day.

Teaching and Pedagogy

This activity is a complex ballet that involves almost everyone in the classroom. With younger students, you may have to practice the different parts of the activity separately before you can pull the whole thing off; doing activity #5 first will be crucial for them!

It is also important to help students understand that what the person in the center in the Earth position sees is what we all see from here on Earth. Both the daily apparent motion (diurnal motion) and the more gradual orbital motion of the Moon should be apparent to them as they participate in the activity.

Don't worry if the very youngest students don't completely catch on to the entire scientific significance of the activity with all its subtlety! Introducing students to a scientifically accurate concept when they are young will help these ideas to 'click!' when they see them again in a year or two when they are older and more sophisticated thinkers!

Student Outcomes

What will the student discover?

1. The Earth spins and the Moon also revolves in orbit – both bodies are moving at the same time.

2. The combination of the spinning Earth and revolving Moon create changes in the way we see the Moon each night.
3. Being able to imagine standing far off in space (instead of being trapped on the Earth's surface!) makes it easier to understand what is happening and how the Earth-Moon system works.

What will your students learn about science?

1. Keeping accurate time, and recording when things happen, can show us many subtle and interesting things that we might not otherwise notice!
2. Sometimes what we think we see (apparent motion) is not what is actually happening (orbital motion). Only careful experiments and accurate time and record keeping can help us sort things out!

Conducting the Activity

Materials

1. Artificial horizon (See activity #7)
2. A set of irrigation flags with clock hours on them (See activity #7)
3. Sidewalk chalk (for pavement), or 30 unmarked irrigation flags (for a lawn) to mark out the Moon's orbit
4. Sun model – a 12-inch yellow vinyl play ball is preferred ($3), but any soccer or basketball will do.
5. Moon model – a 12-inch vinyl play ball – dark blue or black is preferred, but you can paint any color ball half-black, half-white for this.
6. Ten, 12-inch squares of poster board (construction paper or cardboard may be used)
7. A can of flat-black spray paint
8. A can of flat-white spray paint
9. Markers or paints

Building the Moonrise and Moonset Model

1. Take seven, 12-inch squares of poster board and mark then with large numerals 1-7. If you do not have a separate ball for your Sun model, draw and label a large Sun on another piece of poster board.
2. **[Teacher]** Make a Moon model by masking off half of your dark-colored vinyl play ball with masking tape and newspaper. Prop the ball on an empty soup can and spray paint half the ball flat white. Let the ball dry completely before handling it.

   Note: If the paint on your model does not dry properly, dust it liberally with corn starch and let it sit overnight. Brush off the corn starch with a dry paint brush and your model will be perfectly dry and ready to use!
3. Now take all the pieces of your model outdoors and choose a place on the lawn or playground for the Earth and mark it with chalk or an irrigation flag. Have one student start at the Earth position, and walk two steps away. Stretch a piece of string between the Earth position and this student. Using this string as a compass, mark out the face of the clock, starting with Noon. Remember that this is a 24-hour clock face! Instead of 12, 3, 6, and 9 o'clock, we will have Noon, 6pm, Midnight, and 6am at the cardinal points.
4. Have a student start at the Earth position and walk 4-½ steps away – this is the distance to the Moon's orbit. Stretch a string between the Earth position and this student as a compass. Mark out the path of the Moon's orbit with sidewalk chalk if on pavement, or with a series of irrigation flags about 2 ft. apart if you are on a lawn.
5. Have a student hold the Sun model well outside the Moon's orbit in the Noon position. This will allow the students to see the Moon both in the evening and morning if you continue the Moon's orbit long enough!
6. One student will hold the Moon model, also starting in the Noon position. Remind them to keep the white portion of the Moon pointing in the same direction at all times! With the Moon in this position, the student in the Earth position will see 'new moon' – none of the white portion of your Moon model will be visible.
7. One student will now play the Earth – they get to wear the Time Hat you have prepared! Have this student use the rope loops to hold the artificial horizon against their back (rather like a backpack!) while standing at the center of the circle. Start the student off facing the noon flag – remember to emphasize that ***the student in the Earth position is the hour hand of the clock*** – whichever flag is straight ahead of them – that's what time it is on the ***Earth Clock***!

8. Have a student stand just outside the lunar orbit holding up the "Day 1" poster board to mark the Moon's first position. The stage is now set, time to set Earth and Moon in motion!

Exploring the Moonrise and Moonset Model

1. As the Earth turns slowly anti-clockwise in place (revolving on its axis!), have the Earth student look to their right (over the western horizon). Tell them to **stop** when they can no longer see the Moon – this is ***moonset***! The 'Earth' can now look straight ahead – the arrow on the Time Hat will now point to the correct time of moonset! (This will be about 6pm.)
2. As the Earth continues to spin, the Moon moves one step anti-clockwise around its orbit[4], and another student will mark the position by holding up the poster board denoting the number of the new day.
3. Point out to your students that the spinning Earth will now have to turn just a bit farther than 360-degrees to see the Moon over the eastern horizon again – this is ***moonrise***. When they reach the point where they can see the Moon again – check the Earth clock – it should show about 7 pm. Moonrise has changed by about an hour!
4. Have the 'Earth' take note of the Moon's phase at moonrise on the second day – if the bright side of the Moon has been held in a steady direction, they will see a thin crescent moon!
5. By continuing to advance the Moon each day, everyone can see that the Moon is moving from ***west to east*** in its orbit, making moonrise and moonset time about an hour later each day. But the student playing Earth will see something else – as they spin slowly to the left (eastward!), the Moon will rise over the eastern horizon, and travel across the sky (their field of vision) and set in the west. Each day will also see the Moon's phase increase, the crescent will gradually increase to quarter phase, and then gibbous and full if you continue the activity long enough.
6. Allow as many students as possible to take the Earth position and try this out. There is nothing like being at the center of things to improve your perspective and understand cognitively and kinesthetically that the Earth's spin creates the ***east to west*** motion we see each day, and the Moon's orbital motion creates the ***west to east*** motion that we see over days and weeks.

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[4] When we set up the radius of the Moon's orbit as 4.5 steps, we created a circumference of 28 steps – the same as the Moon's 28 day orbit around the Earth. Each day – one spin around for the student playing Earth - the student holding the Moon model moves one step in orbit.

Discussion Questions

1. Challenge groups to present what they have learned to the class. Give each group two minutes to explain the daily change in moonrise time and give a small prize to the best group.

   Answer: Communicating what we know puts us on the road to true mastery of a subject. It is also an excellent assessment for the effectiveness of the activity. Ask questions of your groups and encourage others to do so as well. By the time you have finished, everyone will have learned a little more about the Moon!

2. It turns out that the Moonrise time advances about 52 minutes each day. Challenge to students to explain why this change is ***less than 1 hour***.

   Answer: This question again depends upon ratios; this time we will compare the ratio of the time for Earth to spin once (24 hours) to the time it takes for the moon to orbit the Earth (28 days.)

   A day has 24 hours while the Moon orbits in 28 days. 24/28 gives us .857, if we multiply 60 minutes by .857, we get 51.4 minutes change per day.

Supplemental Materials

Going Deeper

1. Aristotle said ***the Earth was fixed***; he believed that the Earth was immobile, it neither spun on its axis nor orbited around the Sun. In fact, Aristotle believed that the Earth didn't move though space at all, and his models dominated scientific thinking for almost 2000 years! Use the internet to find some the ancient scientific explanations Aristotle used to try and convince people that the Earth did not move or spin, can you explain why these are not true using what you have learned in these activities?
2. Making an accurate clock was an important scientific quest for many centuries! In fact, scientists today are still striving to make ever more accurate clocks! Can you think of a way to make an accurate clock? Can you build one? [Hint: Start your students looking at pendulums and old-fashioned grandfather clocks. They may also want to investigate Galileo and his ***water clock***!]

Being an Astronomer

It is time to be a backyard astronomer again and take another look at the Moon! Start at the new moon phase and watch over a series of nights to see where the Moon appears at sunset. Watching the Moon at the same time each day will be important for the success of this activity!

Students can use irrigation flags, or even just sticks or small rocks to note where the Moon appears over the horizon each night. Place one flag to mark your observing spot, stand in this same place each night. Standing in your chosen spot, point to the position of the Moon at sunset. Take a 6-foot piece of string and stretch it across the ground and use a flag or stone to mark the direction in which you see the Moon. A parent can help with this!

Over the course of several nights, you will note that the position of the Moon in the sky at sunset moves steadily from ***west to east!*** Our scientific model of the Moon's orbit is confirmed! If the student or parent has a smart phone, take a photo of the diagram you've created after a week or so of observations to show what you have discovered!

Being a Scientist

Scientists often gather data to detect patterns in Nature; you can do this with the Moon as well. For this activity, it is important to have a consistent – and safe! – from which to watch the Moon each night. One easy way to do this is if you have a window that looks to the west; this keeps you inside safe and warm! The best time to do this is ***just after new moon.*** This means the Moon will be visible in the western sky just after sunset.

Watch the Moon set into the west and record the time when the Moon is no longer visible. This may be when the Moon drops below the horizon, or when it goes behind a building; as long as you use the same point of reference each night your experiment will work fine.

Keep in mind that the Moon sets ***later each night,*** you will only be able to get three or perhaps four nights before moonset is too late for you to stay up!

Record the time of moonset each night. After you have finished collecting several days of data, do the math to figure out how many minutes of change you observed in moonset each day.

Our activity predicts a change of about 51 minutes change each day. Can your observations confirm this? How close did you get to this figure?

Following Up

Have you been keeping track on your whiteboard of things like the phase of the Moon and hours of daylight along with the date and day of the week? This can be a great time to add a new feature: tracking the Moon's position in orbit around the Earth.

Make a set of 'orbital magnets' by coloring small circles of cardboard – one yellow for the Sun, one blue for the Earth, and a grey one for the Moon. You can move the Moon around the Earth, changing its position 2-3 times each week. Remember that during one entire week (7 days), the Moon must move 90 degrees in orbit.

Unit 5:

Measuring and Mapping the Sky

Observation and recording what we see in an accurate way is the foundation of all scientific knowledge. Map making is one of the oldest scientific activities, it certainly predates written language and recorded history by many millennia. The oldest known drawings of constellations are on clay tablets more than 15,000 years old; maps of the lunar phases date back more than 30,000 years. Even though map making is a very ancient activity, it is not a natural one. Map making is an acquired skill that requires practice, but with the use of simple tools even very young students can do a remarkable job of it.

Maps are also great teaching tools. Keep in mind that younger students are very visual learners. Young students who possess only basic literary and logical skills often find it difficult to follow ideas or arguments that are presented through language – this is also a fundamental problem for the ESL student.

Maps put information in an easy to understand visual format, as well as putting information into context which helps the student build a mental framework. Helping students to integrate new knowledge in with what they already know can be a daunting challenge. Map making helps make this process easier, and more effective.

Activity 9:

Altitude and Azimuth:
Your Place in the Sky

The focus of this activity is to teach students to use some simple tools, a compass and a protractor. The compass will be used to measure bearing or ***azimuth*** of a distant object such as a tree or telephone pole. The protractor will be used to measure the angle between the horizon and the distant object, this is also called the ***altitude***. The protractor is not the plastic half-circle model you may be thinking of – instead we will use a human arm and a common classroom ruler to measure angles! It turns out that if you hold a ruler at arm's length, one centimeter measures an angle of one degree. [5]

This activity is also best conducted in the daytime, and can even be done indoors although it works best out in the school yard or playground. After your students learn to use these tools properly, the **Being an Astronomer** section will give them an activity they can use to try their new skills out after dark at home in their own back yards.

Academic Standards

Science and Engineering Practices

Planning and carrying out investigations

Analyzing and interpreting data

Using mathematics

Crosscutting Concepts

Scale, proportion, and quantity

Next Generation Science Standards

Engineering and design (K-5, 6-8, 9-12)

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[5] To be mathematically precise, holding a ruler 57.2 cm away from your eye will make 1 cm subtend an angle of exactly 1° – and this corresponds nicely with the length of the average adult human arm. Children's arms are significantly shorter, so the angle measure will be inaccurate in an absolute scientific sense. It is the concept of measuring angles and the technique of using a ruler to measure them that we are interested in here however, not whether or not a 2nd grader is taking technically precise scientific data for an experiment!

For the Educator

Facts you need to know

1. A small magnetic compass can tell us which way we are pointing; this direction or ***compass bearing*** is also called ***azimuth.*** In this system, north is 0^o, east is 90^o, south is 180^o, and west is 270^o
2. How high something is off the horizon is called ***altitude***. We record this angle between the horizon and any object in degrees and measure it with a simple classroom ruler.
3. By measuring ***altitude*** and ***azimuth*** together, we can precisely locate any object in the sky!
4. Measuring angles is typically done with a protractor. We can make a simple device using two rulers bolted together to reproduce angles and record them accurately, allowing us measure them later in the classroom. This will be very helpful in mapping constellations!

Teaching and Pedagogy

Unlike our previous activities, this one is about learning to use tools to measure things. You may be thinking: 'But I already teach my students how to use a ruler and a protractor to measure things!' This activity is fundamentally different.

With this new activity, students can learn to measure things that are too big, or too far away to measure in any conventional way. Learning how to measure distant things like the Moon, the Sun, and other planets and stars is a problem that astronomers have been dealing with for many thousands of years – and we are still working on it today!

Once your students have mastered using the compass and ruler to measure altitude and azimuth, students can apply these skills to actually map the position of the Moon in the sky! The important thing with this activity is to make sure the students ***hold the ruler at arm's length.*** Holding the ruler at arm's length insures that the distance between the eye and the ruler is the same every time. If your students do not do this, their results will not be consistent!

Student Outcomes

What will the student discover?

1. Using a magnetic compass and a ruler to measure altitude and azimuth will allow your students to accurately observe and record the position of any object in the sky whether near or far!
2. Using two classroom rulers fastened together, your students will learn to methodically produce accurate maps of any constellation in the sky, reproducing size and shape accurately.
3. Map making is a valuable scientific skill that requires good observing skills and patience! Accurate maps of constellations help us understand the relative size and shape of constellations – even if they are in very different parts of the sky!

What will your students learn about science?

1. Many students confuse ***observing*** with looking. Observing is a useful and practical skill that is essential to the scientist and astronomer. These exercises will help develop this valuable skill in your students, regardless of age.
2. ***Mapping***, recording the position and size of an object relative to the things around it is another way to make a scientific model. In this case, the model is put down on paper instead of being made of objects, but the principle and usefulness is precisely the same!

Conducting the Activity

Materials

1. Small (at least 1-inch, larger 2 or 3-inch sizes will be easier to use) magnetic compass. If your students have smart phones, there are many compass apps available for free.
2. A Ruler marked in ***centimeters***
3. Sidewalk chalk

Building the Altitude-Azimuth Measuring Device

This activity requires no construction – we are simply learning to use a ruler and compass in a new way!

Exploring and Measuring Altitude and Azimuth

1. **[Teacher]** Take sidewalk chalk out to the play yard and mark an X to identify 10 or so places for students to stand while taking measurements. You may also wish to number these spots and write the name of the target next to the X. A simple worksheet which asks students to record the altitude and azimuth and then describe or even draw the object they are measuring is useful.

2. Have the students stand on a fixed place (X marks the spot!) and hold the compass flat and level in their hands. Now turn toward the target (a distant tree or any other object) and adjust the compass so the N lines up with the compass needle; the direction you are looking toward the object shows you the bearing or azimuth direction.

   Using the compass properly will take some practice. This is often best done in the classroom where everyone can turn to each of the walls and corners of the room and measure azimuth bearings together to be sure everyone is doing this correctly and getting the same results.[6]

3. Once everyone has become familiar with the compass and taking azimuth bearings, it is now time to try measuring altitude. Once again, this can be practiced indoors or out.

   Have students stand on the mark and look toward the object they wish to measure. Hold the ruler at arm's length and count how many centimeters 'tall' the object is. It is sometimes useful for students to work in pairs. One student holds the ruler and sights the object, while the other runs their finger slowly up the ruler. When the finger reaches the top of the object, the observer calls "Stop!" and the measurement is read off the ruler. Record the measurement on the worksheet.

Discussion Questions:

1. If everyone measured the same things, why did we get so many different answers? Shouldn't there be ***one correct answer?***

   Answer: The idea that there can be more than one correct answer can be disconcerting to some! In this case, apart from natural errors in measurement, some children have shorter or longer arms, some may not have stood in exactly the same place when they took their measurements. For nearby objects like buildings and flagpoles, the errors can be significant! Remind the students that

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[6] Keep in mind that metal distorts a compass! Compasses often will not work properly on a desktop because the metal supports beneath the desk will interfere and throw off the reading – this is why we hold the compass in our hands when using it to take a bearing.

this activity is about learning to use tools correctly, not necessarily about getting the right answers!

2. If everyone measures a building or a flagpole so differently, how can we expect to measure the Moon and get a good answer?

   Answer: When we measure things that are nearby such as a building or a streetlight, they are so close to us that moving our position just a little can cause a big change in the measurement. When we measure very distant things like the Moon however, it is so far away that the little distance between one person and another – even across town – will make no change in our measurement.

Supplemental Materials

Going Deeper:

Altitude-Azimuth is only one way of measuring the sky. This measuring system is centered on the point where the student stands. If two students were measuring the altitude and azimuth of Mars in the night sky, their measurements would depend not only on where they were standing, but the exact time when the measurements were taken.

The other principal measurement system for astronomers is called the Right Ascension – Declination system, or RA-Dec. This system borrows from the latitude-longitude system we use to measure our position on the Earth. Unlike the Altitude-Azimuth system, the RA-Dec system does not depend upon the observer at all.

See if you can find a map of the night sky using the RA-Dec system. What similarities do you see between this and the latitude-longitude system we use on Earth? What advantages would this system have for astronomers?

Being an Astronomer:

Now that your students have learned to measure altitude and azimuth, let’s apply these skills to measure and plot the path of the Moon! There are two ways to do this, the one-nighter activity that measures the Moon’s path through the sky over a single evening; and the multi-night activity that measures the Moon’s orbital motion over several days. Let’s look at each activity separately.

Being a Scientist:

Many coordinate systems have something in common – they can use the Pythagorean Theorem to determine distances. Take a look at a star map with lines of right ascension and declination on it. Each hour of right ascension = 15 degrees.

Find two stars or constellations and measure the distance between them in both the right ascension direction and the declination direction. Treat these measurements like two sides of a triangle and use Pythagoras' equation to find the distance.

$$Distance = \sqrt{RA^2 + Dec^2}$$

Following Up:

Ancient cultures used many different ways to measure and mark the positions of objects in the sky. Pyramids, henges, and Sun-circles are just a few. See if you can find out how the Pyramids of Giza in Egypt or the Stonehenge in England were used for astronomy.

Activity 10:

Measuring the Nightly Path of the Moon

There is a misconception that 'doing real astronomy' is difficult and expensive, only highly trained and generously funded people can do it; this book is designed to show that both of these ideas are false. Measuring the Moon's orbital path through the sky is simple enough that a seven year old can do it in their own back yard with a little parental help.

This activity is simple enough in concept, and can be conducted any night the Moon is visible for several hours in the sky; practically speaking, this works best in the week between first quarter moon and full moon. Students will be taking an altitude and azimuth measurement of the Moon every hour for 4-5 hours. At least four separate measurements are needed for best results. The Moon's diurnal motion will be plotted on a simple graph after the measurements are taken.

Academic Standards

Science and Engineering Practices

Asking questions and defining problems

Planning and carrying out investigations

Analyzing and interpreting data

Using mathematics

Obtain, evaluate, and communicate information

Crosscutting Concepts

Patterns in nature

Scale, proportion, and quantity

Stability and change

Next Generation Science Standards

Space systems (K-5, 6-8, 9-12)

The Earth-Moon system (6-8, 9-12)

Gravitation and orbits (6-8, 9-12)

For the Educator

Facts you need to know

1. The Moon's nightly path across the sky is ***apparent motion.*** This movement is actually an illusion caused by the rotation of the Earth.
2. We see moonrise and moonset primarily because the Earth spins on its axis once every 24 hours.
3. When we measure the Moon's nightly motion, we are actually measuring the rotational motion of the Earth.

Teaching and Pedagogy

This activity is certainly about applying the measuring skills that we learned in Activity #9, but it does more than that. This activity allows students to take real measurements and then plot them out on a graph to help them understand what is actually happening in the sky as they watch the Moon sink toward the western horizon.

All too often, graphing is put forward with data that is detached from reality – this activity puts the activity of graphing solidly in the child's realm of experience and allows them to see that mathematics and graphing have a concrete benefit in real-world situations.

Even if you think that the graphing activity is a bit too much for your younger students, you can still take these measurements and plot them on the board together. This activity makes a wonderful introduction to graphing and its power to reveal mathematical truths in an appealing, visual format.

Student Outcomes

What will the student discover?

1. The sky is always changing! The idea that things in the sky are constant and unchanging is a common misconception. By observing the sky over just a few hours, students will see that the objects in the sky move, changing position in a regular way.
2. Math helps us describe the change we see in a clear and precise way. Students often ask: "What do we need this for?" By adding numbers into our lessons in a natural way, we show our students that ***math is good for something***, it isn't just a puzzle to solve and struggle over!

3. Things that look the same are not always identical. The idea of observing the Moon for a few hours one night – and then doing the same observation at the same time over several nights – might seem nonsensical. But there is power in observation, on one night, we see the Earth spinning. Over several nights, we see the Moon moving around the Earth in orbit!

What will your students learn about science?

1. These activities bring home to students that there is no such thing as 'just looking' or 'just measuring'. Just like playing the violin or dribbling a soccer ball, observing and then carefully measuring and recording what you see are skills that require patience and discipline to master.
2. Some students may feel frustrated at first when they try these activities, especially if they do not get the quick and easy results they had been expecting. To be quite frank, some teachers delving into STEM science activities in the classroom for the first time often feel the same!
3. Remind your students (and yourself!) that ***simple isn't always easy***! This elementary fact is a stumbling block for students of every age and academic level. The corollary idea that ***diligent practice brings results*** is also worth teaching – and remembering! As you and your students practice these activities together, your results and consistency will improve over time!
4. Science often does not proceed smoothly. Often there are bumps and missteps along the way. As we have seen with Aristotle's Earth-centered model of the solar system, sometimes these wrong ideas can persist for a very long time! It is good for our students to understand that science is a practical skill, not unlike playing a sport or a musical instrument; it requires some talent, (and lots of practice!) to excel at it.

Conducting the Activity

Materials

1. A ruler marked in centimeters
2. A yardstick, tape measure, or a ruler marked in inches will work equally well – the measurements just need to be converted before plotting them on a graph.
3. A compass for measuring direction.

4. If the student doesn't have a compass, the parent's phone will suffice. Most smart phones already have a compass app on them – if not, there are many free apps of this type readily available.

Measuring the Moon's Nightly Path Across the Sky

1. Begin at sunset by measuring the ***altitude of the Moon*** with a ruler – this is the Moon's apparent distance above the horizon. Hold the ruler at arm's length and measure the distance from the horizon to the center of the Moon's disk.

   If the Moon is too high off the horizon to measure with a simple ruler, try stretching a piece of string from the horizon to the Moon's altitude, tie a knot to mark the length and then measure the string later.

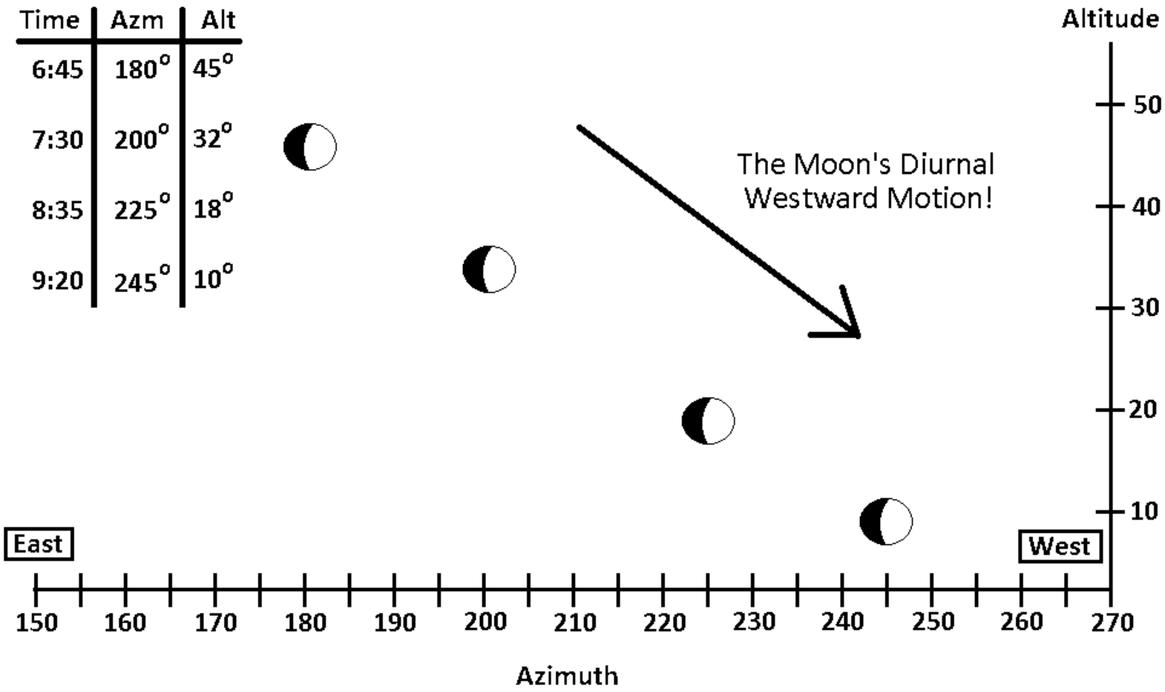
   If your ruler does not show centimeters, that's okay! Just take the altitude in inches and multiply by 2.5 to get centimeters – and degrees!

   Example: The string measures as 18 inches. 18 x 2.5 = 45 cm = 45 degrees altitude!

2. Measure the ***azimuth of the Moon*** with a compass. The easiest way to do this is with a compass app on a smartphone. Point the smartphone at the Moon and read the azimuth angle off the display. If you use a conventional compass, keep the needle aligned with north, then look in the direction of the Moon and find the azimuth bearing. Use the instructions that come with the compass to help you.

3. Repeat the exercise, measuring the altitude and azimuth position 4-5 times. Measurements should be taken at least 45 minutes apart to insure that the Moon has moved measurably. Record your measurements: ***time, altitude, and azimuth*** neatly each time so you can graph them later.

4. The next day in class, plot out your Moon position data on a graph as shown below. You can use color-dot stickers to plot the Moon's position and color in the phase if you like!



Time	Azm	Alt
6:45	180°	45°
7:30	200°	32°
8:35	225°	18°
9:20	245°	10°

Discussion Questions

1. How do the ideas of ***altitude*** and ***azimuth*** fit into this activity?

   Answer: With any graph, we need two measurements to locate a point. In math, we normally label one axis ***x*** and the other axis ***y***. In this activity, the vertical axis is altitude (the distance off the horizon) and the horizontal axis is azimuth (the compass direction).

2. Graphs in math usually show locations (points) or equations (lines), what does this graph show?

   Answer: The ***diurnal*** (daily) motion of the Moon across the sky.

3. What is causing the motion of the Moon that we see in a single evening as it sinks toward the horizon?

   Answer: The rotation of the Earth (The Moon actually moves from west to east!)

Supplemental Materials

Going Deeper

This time, our Going Deeper activity asks our students to change the time scale of the activity. Instead of observing the Moon for a few hours over the course of one evening, this activity asks them to observe consistently for 5-7 successive nights. While this may seem like a small change, the requirement to continue an investigation in a focused way over a longer period of time is excellent exercise for the gifted child, it teaches persistence and resilience as well as scientific facts. You will find precise instructions for this in ***Activity #11.***

It is also useful to know that this activity, although superficially the same, really measures something quite different! Observing the Moon's motion for a few hours over a single evening shows us the Moon's east to west motion which is due to the ***Earth's rotation*** every 24 hours on its own axis.

However, when we observe the Moon at the same time over a period of days, we are now recording something very different. We are now measuring the Moon's ***orbital motion*** as it travels around the Earth each month!

This difference will become apparent when your students plot their data on the graph. Instead of seeing the points move from left to right (east to west) across the paper, the new graph shows the points moving the other direction – west to east! This is because the Moon in orbit actually ***moves eastward across the sky*** as it circles the Earth in space.

Being a Scientist

Part of the power of science is when we add careful numerical measurements to our observations, wonderful mathematical patterns emerge that help us understand, and predict Nature.

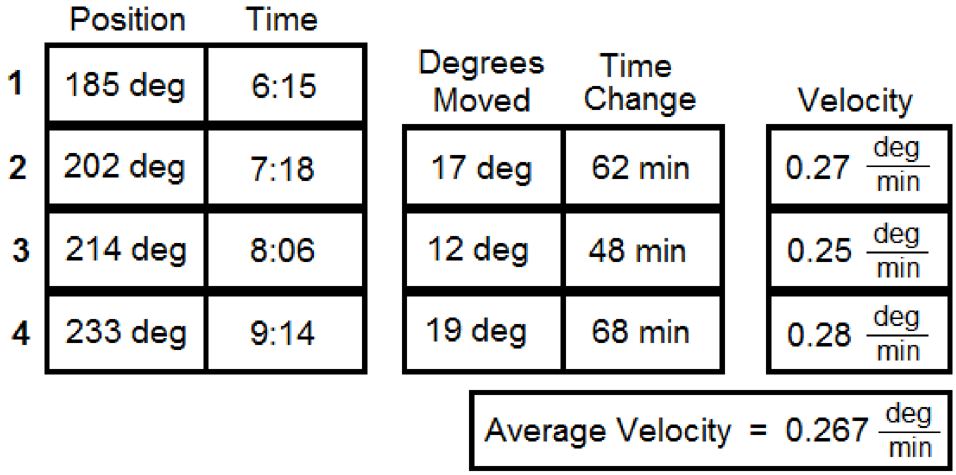
When we see anything moving, one natural question to ask is: "How fast is it going?" There are many ways to answer such a question; it is common to measure speed in either miles (or kilometers) per hour.

This is not the only way to measure speed! When something ***moves in a circle*** like the Moon circling the Earth, we don't measure its change in distance because the Moon is always about the same distance away from the Earth. Instead, we ***measure degrees*** instead of miles or kilometers.

Your activity is already doing this; when students record the compass direction of the Moon in degrees, they are measuring the Moon's position. By adding the ***time of day*** to each observation, they will have everything they need to measure the Moon's ***angular velocity*** in degrees per minute.

Look at the example data chart below. The student records time and compass position of the Moon in the first two columns. To get degrees moved, start with position #2 and subtract the value above – here we subtract 202 – 185 = 17 degrees. Time is treated in the same way – here we get 62 minutes from 6:18 to 7:18.

The Velocity is calculated by dividing degrees moved by time change – here we divide 17 / 62 = 0.27 degrees per minute. Finding similar values in the last column every time gives us confidence that we have made good measurements.



	Position	Time	Degrees Moved	Time Change	Velocity
1	185 deg	6:15			
2	202 deg	7:18	17 deg	62 min	$0.27\ \frac{\text{deg}}{\text{min}}$
3	214 deg	8:06	12 deg	48 min	$0.25\ \frac{\text{deg}}{\text{min}}$
4	233 deg	9:14	19 deg	68 min	$0.28\ \frac{\text{deg}}{\text{min}}$

Average Velocity = $0.267\ \frac{\text{deg}}{\text{min}}$

Remember: if you chart data taken ***over a single evening,*** you are measuring the speed at which the Earth spins. If you chart data taken over several nights, plotting the position of the Moon at the ***same time each night***, then you are measuring the orbital speed of the Moon!

Following Up

Whatever the age level or math level of your students, every one of them can observe the Moon moving in the sky. Watching the Moon sink slowly into the west on a clear night a few days after the new moon can be very gratifying. Students will notice that not only does the Moon move westward, but so do bright stars in the sky. This is observing ***the rotation of the Earth***.

When students later observe the Moon several nights in succession, looking at the same time each night, they will notice something different. Unlike the stars which start out in roughly the same position each night, ***the Moon begins in a different position each night!*** When we observe this, we are seeing the Moon moving ***in orbit around the Earth.***

Activity 11:

Measuring the Moon's Orbital Motion

Try activity 9 again, but this time measure the Moon's position in altitude and azimuth at the same time for several days beginning shortly after new moon, you will find that the graph is similar except that the points move ***eastward*** showing orbital motion and that the phase will change over several days! In order for this activity to be successful, students must remember to take their measurements at approximately the ***same time every day***.

Academic Standards

Science and Engineering Practices:

Asking questions and defining problems

Planning and carrying out investigations

Analyzing and interpreting data

Using mathematics

Argument from evidence

Crosscutting Concepts

Patterns in nature

Systems and system models

Stability and change

Next Generation Science Standards

Space systems (K-5, 6-8, 9-12)

The Earth-Moon system (6-8, 9-12)

Gravitation and orbits (6-8, 9-12)

For the Educator

Facts you need to know

1. The Moon's orbit around the Earth takes approximately 28 days.
2. Because the Moon takes 4 weeks to orbit the Earth once – it takes about two weeks for the Moon to move from new moon (on the western horizon) to full moon (on the eastern horizon.)
3. You will see that the Moon's orbital motion moves west to east – this is in the ***opposite direction*** from its apparent east to west nightly motion.

Teaching and Pedagogy

As we have discussed in Activity #10 above, this activity is very similar. The process of measuring the Moon's position in the sky (Altitude and Azimuth) are identical; the recording of the data will be made on an identical graph.

There ***are differences*** in the two activities, and these need to be emphasized for your students. Activity #10 is a ***one night event***, all the data needed is gathered on one night, preferably just a few nights after the new moon. For Activity #10, students observe the Moon ***multiple times on the same night***.

Activity #11 is different. This activity requires the student to observe the Moon of multiple successive nights – making a single observation at the same time each evening.

This sort of activity requires patience and persistence. There is no way to speed up the process, and neglecting the observations will spoil the data. Each observation takes only a few minutes, but the requirement for the observation to be taken at the same time means that ***parent support*** is needed for this activity.

Looking at it another way, this activity is an excellent way to improve parent involvement! You might wish to present this activity at a Back to School event, and get the parents involved in your school's STEM program.

Student Outcomes

What will the student discover?

1. Observations that look similar don't always yield the same results. Sometimes paying attention to subtle details can yield ingenious discoveries.

2. It is possible to track the Moon's movement around the Earth. The Moon in orbit seems to represent the unreachable in Nature; it passes above us in the skies, but we cannot touch or influence it. Science gives us the ability to track, measure, and understand things that we cannot reach or touch.
3. The Moon actually moves ***eastward*** in orbit around the Earth. Everything we observe in the skies moves ***westward***, rising in the east and setting in the west. It is astonishing to many people to learn that the Moon travels in the opposite direction as it orbits the Earth.

What will your students learn about science?

1. Science rewards the persistent. It is not easy to make observations over several nights, but the reward is the discovery of something astonishing – the Moon travels eastward – unlike most other objects in the sky.
2. Planning and foresight are essential in any scientific activity. These skills pay many dividends in everyday life as well.

Conducting the Activity

Materials

1. A ruler marked in centimeters
2. A yardstick, tape measure, or a ruler marked in inches will work equally well – the measurements just need to be converted before plotting them on a graph.
3. A compass for measuring direction.
4. If the student doesn't have a compass, the parent's phone will suffice. Most smart phones already have a compass app on them – if not, there are many free apps of this type readily available.

Measuring the Moon's Orbital Motion

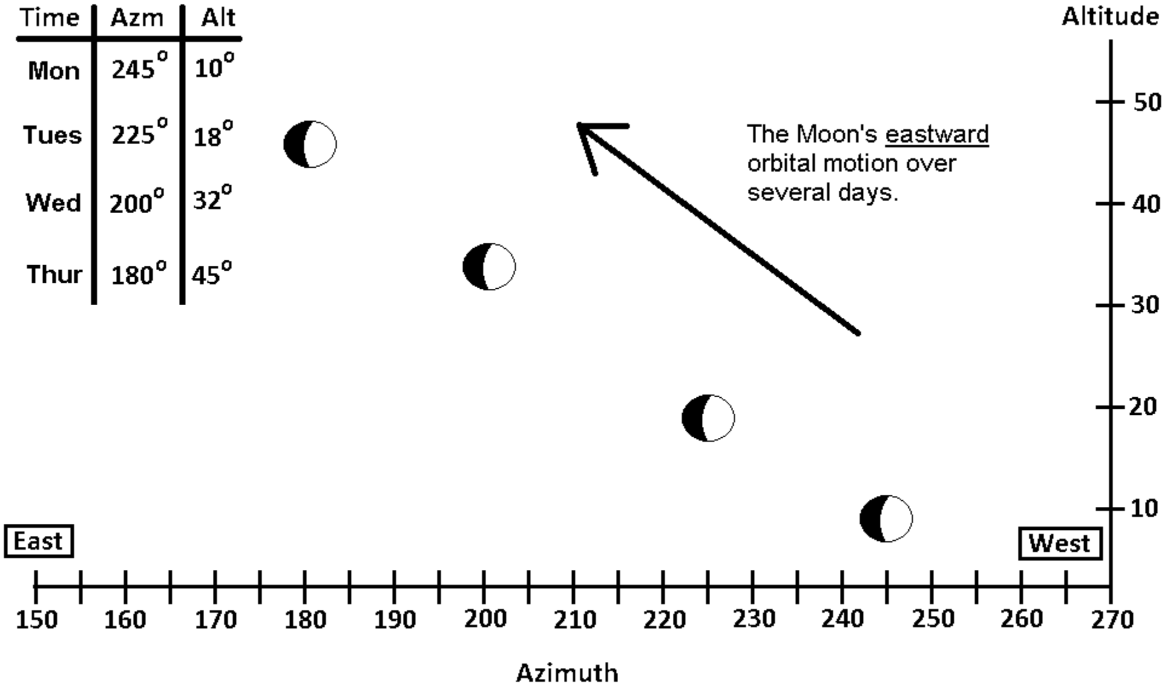
1. Begin at sunset by measuring the ***altitude of the Moon*** with a ruler – this is the Moon's apparent distance above the horizon. Hold the ruler at arm's length and measure the distance from the horizon to the center of the Moon's disk.

If the Moon is too high off the horizon to measure with a simple ruler, try stretching a piece of string from the horizon to the Moon's altitude, tie a knot to mark the length and then measure the string later.

If your ruler does not show centimeters, that's okay! Just take the altitude in inches and multiply by 2.5 to get centimeters – and degrees!

Example: The string measures as 18 inches. 18 x 2.5 = 45 cm = 45 degrees altitude!

2. Measure the ***azimuth of the Moon*** with a compass. The easiest way to do this is with a compass app on a smartphone. Point the smartphone at the Moon and read the azimuth angle off the display. If you use a conventional compass, keep the needle aligned with north, then look in the direction of the Moon and find the azimuth bearing. Use the instructions that come with the compass to help you.
3. Repeat the exercise ***for 3-5 nights in a row***, measuring the altitude and azimuth position ***at the same time each night***. Measurements should be taken as close to the same time as possible each night. Record your measurements: ***time, date, altitude, and azimuth*** neatly each time so you can graph them later.
4. The next day in class, plot out your Moon position data on a graph as shown below. You can use color-dot stickers to plot the Moon's position and color in the phase if you like!



Time	Azm	Alt
Mon	245°	10°
Tues	225°	18°
Wed	200°	32°
Thur	180°	45°

Discussion Questions

1. How does Activity #11 differ from Activity #10?

   Answer: Activity #10 was a ***one-night activity*** that we used to measure the Moon's daily motion. Activity #11 requires ***several nights*** to measure the Moon's movement in orbit around the Earth.

2. Why must we observe the Moon for several days to see its orbital motion?

   Answer: The Moon takes 28 days to circle the Earth once – it moves too little in a single night to measure this change easily.

3. What is causing the Moon to appear to move ***eastward*** over several days?

   Answer: This is the Moon's ***actual orbital motion*** around the Earth.

Supplemental Materials

Going Deeper

It is often valuable in science to repeat an activity a number of times to see if you get the same answer. Getting a repeatable answer is considered to be an indication that the experiment was done correctly and that the conclusions drawn from the results are reasonable.

For this activity, it turns out that once again, things are not as simple as they seem. If you run the activity the first time in the fall semester, it will be instructive to run the activity again late in the spring semester. You will find the results to be quite different!

In the fall and winter, the Moon travels high above the horizon, taking a longer path through the night skies. While in the late spring and summer, the Moon travels a lower path much closer to the southern horizon.[7]

The reason for this is the ***tilt of the Earth's axis***. We shall examine this idea later in the book.

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[7] This book is written for teachers and students in the ***northern hemisphere***. If you are teaching in the southern hemisphere, the situation will be reversed. The summer moon rides very high above the northern horizon, while the winter Moon stays closer to the northern horizon as it crosses the sky.

Being an Astronomer

Ancient astronomers paid great attention to the ***constellations of the zodiac.*** These 13 constellations lie along the path of the Moon, Sun, and planets as they move across the sky.

Many smartphones have apps available that allow you to point the phone at the sky and see a map of constellations. These applications help people identify constellations, planets, and find the names of stars in the sky.

Try using one of these applications and identify which constellation the Moon lies in as you observe it for several nights. The fact that the Moon lies in different constellations as you observe it over several days is ***additional confirmation*** that the Moon is really moving in orbit around the Earth. Add this constellation data to your graph of the Moon's orbital motion!

Want more challenge? Leave the smartphone alone and try to identify constellations from the patterns of the stars and a star map. Excellent monthly star maps are available on line for free.

Being a Scientist

Once again, we ask the question: "How fast the Moon moving in orbit?" This time we will not be measuring degrees per minute, but rather how many ***degrees per day*** does the Moon move in orbit?

Look at the example data chart below. The student records the day and compass position of the Moon in the first two columns. To get degrees moved, start with position #2 and subtract the value above – here we subtract 272 – 285 = -13 degrees (the negative value indicates ***eastward motion***.) Time is always 1 day because we observe the Moon at the same time each evening.

The Velocity is calculated by dividing degrees moved by time change, here the time change is always 1, so the degrees moved is the same as the velocity. Finding similar values in the last column every time gives us confidence that we have made good measurements.

	Position	Day	Degrees Moved	Time Change	Velocity
1	285 deg	Mon			
2	272 deg	Tues	13 deg	1 day	$13 \frac{\text{deg}}{\text{day}}$
3	259 deg	Wed	13 deg	1 day	$13 \frac{\text{deg}}{\text{day}}$
4	245 deg	Thur	14 deg	1 day	$14 \frac{\text{deg}}{\text{day}}$

Average Velocity = $13.3 \frac{\text{deg}}{\text{day}}$

For our last step, determine how long it would take the Moon to orbit the Earth at this speed. To do this, divide 360 degrees by the average velocity. Here: 360 / 13.3 = 27 days per orbit. Any value between 25 and 30 days per orbit is a reasonably good match to the true value of 28.3 days.

Following Up

The two moons of Mars, Phobos and Deimos, are an interesting comparison to Earth's moon. These two moons move around Mars at very different speeds from each other – and much faster than Earth's moon.

What can you find out about the orbital period of Phobos and Deimos? Why are they so different from each other? What controls the speed of a satellite in orbit?

Activity 12:

Measuring the Earth with Eratosthenes

An ancient Greek astronomer named ***Eratosthenes*** was the first man to measure the size of the Earth accurately. His method was very simple: he measured the angle made by a shadow cast from a vertical stick in two different cities on the same day and time. With the help of another teacher, you can recreate Eratosthenes' experiment and your students can measure the size of the Earth for themselves! All you will need is two yardsticks, a protractor, a magnetic compass, and a bit of string.

Academic Standards

Science and Engineering Practices:

Asking questions and defining problems

Planning and carrying out investigations

Analyzing and interpreting data

Using mathematics

Constructing explanations

Argument from evidence

Obtain, evaluate, and communicate information

Crosscutting Concepts

Scale, proportion, and quantity

Systems and system models

Next Generation Science Standards

Engineering and design (K-5, 6-8, 9-12)

The Earth-Moon system (6-8, 9-12)

For the Educator

Facts you need to know

1. The Earth's circumference was first accurately measured more than 2,200 years ago by a Greek astronomer named Eratosthenes.
2. Eratosthenes method was very simple; he measured the length of a shadow from a vertical stick of a known height in two cities on the same day. The ratio between the north-south distance between the two cities and the angles measured gave a ratio which allowed Eratosthenes to calculate the size of the Earth.

Teaching and Pedagogy

This is a wonderful example of practical geometry and a powerful introduction into ancient cultures; the activity is not just STEM, but cross-curricular as well. It is a common misconception that just because cultures were ancient, they must have been primitive or simplistic. We often confuse technological sophistication for learning and knowledge. The activity where students actually work together with children from another school is living proof that this is not so.

This activity is also another example of the practical application of mathematics. Math needn't be complex or totally divorced from reality; children actually respond and learn better when mathematics are presented in a real-world concept. I can think of no more dramatic answer to the perennial question: "What are we gonna use this math junk for anyway?" than to say: "We're going to measure the size of the Earth today!"

Student Outcomes

What will the student discover?

1. This is a lovely project for many reasons; as with Activity #10 and #11, students are able to use simple methods to do amazing things, in this case to measure the entire Earth.
2. Eratosthenes measured the Earth to within 2% of the modern measured value. Using a stick, protractor, and a piece of string you students can easily do as well.

What will your students learn about science?

1. Science is a cooperative venture. Without the help of student scientists at another school, this activity is not possible. Even though the activity itself is extremely simple (measure one angle at a specific time of day,) without cooperation nothing is gained.

Conducting the Activity

Materials

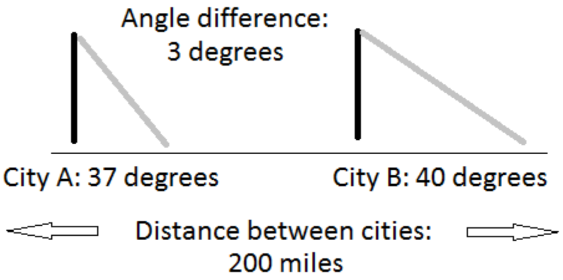
1. A meter stick
2. String or twine
3. An accurate protractor

Measuring the Earth with Eratosthenes

1. The first step is to contact another teacher at your same grade level who lives at least 100 miles directly north or south of you – farther apart is better for this experiment. A direct north-south line between the cities is also important for this, you will need to know as exactly as possible how many miles north or south of you the other school is as opposed to the direct mileage between the cities. Look a map and select a likely city, research their schools on the internet and reach out to someone by email and send them an invitation to join your class in this exciting project. It may take one or two tries, but I bet you can find a partner without too much difficulty!
2. When the big day arrives, send an email in the morning to be sure you have sunny weather in both cities. A few minutes before noon, set up the yard sticks in the playground area. One stick should be held vertically, (use a small carpenter's level for this). Use the compass to lay out the second yardstick flat on the ground so that it points directly north. You have now made a simple sundial! Watch as the shadow moves clockwise; when the shadow lies directly along the flat yardstick, measure and record the position where the tip of the shadow falls. Depending on your location and the time of year, the shadow may extend past the end of the flat yardstick – that's okay, just mark its position with some sidewalk chalk.
3. Now that you've marked the tip of the shadow, stretch a piece of string from the top of the vertical yardstick down to where the tip of the shadow touched the ground. Measure the angle between the vertical stick and the string with a protractor as accurately as you can and record it. Email this information to each other – it will be the ***difference between the angles*** that will be important for this activity!

4. Eratosthenes believed that the Earth was round, and so the angle of the Sun in the sky would be different depending on how far north you were from the equator – and he was right! By setting up a simple ratio and proportion between the difference in the two angles and the distance between the cities, he was able to accurately measure the circumference of the Earth for the first time about 2,300 years ago. Eratosthenes' calculation for the size of the Earth was accurate to within about 2% of our modern value, how close can your students get? Set up your calculation as shown below!

Eratosthenes' experiment to measure the Earth!



$$\frac{\text{360 degrees}}{\text{Angle difference}} = \frac{\text{Size of Earth}}{\text{Distance between cities}}$$

$$\text{Size of Earth} = \frac{\text{360 degrees} \times \text{Distance between cities}}{\text{Angle difference}}$$

$$\text{Size of Earth} = \text{24,000 miles}$$

5. The actual circumference of the Earth is 24,900 miles. The example above was done by my own students several years ago and shows a value within 4% of the true size of the Earth – pretty good for kids using some string and a protractor! How close will your students get!

Discussion Questions

1. Eratosthenes obviously didn't have a telephone or the internet, how do you think he managed to do this activity in ancient Egypt? (Egypt was then part of the Greek/Macedonian empire.)

   Answer: Eratosthenes did not take both measurements on the same day! The astronomer took a measure of the solar angle in the town of Syene in southern Egypt on the summer solstice. He then walked to the town of Alexandria in northern Egypt and carefully measured the distance along the way and measured the solar angle again on the summer solstice in the following year.

2. We sometimes think of ancient peoples as 'primitive' or even 'ignorant'. What do you think of the ancient Greek culture of Eratosthenes now that you know that people in this era were able to measure the size of the Earth and Moon, and even measure the distance between them accurately?

   Answer: The ancient cultures were not all ignorant or primitive! Many cultures have had 'dark ages' where learning was not advanced, but ancient cultures were in many ways remarkably advanced!

Supplemental Materials

Going Deeper

Understanding what is happening when we measure the solar angle at two different locations, and how this helps us measure the Earth, is a masterpiece of scientific thinking. Sometimes the power of a simple experiment or argument are difficult to grasp.

One of the ways to comprehend the thinking of Eratosthenes is to draw the Earth and Sun, showing the angles between the Earth's core and the lines representing the rays of the Sun. See if you can understand Eratosthenes ideas this way!

There are many drawings of Eratosthenes ideas on the internet to help you!

Being an Astronomer

Measuring the solar angle with a stick, string, and protractor is another exercise that can show how the sky changes through the seasons. If your students can measure the solar angle once a week and keep a running record of the results, you will find that the solar angle changes measurably through the seasons.

Can you find a relation between the solar angle and the season?

Being a Scientist:

Climatic change is a hot topic in research and political debate these days, but climate doesn't just change slowly over centuries. The climatic change of the seasonal weather caused by the change in the solar angle is both powerful and measureable.

If your students keep a running record of both the solar angle and the average high temperature for each week, and interesting relationship will be revealed.

Create two graphs, one showing the solar angle over time, the other showing the weekly average high temperature over time. Compare the two graphs; what do you find?

The Sun is the most powerful factor in our climatic change. By comparing solar angle to temperature fluctuations, we can find a powerful link between how much sunlight we receive and our local temperatures.

Following Up

Ancient scientists like Eratosthenes, Pythagoras, Aristotle, and many others contributed to our modern scientific knowledge. Look into some of the ideas and discoveries of these ancient masters and see what you can find!

Activity 13:

Mapping the Constellations

One of the most fundamental activities of science – and exploration – is to record what we see. Map making is perhaps the oldest expression of this human need to record what we know and share it with others; it long predates other scientific activities and even predates written language.

When we want to make a map of a place where we live, such as our school neighborhood, or even make a map of a place we have been to, such as a summer vacation spot, that may be one thing. How do make a map of a place so far away we can never possibly go there? How do we make a map of the stars? Fortunately, this is not as hard as it sounds! Once again, science extends our reach and allows our minds to go where our bodies could not possibly follow.

The device that we will build is called a ***pantograph.*** This device is based upon an old-fashioned drawing tool that allowed the user to copy down drawings and make them different sizes without distortions. We will use our pantograph to accurately copy the constellation patterns that we see in the sky. All we need to do is measure distances between points with a ruler, and copy down angles!

Academic Standards

Science and Engineering Practices:

Planning and carrying out investigations

Analyzing and interpreting data

Using mathematics

Obtain, evaluate, and communicate information

Crosscutting Concepts

Patterns in nature

Stability and change

Next Generation Science Standards

Earth's place in the Universe

For the Educator:

Facts you need to know

1. Seeing patterns of stars (constellations) and naming them is an ancient activity. We have evidence recorded in clay tablets over 15,000 years old documenting and naming star patterns. Almost every ancient and modern culture has done this.
2. The sky has 88 modern constellations that cover the entire visible sky the way states or countries cover a map – there is no space between them.
3. From the continental United States and most of Europe, we can see about 65 constellations – those constellations that lie closer to the southern celestial pole are visible only to those who live in the southern hemisphere.

Teaching and Pedagogy

While very young students may have difficulty with the manual dexterity needed for this activity, older children between grades 3-6 should be able to handle it easily. Once again we see that simple methods can produce beautiful and accurate results. This lab activity will also underscore the idea that observing and recording what you see in an accurate way is a definite skill. It is not always easy to determine which students in your class will be the most skillful at this sort of work, the results may surprise you!

For your students, the idea that they can make beautiful and accurate maps of constellations without a camera or a telescope may amaze them. This method is actually an example of 16th century technology that was used by Danish astronomer ***Tycho Brahe*** (Tee'-kō Bra'-hey).

Tycho is considered by many to have been the greatest observer in history, without the use of a telescope or camera, he mapped the positions of the stars and planets so accurately that their positions were known to an accuracy of 1/5000th of a degree! These measurements were used years later by his assistant, German astronomer ***Johannes Kepler*** to prove that the planets orbited the Sun in elliptical paths instead of circular ones.

Student Outcomes:

What will the student discover?

1. Human beings are very good at recognizing patterns in Nature, for millions of years our survival depended upon it. Humans are so good at finding patterns, that we tend to see them even when they are not there; anyone who has played the "What does that cloud look like?" game has seen this pattern recognition ability in action.
2. Constellations are patterns we see in the stars. Different cultures recognize different objects when looking at the same stars. The constellation pattern we call the 'Big Dipper' in America is called 'The Plough' in Britain, and 'The Ax' by some Native American cultures.
3. Part of discovery is the naming process. A biologist who discovers a new species of beetle, an astronomer who discovers a new asteroid, all discoverers are granted the privilege of naming their discoveries. When children discover and record a new pattern of stars, they can name their discovery, too.

What will your students learn about science?

1. The first task of any scientist is to observe accurately and record what they see. Accurately recording the positions of things you see relative to one another creates a map – perhaps the oldest and most fundamental type of scientific model! Astronomers from many cultures around the world have been making maps of constellations to help them create calendars and predict the changing of the seasons for many thousands of years.
2. We have evidence of constellation maps recorded in clay tablets from ancient Persia that are more than 15,000 years old. Many scientists believe that structures such as Stonehenge were actually maps and calendar measuring devices made of wood and stone that helped pre-historic mankind mark the constellations and measure the changing of the seasons.
3. Scientific models, whether we build them physically, create them on paper, or record them in the language of mathematics all serve to help us understand the world we live in. Learning to create these scientific models in any form can be a valuable job skill – and an exciting career!

Conducting the Activity

Materials

1. Two flat, wooden classroom rulers for each student, marked in centimeters
2. One 3/16 x ½ bolt and a lock washer and wingnut to match for each student (The local home improvement center can easily help you with this!)
3. Electric drill with 3/16 – ¼ inch drill bit
4. 6 pieces of large butcher paper or craft paper, each appx. 30” x 48”
5. Construction paper, pencils, markers

Building the Pantograph:

1. **[Teacher]** Use the butcher paper and draw six constellations on paper and label them. This works well if you use well-known and recognizable constellations such as ***Ursa Major*** (The Big Dipper), ***Orion*** (The Hunter), ***Gemini*** (The Twins), etc. Draw in the brightest stars (make the dots large – 1” or better) and connect them with clear lines drawn in with a heavy marker.

   Place these constellation diagrams around the room well up on your classroom walls where they can be easily seen. If you haven’t much wall space in your classroom, these often work well when posted in the hallways or even outside the classroom on the building wall.

2. **[Teacher]** Now you must attach two rulers together using the bolt and wingnut. Some rulers come with holes near one end, if yours do not have this you will have to drill the holes. Rubber band two rulers together and drill a hole about ¾ inch from one end – be sure you have a block of wood behind the rulers as you drill to keep from marring your classroom tables! If you are really on a budget, try using cheap yardsticks from the paint department at the home improvement store – each one can be cut into three inexpensive, 12-inch rulers!

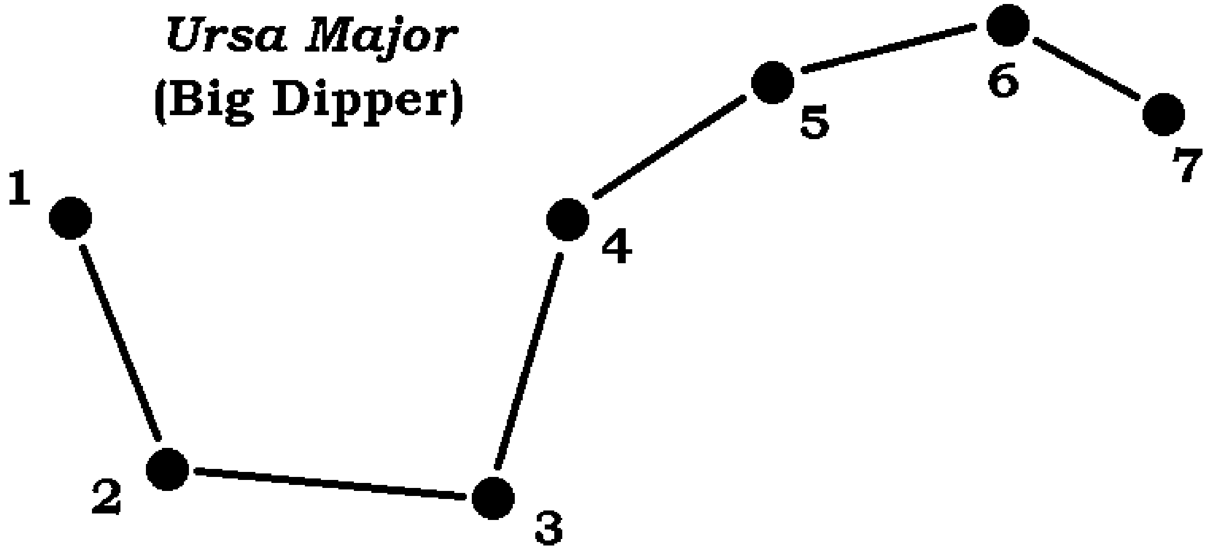
3. With the hole drilled, slip the bolt through the hole and secure the rulers together using the wingnut. This needn’t be over tight, students must be able to slide the rulers apart

to form an angle. If the rulers slide too easily, try putting a piece of stick-on felt between the rulers for added friction.

These two rulers form a simple ***pantograph***, a device for copying shapes and angles precisely.

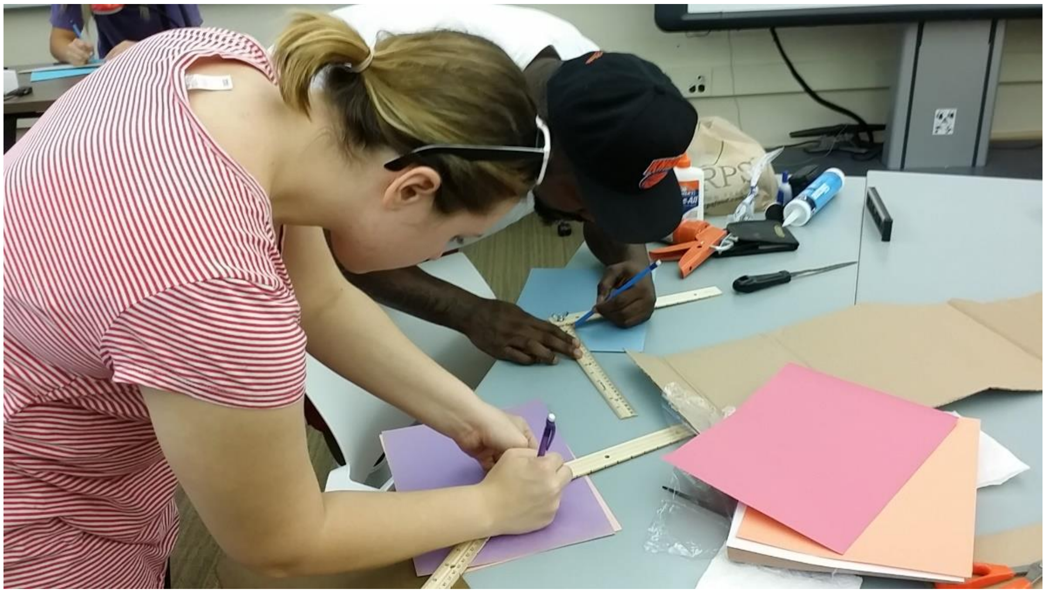
Using the Pantograph to Record Constellations:

1. To copy and map a constellation, we need only look at three stars at a time. Any three stars will form an angle, with the center star at the vertex of the angle. Let's take the Big Dipper as an example, see figure below.



Constellation diagram of *Ursa Major*

2. Have your student stand 8-10 feet back from your Big Dipper poster – have them hold their rulers at arm's length, if the line between stars #1 and #2 appears to be 4-6 cm long, they are at the right distance. (You can try this yourself to help them!)
3. Now adjust the two rulers so that star #2 is at the center, and they can measure the distance to the other two stars simultaneously. Now ***without adjusting the angle between the rulers***, transfer the measurements to a piece of construction paper.



4. Next measure the angle and distance between stars #2 – #3 – #4. Transfer this angle and distance to your paper, which adds star #4 to your map. Continue to proceed along the diagram until you have measured and mapped all seven stars in the constellation.

Discussion Questions

1. We have some constellation maps that are over 15,000 years old! How do you think those ancient people made these constellation maps?

   Answer: The most ancient constellation maps were etched into clay slabs and then fired to make a permanent record. These astronomers probably sketched what they saw as an artist would. By the 1300's, astronomers were using methods very much like those you just used! Modern astronomers use photographs from telescopes and satellites and even computer software to help them make even more accurate maps!

2. What else could you use this mapping method for?

   Answer: Interestingly, this method is based upon the ***pantograph*** – a device that allows an artist or illustrator to copy a drawing and even change its size in a precise way. Your star-mapping device can be used to map any object where there are distinctive points. Try mapping a school building! Just remember to number the points and measure them in ordered sequence one after the other!

Supplemental Materials

Going Deeper

Most constellations have a connection to mythology, the constellations of the Zodiac are good examples of this. Look at a star map and pick a constellation that interest your students. Try doing an internet search or looking in a book of myths and legends to see if you can find more information about what the constellation is supposed to represent.

Being an Astronomer:

If your students have had good success with mapping constellations on the walls of your classroom, it is now time for them to try the same activity at night with a real constellation. It will not matter which constellation they choose, and in fact, students often have trouble picking out the constellations unless there is someone knowledgeable there to help them!

Lack of constellation knowledge won't matter a bit – constellations are just arbitrary patterns chosen by people anyway. Any group of bright stars your students choose can easily be measured and recorded accurately on a piece of paper from their back yard. Have your students bring their results back to the classroom. If the children do not know the name of the constellation – have them make one up and tell everyone what these constellation represent to them. Hang these masterworks on your classroom walls for everyone to enjoy!

Being a Scientist:

When you use your pantograph to map a constellation, you should be holding the device at arm's length to make sure the constellation will fit on a single sheet of drawing or construction paper.

After you have drawn the constellation, use a ruler to measure the distance between the stars ***in centimeters*** – write the length down on the lines defining your constellation. The reason that we do this is simple, at arm's length (57.2 cm to be precise) one centimeter of length also measures ***one degree of arc***. This is called ***angular distance***, and it is the way that we measure size of, and distance between, objects in the sky.

How large are your constellations? If you measure the distance from the center of one constellation to the next with a ruler at night, how far apart are they? Keep in mind that the sky is 180 degrees wide from horizon to horizon; this will give you a better idea of how large the constellations are compared to each other, and compared to the size of the entire sky.

Following Up:

We assume the stars are unchanging, but in fact they are not. The constellations that we see in the sky start each night about 1 degree farther west. The result is that over a period of months, we see different constellations when we go outdoors after sunset.

Programs such as ***Stellarium*** (free star-mapping software from www.stellarium.org) show us star maps for the sky any night of the year, and for any location on Earth. You can use such software to see how the constellations change from month to month.

Set up the Stellarium software (or any night sky mapping software) to show the evening sky for today's date. Then use the calendar function to advance the date one month at a time. You will notice that the April sky in springtime looks little like the summer sky in July, or the autumn sky in October.

Keep an eye on your own sky at night and watch the constellations change from month to month. You will say goodbye to old friends as they sink in the west and welcome new constellations as they rise out of the east as the seasons go by!

Unit 6:

Exploring Gravity

Gravity is one of the most fundamental, and most mysterious, forces in our universe. There is an adage in astronomy that "*Gravity controls everything*." Gravity was first explored mathematically and scientifically by Galileo in the early 1600's. It was Galileo who first realized that gravity acts on all things equally and that everything falls at the same rate regardless of its mass. Galileo also explored gravitation using ramps and pendulums – something that even the youngest students can experience and begin to understand in school today.

The function of gravity on the solar system was largely unknown until Isaac Newton proposed his ***theory of universal gravitation*** in 1665. Newton's theory says that all things possess gravity and attract each other across space. Therefore while the Earth's gravity attracts you and holds you on the surface, your gravity also attracts the Earth! Newton also proved mathematically that gravitational force controlled all the orbits in our solar system – both those of planets going around the Sun as well as the orbits or moons around various planets. In fact, it was the falling apple that led Newton to prove that the Moon is really falling in its orbit around the Earth. Newton used his ideas to propose that artificial satellites were actually possible some 300 years before anyone actually launched one into Earth orbit.

The concept of what gravity actually is remained mysterious until Albert Einstein figured it out in his ***Theory of Relativity*** which was developed between 1905 and 1915. Einstein argued that space and time are actually one unified thing called ***spacetime***. According to Einstein, it was the curvature of this spacetime that really creates the gravitational force that produces the effects studied by Newton and Galileo. While Einstein's theory is well beyond most of us mathematically speaking, it is perfectly possible for young students to build simple Einsteinian models and explore the concepts of spacetime and gravity in the classroom!

In this unit, the activities we attempt will be arranged ***historically***; that is, we will try some of Galileo's ideas first, then explore Newton, and finally Einstein. What? You didn't think you could teach 21st century science to elementary school children!? Yes, ***you can!*** Let's get started!

Activity 14:

Galileo Explores Gravity with Pendulums

Legend has it that a young Galileo observed the swinging of a censer in church one day and noted that the incense burners kept swinging in time with each other as long as the chains that held them were of the same length. Galileo constructed his own pendulums and continued to experiment with them for much of his life. Like Galileo, we have much to learn from a swinging weight on the end of a length of string!

Academic Standards

Science and Engineering Practices

Planning and carrying out investigations
Analyzing and interpreting data
Argument from evidence

Crosscutting Concepts

Cause and effect
Structure and function

Next Generation Science Standards

Forces and interactions (K-5, 6-8, 9-12)
Structure and function (K-5, 6-8, 9-12)
Engineering and design (K-5, 6-8, 9-12)
Gravitation and orbits (6-8, 9-12)

For the Educator

Facts you need to know

1. Everything has its own gravity and gravity is always attractive. (Newton's law of gravity.)
2. Gravity is a property of mass; the more mass an object has, the more powerful its gravitational force will be. (Newton's law of gravity.)

3. Gravity makes everything fall at the same rate, but we can reduce gravity's force, slow it down if you will, by using a ramp or a pendulum. (Galileo)
4. Gravity is created when massive objects like planets pull on and stretch spacetime. (Einstein's theory of general relativity.)

Teaching and Pedagogy

K-8 educators often shy away from topics like gravitation because they feel like the mathematics required will be beyond their younger student's grasp. While this may be true, there is no reason to avoid topics like gravity which can be explored conceptually with low-cost, hands-on activities.

The key to making such activities successful in the classroom is an ***active guidance*** by the teacher that points out key ideas. Students, like everyone else, often see things all the while missing the important facts and ideas. Pointing out these ideas is the teacher's role here; active guidance also helps students avoid forming misconceptions as they explore new activities.

Linking accurate observations with key ideas and explanations is a critical role for the educator. As a classroom teacher, you don't need a mathematically sophisticated understanding of astronomy and physics to conduct successful science activities. You do need to understand a few key facts and ideas, and be able to recognize them and point them out as your students explore and learn.

Student Outcomes:

What will the student discover?

1. How heavy something is makes no difference in how fast it falls. This was very confusing to ancient scientists, and still is to many modern people as well! Aristotle taught that the heavier a thing is, the faster it falls. It was Galileo who first proved Aristotle wrong and showed that all things fall at the same rate.
2. It is the length of the string, not the weight on the end of it which controls how long it takes for a pendulum to swing back and forth.
3. The way a weight swings on a string is intimately connected with ***the way that all things fall.*** We will explore this further in future activities.

What will your students learn about science?

1. Old and established ideas are not necessarily true. We do not owe an idea respect or reverence simply because it is old, but we don't just throw out ideas because they are old, either! Experimental evidence always trumps tradition.
2. There are often subtle connections in science. The idea that a weight on a pendulum string is ***actually falling*** as it swings is both powerful and subtle. Scientists and mathematicians had used and observed pendulums for thousands of years before Galileo discovered this important connection.
3. Often, we can see and describe a pattern before we can understand it mathematically. In this case, our students will be exploring gravity in a powerful conceptual way to prepare them for the mathematical explanations they will be exposed to in years to come.

Conducting the Activity

Materials

1. A ball of string, sturdy thread, or twine
2. 20+ 3/8" metal washers to serve as weights
3. Several large paper clips
4. Wooden or plastic ruler
5. A timer (a stopwatch app on a smart phone works well!)
6. An 18-inch long flat board. This can be almost anything from a piece of sturdy cardboard, to a 2x4, a piece of shelving…
7. [Optional] Three cup-hooks (the sort that hold up coffee cups beneath a shelf)
8. Several rocks of various sizes, from fingernail size to chicken-egg sized.

Building the Pendulum Model:

1. **[Teacher]** Securely screw three cup hooks into one side of your flat board. If you are using a piece of sturdy cardboard (triple thickness of copy paper box glued together with white glue does well!), you should use hot glue or super glue to make sure the hooks will not slip out! The board can now be placed across the backs of two chairs so that pendulum weights attached to the hooks can swing freely.

2. Thread some washers onto three paper clips. 2 washers for the pendulum-A, 5 washers for pendulum-B, and 8 washers for pendulum-C. Tie a 2-ft length of string to each paper clip.

Exploring the Pendulum Model

1. Now ask the class which pendulum will swing the fastest and which the slowest? Ask they to write down their answers and rate them 1-2-3.
2. Now it is time to test our predictions! Secure all three strings to the hooks on the board. The exact length is not important, but use a ruler to insure that all three strings are the ***same length***. Knot the strings securely and trim off any extra string with a scissors.
3. With the board held steady, use the ruler to pull back the weights just a few inches and then release them together as the timer starts. Assign students to count how many complete swings out and back each pendulum makes. The timer lets the clock run for 5 seconds and then calls "STOP!"
4. Note: Do not pull the pendulums back too far – this will interfere with good results. Pulling back 4-inches at most will work best.
5. Most students will be amazed that the light, medium, and heavy weight pendulums all swing at the ***same rate!*** Weight has ***nothing*** to do with the speed of a pendulum! More on this in a bit!
6. Ask your students to figure out a way for three pendulums to swing as different speeds. It probably won't take long for someone to cry out: "Try different lengths!" Redo the pendulums so they all have the same number of washers (5 works well). Change the string on them so you have one short, one medium, and one long pendulum.
7. Ask the students to think and record their predictions on a piece of paper again. It won't take long for them to see that the shortest pendulum races along, while the longest moves at the slowest pace. Length is the crucial factor in pendulum time!

Discussion Questions

1. What was the most surprising thing you learned about pendulums today?

   Answer: Most students are amazed that weight has nothing to do with how fast a pendulum swings. Aristotle's misconception that heavy things must fall faster than lighter ones is still alive and well today!

2. Why are Grandfather Clocks so tall? (Look up an image of one on the internet!)

   Answer: The pendulum on a Grandfather clock is about 2-feet long, this isn't a coincidence! At this size, each swing of the pendulum from one side of the clock to another takes 1 second. The size of the clock is controlled by Earth's gravity!

3. How would you have to change the design of a grandfather clock if you were to build one on the Moon?

   Answer: In the Moon's 1/6th gravity, things fall much more slowly, and pendulums swing more slowly as well. In order to make a clock that tick-tocked once per second, the pendulum would have to be much shorter. A grandfather clock on the Moon would be only about 18-inches tall!

4. What is the main thing that pendulums tell us about gravity?

   Answer: Because a pendulum swings at the same speed no matter how large the weight is, this tells us that everything must fall at the same speed regardless of weight! Galileo referred to this property of matter as ***inertia.*** We will come at this idea again in Activity #16.

Supplemental Materials

Going Deeper

History tells us that Galileo first noticed the relationship between pendulum length and ***period*** (the time it takes for one swing out and back again) by watching and incense censer being swung back and forth during a church service. Galileo went on to investigate gravity with pendulums, ramps, even by dropping various iron weights off the leaning tower in Pisa, Italy!

Our exploration of gravity and pendulums is a simple (and surprising!), event for students. But why doesn't weight cause the time of the pendulum to change? Don't large weights experience more gravitational force than small ones? Shouldn't the larger gravitational force cause them to go faster than the lighter weights? Surprisingly, the answer is no!

Galileo realized that although larger weights experience more gravitational force, they are also harder to move – Galileo called this property of matter ***inertia***. You can try it yourself with a couple of rocks. Take a small rock, perhaps one inch across and see how far you can throw it. Now choose a larger rock, say 4 inches wide and see how far you can throw that! Your arm is just as strong, but inertia makes it harder to get the large rock moving so you cannot throw it as fast – or as far. If you are leery of trying to have your students throw rocks in school (really!?), have them try and throw a rubber T-ball and a basketball on the athletic field.

For our pendulums, it is much the same. The greater weight of the largest pendulum means it is pulled down with much more gravitational force than the lighter pendulum experiences. But the larger pendulum is also harder to move – the force of gravity and the pendulum weight's inertia balance out exactly, and so the period of the pendulum remains the same as long as the length is the same. For our grandfather clock, a pendulum length of 50 cm (20 inches) makes the pendulum tick-tock gracefully with a two second period; one second to swing out, and one second to swing back. A grandfather clock pendulum on the Moon would be much shorter, just 8.2 cm long, because the Moon's gravity is 1/6th that of Earth. On Jupiter, where the gravity is almost 4x that of Earth, a grandfather clock pendulum would have to be 2 meters long, that's almost 7 feet!

Being an Astronomer

One of Isaac Newton's great rivals was fellow British scientist Robert Hooke. Newton had perhaps the greatest mind ever for developing far reaching and sophisticated mathematical models and theories, but Robert Hooke was by far the more practical of the two men. Science needs both types!

After Newton had published his theory of universal gravitation that mathematically demonstrated both how and why planets orbit the Sun in neat elliptical pathways, Robert Hooke upstaged Newton at a meeting of the Royal Society (the British Academy of Science and Mathematics) by demonstrating what is called ***Hooke's Pendulum***, a simple and effective demonstration of orbital motion that you can reproduce in your classroom today.

While Newton had used many pages of complex and sophisticated mathematics using algebra, trigonometry, and calculus proving that planetary orbits were caused by the gravitational attraction of the Sun, Hooke used a simple mechanical model to demonstrate the same effect in seconds using no math at all! Everyone who saw it understood it almost instantly – your students will too!

Being a Scientist

Calculating the period, or cycle time of a pendulum is not terribly difficult; it can be done easily with most any school calculator. It is often interesting, and productive, for the gifted student to grapple with mathematical explanations rather than simply sticking to conceptual ideas.

The formula for the period of a pendulum involves only three numbers, and only one of these needs to be measured. For the purpose of our calculation, we needn't worry about units. Our answer will automatically come out in seconds.

$$T = 2\pi\sqrt{\frac{L}{g}}$$

- We use ***T*** to represent the time or ***period*** needed for a pendulum to swing all the way out and back again. This is measured in seconds.
- We use ***L*** to measure the ***length*** of the pendulum. This is just the length of the string and is measured in meters. If you use measure the string in ***centimeters***, divide your answer by 100 to convert the value into meters.
- π (or pi) is the ratio of a circles diameter to its circumference. This number never changes: $\pi = 3.14$
- ***g*** is used to represent the ***gravitational constant for the Earth***. This is the rate at which things fall when we drop them – it applies to ***all objects***, regardless of size, weight, or shape. $g = 9.81\ \mathrm{m/s^2}$.

1. Begin by taking the Length and divide by 9.81. Write this answer down.
2. Take the square root of the first answer, write this value down.
3. Multiply the second answer by 2, and then multiply again by 3.14.
4. This final answer should be the period of your pendulum in seconds. Measure the period of your pendulum with a stop watch and see how close you get!

   Let's try an example. Let's say your string is 25 cm long (that's 0.25 meters!). You calculate the period like this:

$$T = 2\pi\sqrt{\frac{L}{g}}$$

$$T = 2\pi\sqrt{\frac{0.25\ \text{m}}{9.81\ \text{m/s}^2}}$$

$$T = 1.0\ \text{sec}$$

Following Up

Pendulums are used in many kinds of devices, from scientific and time keeping instruments to musical instruments. Besides the types of pendulums that swing on a string, essentially anything that vibrates back and forth can be considered a pendulum.

A guitar string vibrates back and forth when it is plucked, this back and forth motion is much the same as a clock pendulum – and the mathematics that governs the behavior of vibrating strings and pendulums is much the same. The wings of a fly, even the musical note we make when we blow across the mouth of a partially filled bottle are examples of vibrating pendulums in nature. How many can you think of?

Activity 15:

Hooke's Pendulum

Robert Hooke and Isaac Newton were great rivals both in European science and mathematics, as well as in the Royal Society for Science and Mathematics where Newton was president. Both men were fiercely competitive, and jealous of their work and fame. When Newton published his theory of gravity in the book ***Principia Mathematica***, he struggled and failed to develop a simple and convincing demonstration for the mathematical concept that only a center-seeking force (gravity) and the straight line motion of a mass (momentum) are needed to create an orbit. Robert Hooke's simple pendulum experiment achieved this and was considered a great triumph!

Academic Standards

Science and Engineering Practices

Developing and using models
Constructing explanations
Obtain, evaluate, and communicate information

Crosscutting Concepts

Cause and effect
Systems and system models

Next Generation Science Standards

Forces and interactions (K-5, 6-8, 9-12)

Gravitation and orbits (6-8, 9-12)

For the Educator

Facts you need to know

1. For any body in orbit such as a moon or planet, the force of gravity always pulls toward the center of the primary body. For example, the Earth's gravity always pulls the Moon directly toward the center of the Earth.

2. If you draw a line from the center of the Moon to the center of the Earth, the Moon's momentum is always perpendicular to this. In other words, the Moon's momentum would take it off into space on a straight line. This is true for any body in orbit.
3. It is the combination of straight-line momentum, and a center-seeking gravitational pull that produces a smooth, elliptical orbit. The realization that an orbit required only two things acting on a moon or planet was Robert Hooke's stroke of genius.

Teaching and Pedagogy

One thing that Galileo noted about a simple pendulum – a weight suspended by a string – is that the pendulum mass always passes under its point of rest. That is, if we hang a weight by a string, and mark the point directly under the unmoving weight, we have found the ***point of rest*** for that pendulum. Pull the weight back and release it, the weight will travel straight back and pass over that point, ***no matter which direction we start from.***

You may also notice that if the pendulum is at rest, the string points ***directly to the center of the Earth.*** Any time we drop an object, letting it fall straight downward, the object also falls directly toward the center of the Earth. It is this connection between gravity and pendulums that Robert Hooke noticed and later used in his demonstration.

Gravity always pulls objects toward the center. Every object on our planet falls toward the center of the Earth, every planet is pulled toward the center of the Sun. Gravity is a ***centripetal,*** or center-seeking force. Pointing out this connection between gravity and pendulums will start your students thinking more deeply about gravity!

This is a fun and simple activity, but it seems to fascinate everyone. Students of all ages love to play with this mechanism and see how circular or how elliptical an orbit they can create! My suggestion to you is: let them play! As we have seen before, playing with scientific models is a wonderful way to build deep cognitive understanding of how Nature works. Our job as teachers is not to limit the play, but to reinforce the intuitive learning and help students acquire the vocabulary and fluency to express what they have learned to others (and on assessments!)

If you have a 'Back to School' night or PTA night, even a science fair, this is a great project for students to use to demonstrate what they have learned. The adults who see this will be just as impressed as the children were the first time they saw the demonstration; not because you can make a weight circle a pendulum, but because of the deep links that can be drawn between the pendulum's elliptical motion and the Moon's orbit in space!

Student Outcomes

What will the student discover?

1. Gravity is a ***centripetal***, or center-seeking force.
2. Gravity's center-seeking action is at play whether we consider a pendulum, or a moon in orbit around a planet.
3. Center-seeking gravity and a perpendicular momentum are the only things necessary to produce a smooth planetary orbit.

What will your students learn about science?

1. Sometimes science progresses not because of great friendships, but because of great rivalries. Isaac Newton and Robert Hooke were bitter rivals who competed with each other almost all their lives.
2. Hooke's pendulum is an extremely simple idea. People have wondered for centuries why Newton didn't think of the idea himself, but sometimes genius can be found in simplicity as much as in complexity.

Conducting the Activity

Materials

1. A pendulum weight and a string for each student or group of students (see Activity 13)
2. A piece of paper with a large dot on it (dot stickers, markers or crayons work well)

Building Hooke's Pendulum

1. You can use the same pendulum materials you constructed for Activity #14; a board suspended between two chairs or two desks with a cup-hook attached underneath.
2. Hang your pendulum mass by attaching its string to the hook beneath the board. It is essential for this experiment that the board is sturdy and that it is held firmly in place so that it cannot wobble or move as the pendulum swings.
3. Place a piece of paper with a central dot on the floor beneath the pendulum – it is best if the pendulum weight hangs no more than a few centimeters above the center dot. Now your apparatus is ready to go.

Exploring Hooke's Pendulum

1. Hold the string so the pendulum is motionless with the weight suspended over the dot. Pull the pendulum back a few inches and release the weight carefully.
2. Notice that whichever direction you pull the weight back, the pendulum always swings straight back toward the dot in the center. Hooke said this 'modeled gravitational attraction', that is, like gravity, the pendulum is always pulled toward the center. The Sun's gravitational pull tugs every planet straight toward the center of the solar system in this way.
3. Now try something different: pull the pendulum weight back as before and give the weight a little shove toward the side as you release it.
4. Instead of swinging straight back toward the dot in the center, the weight now ***orbits around the center***. With a little experimentation, the students will find that it is almost impossible to make the weight go around in a perfect circle. Instead, the weight most naturally follows and ***elliptical path***, an off-center oval shape which causes the weight to travel sometimes closer to the center, and then sometimes farther away again.

Discussion Questions

1. How do we know that the pendulum is always pulled back into the center just like gravity?

   Answer: Pull the pendulum weight in any direction you wish. Hold it for a moment, then release it; the weight always swings right back toward the center point! If you drop a rock from anywhere on Earth, it will do the same thing – it will fall directly toward the center of the Earth; we call this 'falling straight down.'

2. Is it really impossible to have the pendulum weight go in a perfect circle?

   Answer: No, just very difficult. You must precisely balance the force of your shove (momentum) with the pull toward the center (gravity). Even if you do this, the friction at the top of the pendulum will slow the weight down and cause it to shift into an elliptical motion in just a few seconds.

3. Is this really the way that gravity and orbits work?

   Answer: Yes. Among other things, Robert Hooke took the time to prove mathematically that his pendulum and an orbiting moon are mathematically identical!

Supplemental Materials

Going Deeper

Robert Hooke lived at the same time as Isaac Newton, but he is far less well known. Some of Hooke's work included designing mechanical devices and the use of the microscope to describe accurately small insects, animals, and cells.

Dive into some of Robert Hooke's work and see how much the little-known man contributed to modern science!

Being a Scientist

The ***elliptical orbit*** (oval shaped) is known to be the universal form for all orbiting bodies in the universe. Circular orbits are possible, but this is an unstable arrangement, like balancing a pencil on its point. As a pencil will quickly fall one way or another if balanced on its point, any circular orbit will quickly decay into an elliptical form.

Can you make a circular orbit using a pendulum? How many rotations does it take before the orbit becomes definitely elliptical (oval) in shape? Experiment with Hooke's pendulum and see what you can find out!

Following Up

Natural orbits are one thing, controlled orbits are another. Do an internet search and see if you can find the flightpath for the Apollo moon missions, one of the Mars rover spacecraft, or the Cassini or Juno space probes. These spacecraft have beautiful and complex orbits, controlled by engines and precise controls either from astronauts or from ground control scientists.

Activity 16:

Galileo's Falling Bodies

One of the first biographies of Galileo describes his famous experiment, dropping iron balls of different weights from the top of the famous leaning tower of Pisa. Galileo sought to prove that all objects fell at the same speed, regardless of their weight. You will recall from Activity #14 that the pendulums were also unaffected by their weight; the only way to change the timed length of a pendulum's swing was to change the length of the string that held it.

Aristotle's scientific model stated that things fell to Earth because the 'wanted to reach their natural place', and that the heavier an object was, the faster it would fall. Although it is simplicity itself to do the experiment that Galileo did, Aristotle apparently never did it. Aristotle's fame was such that no one seriously challenged his assertions for over 2,000 years. Galileo's experiment shows us the utility of gathering accurate observational data and comparing it to the predictions of scientific models. This is the very mechanism through which science corrects its own errors.

Academic Standards

Science and Engineering Practices

Asking questions and defining problems

Planning and carrying out investigations

Analyzing and interpreting data

Using mathematics

Argument from evidence

Crosscutting Concepts

Cause and effect

Next Generation Science Standards

Forces and interactions (K-5, 6-8, 9-12)

Gravitation and orbits (6-8, 9-12)

For the Educator

Facts you need to know

1. All objects on Earth fall at the same rate. This rate is called the ***acceleration of gravity***, on Earth this rate is 9.81 m/sec^2. We use the symbol ***g*** to represent this value.
2. ***Acceleration*** means that the velocity at which an object moves is changing is a steady way.
    a. Acceleration can be either positive (speeding up) or negative (slowing down.)
    b. Earth's acceleration is 9.81 m/sec^2. This means you add almost 10 m/s to your speed every second you spend falling. After 3 seconds falling, you are moving over 29 m/s, that's almost 66 mph!

Teaching and Pedagogy

This experiment, like the pendulum in activity #14, shows us that inertia and gravity are closely linked and balance out exactly whenever an object is falling freely toward the ground. Our old friend ***Aristotle*** famously said that heavy objects fall because ***they <u>want</u> to reach the center of the Earth.***

Aristotle hypothesized that a heavier object would 'want to fall more', and so it would fall faster and strike the ground first if dropped with a lighter object. Aristotle was so very well respected as a genius and a scientist that his ideas were not questioned for almost 2000 years! "Aristotle said it, so I believe it!" was the attitude of learned men and women for many centuries.

Galileo was one of the first people to actively confront the established view and test these ideas with experiments, in fact he wrote an entire book of do-it-yourself experiments that allowed people to prove for themselves that Aristotle was wrong about many things, including gravity and the design of the solar system.

Challenging the ideas of Aristotle was highly unpopular; Galileo was imprisoned for his bold, scientific explorations and spent the last 12 years of his life in custody. If we teach children anything about science with these experiments, it must be that there are no sacred traditions in science. We can, and must, question everything by putting it to the experimental test. Those who say: "Don't you believe?" or "Almost everyone agrees, why don't you!?" are not being true to our scientific heritage!

Student Outcomes

What will the student discover?

1. Gravity causes every object to fall at the same rate toward the center of the Earth.
2. Air resistance can powerfully affect the rate at which a light weight or low density object falls.

What will your students learn about science?

1. There a no sacred ideas in science. No matter who says something is true, no matter how long we have 'known a fact', it must stand up to experimental challenge.
2. Gravity is a powerful and universal force. Gravitation affects everything, pulling it toward the ***center of mass*** (usually the center of a planet or star.)
3. ***Gravity*** and ***inertia*** are closely linked. It is the precise match between gravity (the pulling force between two objects like the Earth and a rock) and inertia (the resistance to movement or force) that makes the constant acceleration of gravity a reality.

Conducting the Activity

Materials

1. Flat board about 18 inches long (See Activity 14)
2. Various rocks, from fingernail size to as big as a chicken egg. (any weighty object will do)
3. A single sheet of paper crumpled loosely into a ball
4. A feather or a dried leaf

Building the Galileo's Freefall Model

This model is simply a flat board laid along the edge of a desk or table. The idea is that two or more objects can be tipped off the board at the same time and allowed to fall.

Exploring the Galileo's Freefall Model

1. Set your flat board along the edge of a table top.
2. Place any two rocks (or other weighty objects) on the edge of the board
3. Tip the board slowly and allow both objects to fall off. Ask students to watch to see which one hits the ground first?
4. Try this with various combinations of weights, then try with a weight and a crumpled piece of paper or a dried leaf. (The rock will obviously hit the ground first.)

Discussion Questions

1. How did Galileo prove Aristotle was incorrect?

   Answer: Aristotle would have said that the heaviest objects always fall faster and hit the ground first.

2. Which results would **agree** with Aristotle? Why do you think this happened?

   Answer: The slowly falling leaf and rapidly falling rock would seem to support Aristotle's viewpoint. In fact, it is the resistance of the air that slows the leaf down, the rock is much denser and is not affected as much. There is a famous NASA video showing Apollo 15 astronaut David Scott dropping a metal hammer and a falcon feather on the Moon; in the airless environment, the hammer and feather both fall together perfectly.

3. What lesson about science does Galileo's experiment teach us?

   Answer: Question everything! No scientific theory is so famous or so honored that it should not be questioned. When a theory makes a prediction, we should gather data to see how that prediction holds up!

Supplemental Materials

Going Deeper

Galileo was known for challenging long held beliefs, primarily the ideas of Aristotle. Apart from exploring ideas about gravity, inertia, and friction, Galileo also challenged the idea that the Earth was ***fixed***, or motionless in space.

Aristotle claimed that if a mountain was too big to be moved, then what force could possibly move the entire Earth? Aristotle also knew the approximate size of the Earth

(24,000 mile circumference) and realized that the surface of the Earth must be moving approximately 1000 miles per hour if it spun on its axis once a day. Aristotle said such a great speed would cause huge hurricane winds – and since we don't feel such winds, the Earth must be motionless.

How would you respond to Aristotle's arguments? How did Galileo do so? Even if you cannot figure out how to counter Aristotle's arguments, does that mean that he was correct about the Earth being fixed in space?

Being an Astronomer

Gravity controls the orbits of all satellites of the Earth, from the Moon down to the smallest scientific, weather, and communication satellites rocketed into orbit. The best time to see satellites is in the first 2 hours after sunset or the last two hours before dawn.

Go outside on a quiet and clear night and sit in a lawn chair so you can lean back and watch the sky comfortably; a dark place away from streetlights will be very helpful. As your eyes adapt to the dark, you may notice that there are some fainter stars which drift slowly across the sky.

Watch them carefully – if they are blinking, these are most likely airplanes high in the sky, flying from one city to another. If these drifting stars do not blink at all, then they are likely satellites moving silently across the sky as they travel in low Earth orbit!

Being a Scientist

Once you learn to spot satellites, you can use a simple ruler to judge their speed. Take a lawn chair out as you did before, but this time take a ruler marked in centimeters, along with some paper and pencil to record your findings. A parent or a partner will make the job much easier!

Once you spot a satellite moving across the sky, hold your ruler up at arm's length and start measuring the satellite's progress. When you begin measuring, tell your partner "Go!" and have them begin timing. Measure the satellite's progress for 20-30 cm if you can, then tell your partner "Stop!" Record the time and distance travelled by the satellite.

With a ruler at arm's length, 1 cm is approximately equal to 1 degree of arc. Divide the distance in degrees by the time in seconds to get the speed of the satellite. Because gravity's force is stronger the closer that you get to the Earth, satellites which are in a lower orbit travel faster! See if you can rank your satellites from lowest to highest in orbit!

Following Up

You might get the impression from these activities that Aristotle’s ideas were all silly or ignorant – nothing could be further from the truth. See if you can research some of Aristotle’s ideas; what did he do to become so famous?

Activity 17:

Packard's Acceleration Ramp

We know that gravity makes everything fall to Earth; everyone has heard the old saying: "what goes up must come down!" But the question remains, ***how*** do we fall? When we jump off a diving board into a pool, there is the rush and then the splash, but what is happening to us as we fall? Why do asteroids strike us at such tremendous velocities, upwards of 30,000 miles per hour; how do such large objects get moving so fast? As we shall see, it is gravity which speeds us up as we fall – we call this speeding up: ***acceleration***.

This activity is a simple one, we use a ramp to slow down the fall of a marble so that we can study it more easily. Galileo, and many other scientists and thinkers through the centuries have used ramps to study gravity. This apparatus was originally developed by John Packard, an American high school science teacher in the early 1900's; you can recreate this simple device in your classroom and learn more about gravity!

Academic Standards

Science and Engineering Practices

Developing and using models

Planning and carrying out investigations

Analyzing and interpreting data

Using mathematics

Argument from evidence

Crosscutting Concepts

Cause and effect

Systems and system models

Next Generation Science Standards

Forces and interactions (K-5, 6-8, 9-12)

Engineering and design (K-5, 6-8, 9-12)

Gravitation and orbits (6-8, 9-12)

For the Educator

Facts you need to know

1. Gravity is a steady and consistent force. Gravity pulls us steadily toward the Earth's center, and just as it pulls the pendulum toward its center point, gravity also pulls the ball down the ramp.
2. The horizontal motion of the ball does not affect its vertical motion down the ramp. Try it! If you release a second ball at the same time that the first ball leaves the ruler and let it roll straight down the ramp, both balls will reach the bottom at the same time!
3. The curved path of the ball is the result of just two things:
    a. The ball's horizontal speed coming off of the ruler.
    b. The angle of the ramp.

    If you change either of these, you will change the shape of the curved path the ball takes. Try this – allow your students to play with the apparatus. Put a mark on the bottom edge of the ramp and see if they can adjust the path of the ball to hit it!

Teaching and Pedagogy

Both Galileo and Newton used ramps to study the effects of falling bodies, but Newton brought a much more mathematically sophisticated approach to the matter, employing algebra, graphing, and even the ***calculus*** which he developed entirely by himself. Ramps are useful in studying gravity because they allow us to slow everything down and more easily see what is happening.

In our activity, we use the horizontal marks on our graph to represent time. This works for us because the ramp is tilted in only one direction (the vertical); it is perfectly flat in the other direction (the horizontal). Because our ramp isn't tilted from left to right, the ball's ***horizontal speed*** is unchanged as it rolls across our ramp; the ball takes the same amount of time to cross each square of the graph from left to right!

Younger children may find this hard to grasp, but it is easy to demonstrate to them (and to yourself!) Place the ramp flat on the table and place a marble on it. Now lift any side of the ramp you wish – which way does the ball run? The ball runs ***downhill*** each time of course. Ask your students why the ball doesn't run sideways when you raise one side of the ramp? The children will be quick to tell you that the ramp doesn't tilt that way – exactly correct!

The curved line lets us see quite easily that the ball speeds up only in the downhill direction – and this is the acceleration of gravity at work! Newton went quite a bit farther of course, he related the acceleration in the fall of an apple to the acceleration causing the orbital path of the Moon to curve around the Earth instead of flying off into space!

Student Outcomes

What will the student discover?

1. Gravity is a steady force that never changes. We can manage gravity's effects with ramps and pendulums, but we can never change gravity itself.
2. Gravitational acceleration is the steady increase in speed as gravity pulls on a falling object. Gravity accelerates things whether they fall freely toward the ground, or roll freely down a ramp or hill.
3. Horizontal motion ***cannot effect gravity***. Things fall or roll down ramps at the same rate no matter how fast or slow they move horizontally. ***Vertical and horizontal motion are independent.***

What will your students learn about science?

1. Once again we see that a simple model can reveal wonderful secrets of nature. Gravity has been studied since ancient times, and yet the Packard Apparatus was not developed until a high school teacher invented it in 1906.
2. Wonderful mathematics lurk in the most surprising places. The curve traced out by the rolling ball is a ***parabolic curve***. You may remember studying parabolas when you took algebra in high school, but you were likely not exposed to these curves in this simple and natural manner.

Conducting the Activity

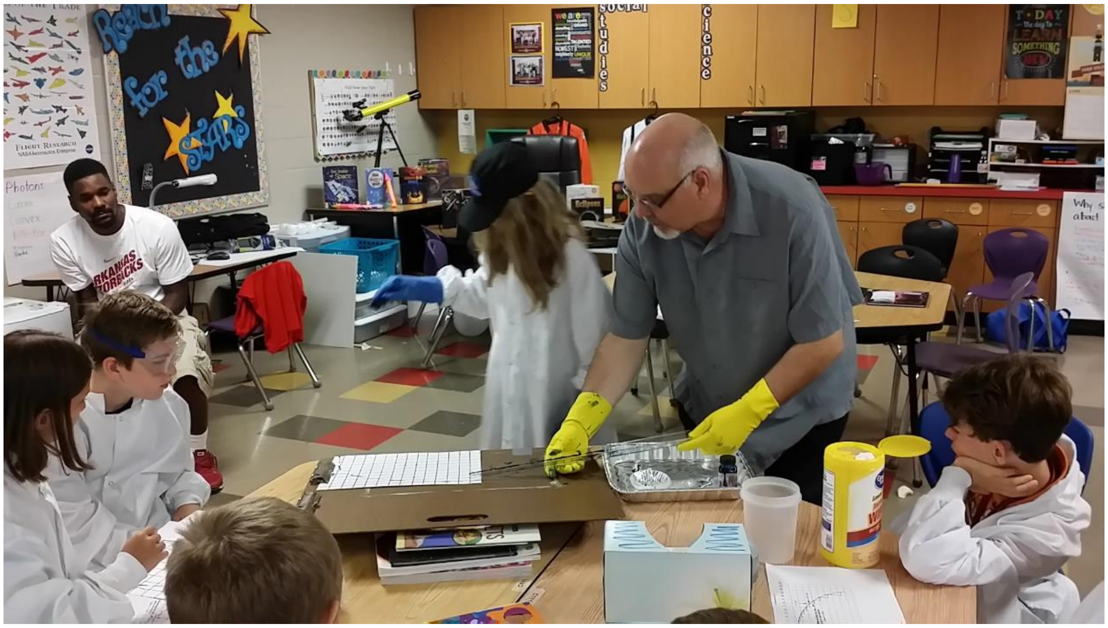
Materials

1. A hard, flat surface for a ramp, at least 24 inches square. A piece of Masonite works well for this, but even a tilted school desk will do in a pinch!
2. A ruler with a groove down the middle. (Alternatively, you can use a 6-inch long piece of wooden corner protector.
3. A large (25mm) marble or ball bearing. The marble should be relatively heavy, glass or metal balls work well, wooden or plastic balls will not.

4. A foam stamp pad, well filled with ink. A thin kitchen sponge saturated with paint in a disposable food container can be substituted for this – but ink works better.
5. 1 piece of very fine (200 grit or higher) sand paper (a common emery board works well for this!)
6. A pair of rubber kitchen gloves or similar
7. Construction paper, rulers, markers, masking tape

Building the Packard Gravity Ramp

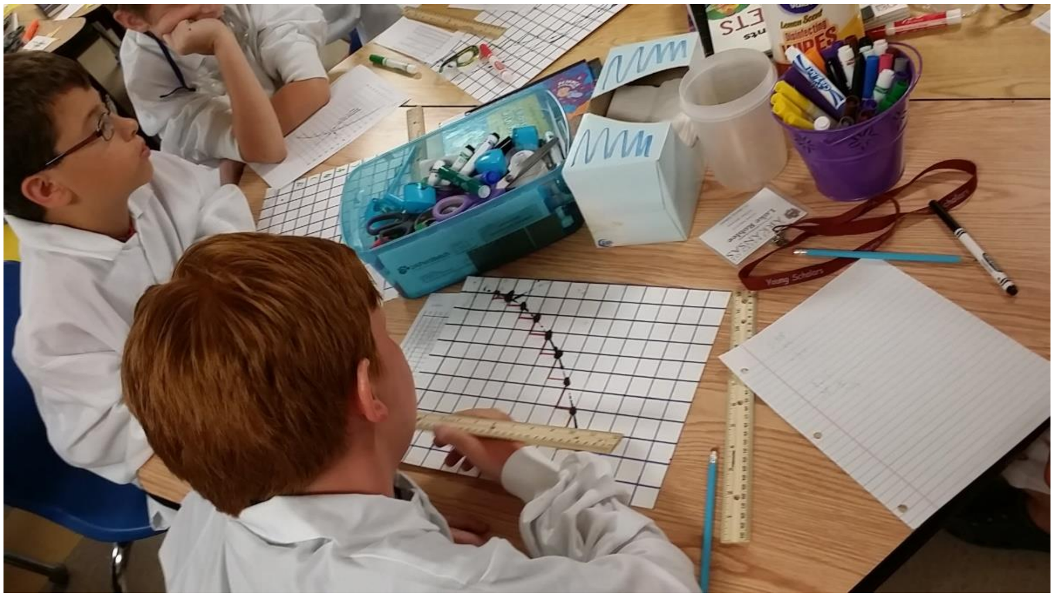
1. **[Teacher]** The marble or ball bearing must be sanded a bit to help it hold ink well. Take your emery board or sand paper and rub the entire surface of the marble vigorously while wearing your kitchen gloves. Do this over a sink or pan of water – the dust from sanding glass can be very abrasive! Rinse the marble occasionally as you sand, when the entire surface has lost its polish and is uniformly dull, you are done. Rinse and dry the marble completely.



2. Use a ruler and draw a grid of ½-inch (1 cm) squares over the entire construction paper. Draw as neatly as you can for best results. If you have large format graph paper, feel free to use it here!
3. Tape your construction paper graph to the ramp board and then prop one end up 4-5 inches with text books so that it is sturdy. You may wish to cover your table with newspaper before you do this activity – the inky marble can be a bit messy!

Exploring the Packard Gravity Ramp

1. Use the ruler with the groove in it as a marble launcher. Allow the marble to roll down the launcher as shown. Practice a few times with a dry marble; ideally, the marble should start at the upper left corner of the ramp and roll off the bottom right corner – this will give you the best results.
2. Once you have this down, put on a kitchen glove and rub the marble over the stamp pad until it is thoroughly covered in ink. Carefully set the ink-covered marble on the launcher and let it go. It should trace a neat, curved path across your graph paper. Allow the ink to dry completely before taking the graph paper off of the ramp. If the line is faint, use a marker or crayon to neatly trace over it to make it more visible.



3. Notice that the curve becomes steeper as it moves from left to right across the graph. The steepness of the curve is an indication of velocity. As the ball rolls faster down the ramp, pulled ever faster by gravity, the curve becomes steeper.
4. The curve is ***never flat***. This tells us that gravity is relentless, speeding the ball ever faster down the ramp as it moves. This continuous speeding up is ***gravitational acceleration.***
5. The curve is also ***very smooth and regular***. This tells us that gravity's pull is steady and unchanging. If gravity were changing, we would see wobbles and irregularities in the curve. Because the curve is steady, we know that gravity is, too!

Discussion Questions

1. What does ***acceleration*** mean to you?

Answer: Acceleration is the steady increase in speed any object experiences as it falls. We won't worry about the mathematical description of acceleration here, it is enough for students to know about the increase in velocity due to gravity as something falls.

2. How did you detect acceleration from your results?

   Answer: The ball travels farther (in the vertical direction) for every unit of time. To go farther in the same time – you must be moving ***faster!***

3. What would happen if you changed the angle of the big ramp?

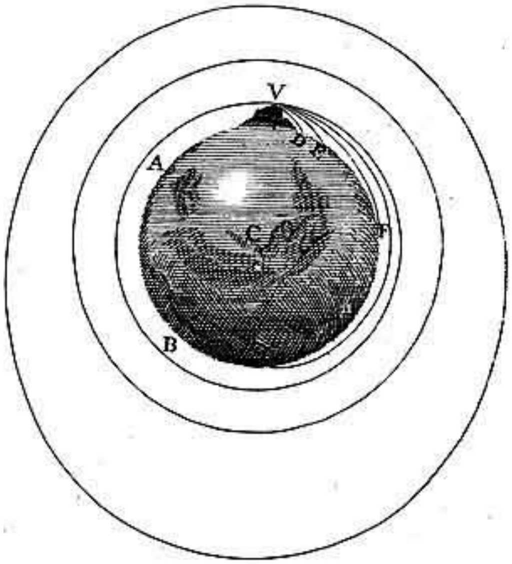
   Answer: Steeper angles give you higher acceleration. Shallower angles give you lower acceleration.

4. What would happen if you changed the angle of the little ramp at the top, but kept the big ramp unchanged?

   Answer: The speed of the ball across the ramp would change – the acceleration down the ramp would not!

Supplemental Materials

Going Deeper



Like the ball rolling down a ramp, satellites are continuously falling around the Earth. Isaac Newton was the first to realize this.

Newton visualized a ball shot from a cannon on a hill at ever greater speeds. Newton realized that not only would the ball travel farther as the horizontal speed increased, he also realized that if the ball were moving fast enough, it would circle the entire Earth.

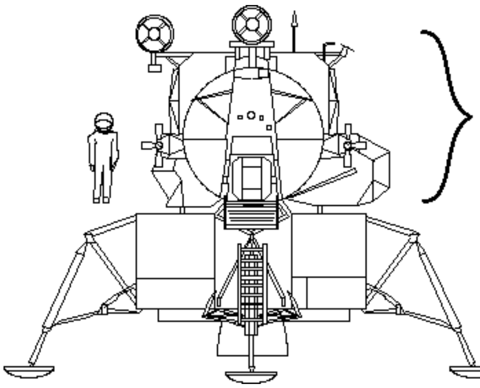
This was the first conception of a man-made satellite. Newton's conception of a satellite launched by man was not realized for 300 years, yet in 1958 the Soviet Union launched ***Sputnik***, the world's first 'artificial moon'.

The great speed required for a satellite to reach orbit is over 17,000 mph – that is more than 22 times the speed of sound!

Being an Astronomer

The escape speed for the Moon is much lower than that of the Earth – this too is due to gravity. The Moon has only 1% of Earth's mass (Earth is 100x heavier). This low mass makes the Moon's gravity about 1/6th that of the Earth's, just over 5,300 mph.

When you compare the escape speed of the Earth, over 25,000 mph, to that of the Moon, it becomes clear that it is easier to launch a rocket away from the Moon than it is to launch a rocket away from the Earth.



Only this section of the LEM left the Moon.

The rocket that left the Moon was just 12-ft tall.

Compare this to the 365 ft tall Saturn V Rocket which left the Earth!

Being a Scientist

1. Have students examine the graph they have made. Each line across the graph from left to right represents one ***tick*** of time. The vertical distance the ball has rolled down the ramp starts with zero at the top and is numbered down the page.
2. Look at how far down the ramp the ball rolls for each tick of time. Have the students draw triangles as shown below to help them see this idea in action. What do they notice?
3. If everything has worked properly, the students should notice that the vertical leg of the triangle gets larger each time because the ball continues to speed up as it rolls down the ramp. Congratulations, you've discovered acceleration!

Following Up

There are many excellent videos and documentaries about the journey from the Earth to the Moon. Find one of these and watch it with your class. The sense of history is as important in science as the sense of the future.

Activity 18:

Einstein's Gravity: The Curvature of Spacetime

The curvature of spacetime and Einstein's concept of gravity may seem like quite a stretch for a non-college classroom; allow me to assure you that it is not! Newton's theory of gravity is no less complex and subtle, yet we feel comfortable with it through long association. Einstein's gravitational model is also powerful and mathematically subtle, but like Newton's ideas of gravity, we can demonstrate it simply with a classroom model that students can grasp cognitively without troubling them (or you!) with the higher mathematics of the subject.

Though you may not realize it, Newton's theory has a huge hole in it. Newton tells us that orbits work because of the force of gravity – a force that pulls all things together. So far so good, but Newton completely sidesteps the issue of ***how gravity works***, he simply insists that it does work, and gives us convincing mathematical models that show us what will happen when any object is in orbit around another. Einstein stepped in and filled in that gap in Newton's theory some 350 years after Newton first published his ideas on gravitation.

Einstein's idea was a simple one, although it may seem a bit odd to you at first. Einstein said that space and time were not separate, but in fact one thing which he called ***spacetime.*** Einstein said that spacetime was a fabric which could be bent and stretched by massive objects. Things like stars and planets caused spacetime to curve, and it was this curvature which we call gravity. If this all seems strange, do not worry – you (and your students!) will see how it works as you build and work with this new model of Einsteinian spacetime-gravity.

Academic Standards

Science and Engineering Practices

Developing and using models

Planning and carrying out investigations

Analyzing and interpreting data

Using mathematics

Argument from evidence

Crosscutting Concepts

Cause and effect

Systems and system models

Next Generation Science Standards

Forces and interactions (K-5, 6-8, 9-12)

Engineering and design (K-5, 6-8, 9-12)

Gravitation and orbits (6-8, 9-12)

For the Educator

Facts you need to know

1. Einstein was a visual thinker. The models we are making reflect Einstein's creative, visual, conceptual thinking.
2. Einstein saw space and time not as separate things, but as one united thing he called ***spacetime***.
3. The fabric of spacetime can bend, stretch, and curve. Einstein saw gravity as the ***curvature of spacetime.***

Teaching and Pedagogy

This model is a wonderful toy; students and adults alike seem to find playing with it irresistible. Like all the best models, this simple device shows us quickly, and intuitively how the universe around us works. Draw your attention back to Galileo and Aristotle. Galileo challenged Aristotle's ideas by doing experiments that highlighted the weaknesses in Aristotle's theories. Scientists of the 17th century were forced to abandon Aristotle's theories in favor of those of Copernicus and the sun-centered solar system. Einstein did much the same thing in the early 20th century by challenging Newton's theory of gravitation.

Much like Galileo, Einstein found that challenging an old established figure and a cherished scientific theory did not make him popular. However, when a critical experiment in 1919 proved that stars do bend spacetime – and the light that shines past them – Einstein became famous almost overnight.

Perhaps more than any other model we discuss in this book, Einstein's model of gravitation needs to be ***played with.*** Rolling BB's or small ball bearings across the empty fabric, then adding a massive marble or weight and trying it again. Actually ***seeing gravity in action***, not as a mysterious force, but as the common sense action of a visual model is uniquely powerful for all students.

Student Outcomes

What will the student discover?

1. Gravity is not a mysterious attracting force. Rather it is the simple and logical reaction to a mass moving over a curved surface.
2. It is relatively simple to understand ***how gravity works*** – much easier than learning how to do the math involved!
3. Masses (like planets and stars) tell spacetime how to curve.
4. The curvature of spacetime tells mass how to move.

What will your students learn about science?

1. Powerful new ideas are often visual or physical in nature – the mathematics often comes later, sometimes many years later!
2. Our understanding of complex ideas often first comes to us visually, often viscerally, long before we can describe or explain what we know.
3. To bridge the gap between our first understanding of an idea, and our ability to explain or discuss what we know, a great deal of play and experimentation is often essential.

Conducting the Activity

Materials

1. A 30-inch plastic hula-hoop (or similar)
2. Eight, 15-inch pieces of 1-inch PVC pipe
3. Eight, 1-inch PVC T-connectors
4. Small can of PVC cement or super glue
5. 1 yard of black spandex fabric or similar (must be stretchy in ***both*** directions!)
6. Two billiard balls
7. Several glass marbles of various sizes, BB's or small ball bearings may also be used

Building Einstein’s Gravity Model

1. Your local home improvement store almost certainly does not have 15-inch sections of PVC piping, you will have to buy a longer piece and cut these yourself. You can easily cut PVC piping with a hacksaw, or with a PVC pipe cutter. Once you have these pieces cut, glue them securely into the T-connectors so that they each form a rigid T-shape.
2. Once the glue is completely dry, measure exactly 12-inches down from the T-connector and cut the PVC pipe off there – this will insure that all the pieces are the same length. These will be the legs for your model to stand on and they must be the same length for everything to be level and work correctly.
3. The T-connectors now need to be cut down as shown below so that they will snap around the hula-hoop. This can be done with a hacksaw, but I find a belt sander to be easier and faster. Check with your custodial department for help with this!
4. Cut a circle of spandex fabric so that it is about 6-inches larger than your hula hoop. Stretch the fabric over the hoop and snap one of the T-connector legs over the fabric to hold it in place. Work on opposite sides of the hoop, stretching the fabric and snapping in the connectors until the fabric is stretched tightly over the entire hoop. You should now have a 30-inch ‘trampoline’ of spandex fabric on short legs of PVC piping. Your model is now ready to use.

Exploring Einstein’s Gravity Model

1. Explain to your students that the black fabric represents the ***fabric of spacetime***. Roll one of your small glass marbles across the fabric and observe what happens – it will roll straight across the circle.
2. Now place a billiard ball by itself in the center of the fabric – what happens? The fabric is stretched! ***Mass tells spacetime how to curve!*** Try different size marbles and weights, let the students see that ***greater mass causes greater curvature*** of the spacetime fabric.
3. With the billiard ball resting in the center of the fabric, try rolling a small marble straight past the billiard ball. It will not roll straight – it ***curves*** toward the larger ball. ***The curvature of spacetime tells mass how to move!***

   Ask your students why the marble curved this time when it rolled straight before? They will quickly realize that the larger ball has stretched and curved the black fabric – it is the curved shape of the fabric that causes the marble’s path to bend toward the larger ball.

This is ***how gravity works!*** This is Einstein's explanation for gravity. A large mass causes the spacetime fabric to curve – and the curved shape of spacetime controls how the masses have to move.

4. Try placing two billiard balls several inches apart from each other on the fabric and observe what happens. The curvature of the fabric causes them to roll toward each other – just as gravity causes all things to be pulled together.
5. Can your students get some of the smaller marbles to orbit around one of the billiard balls? Can they get two billiard balls to orbit around each other? Have fun and play with this model for a while – it is fascinating to everyone who sees it and students will easily see how Einstein's ***spacetime fabric*** creates the effect we call gravity.

Discussion Questions

1. How does Einstein's gravity work?

   Answer: "Mass tells spacetime how to curve. The curvature of spacetime tells mass how to move." – John Wheeler

   This elegant quote from one of Einstein's greatest students explains things perfectly!

2. How is Einstein's model of gravity better than Newton's model?

   Answer: This is likely to generate a lot of comment and discussion, but essentially Einstein's model explains ***how gravity works***, Newton's model simply tells us ***what gravity does***, but fails to explain how it works.

3. Robert Hooke's pendulum model showed how planets orbit a star, can you make a model of an orbiting planet or moon with this model?

   Answer: Yes! The large billiard ball acts nicely as a star while the small marble acts as a planet in orbit. Like Hooke's model, you will find it almost impossible to create a circular orbit with Einstein's model – and for the same reason. Creating the perfect balance between gravity and momentum is hard and friction will cause any circular orbit to quickly decay into an ellipse in any case.

Supplemental Materials

Going Deeper

Sadly, when we add mathematics to a science lesson, we often end up teaching math instead of science. Let's do something different and use the science concepts to help ***understand what the math means.***

One of the first lessons students learn in physics is sometimes called the ***free fall equation***; this simple equation multiplies two numbers to find out how far something falls in a given amount of time. The equation looks like this:

$$h = g * t$$

In this equation, ***h*** stands for height (the distance an object falls); ***g*** stands for the acceleration of gravity; and ***t*** stands for the falling time in seconds. In other words, if you know the value of g (9.81 m/s^2) and the number of seconds an object is falling, you can calculate ***how far it falls.***

Unfortunately, we tend to fall back on something like: "Multiply the two numbers and get the answer for how far the rock falls." Let's see if we can help even our youngest students understand what the math means.

t for time is pretty simple, this is how long anything spends falling. It doesn't matter if it is a rock falling off a cliff or a swimmer falling off a diving board. So what does g mean? ***g is the curvature of spacetime!*** Place a billiard ball in the center of our model to represent the Earth and note how much the fabric curves. Allow a BB to roll toward the billiard ball – see how fast it rolls?

Replace the billiard ball with a large marble – the fabric curves much less now! Let this marble represent our Moon, now allow a BB to roll toward the marble – see how much more slowly it rolls? The gravity on the Moon is less (we fall more slowly) because the curvature of spacetime is less. The gravity on the Earth is more (we fall faster than on the Moon) because the curvature of spacetime is greater here.

And that little g in our equation? g represents ***the curvature of spacetime***. Now we understand the math much more completely. Multiply the falling time by the curvature of spacetime, and you find out how far an object falls. The simple equation is no longer just a multiplication problem, we now understand what each number means, and ***how gravity works!***

Being an Astronomer

Let's look at our gravity model again. Place a billiard ball in the center of the model and look closely at the fabric. Do you notice how the fabric has the greatest curvature right under the billiard ball, but the fabric becomes more flat (less curved) as you move away from the billiard ball.

If gravity works because of the curvature of the fabric of spacetime, then our model seems to suggest that ***gravity gets weaker as you move away from a planet or star.*** What does this mean for things in orbit like spacecraft or moons circling a planet?

Start with a marble and see if you can get it to orbit around our billiard ball planet. Do you notice how the marble moon eventually spirals into the billiard ball planet? What do you notice about the marble's speed as it spirals in? That's right! The marble moon moves faster as it gets closer to the planet it orbits. Let's see if we can confirm this prediction made by our marble with our own observations. Do things that are farther away from the Earth move more slowly across the sky?

Find a clear night and begin observing about 30 minutes after sunset. In a dark sky, you will be able to spot satellites moving across the sky. These satellites look like small stars that drift noticeably across the fixed stars in the constellations. You will find that these satellites move fast enough for you to easily detect their motion. If you could time them all the way across the entire sky, they would complete their journey in a matter of minutes.

Now consider the Moon. As we have seen in previous activities, you can track the motion of the Moon across the sky from east to west, but this takes about 14 days. The Moon is also much farther away than any man-made satellite. Our Moon orbits at a distance of about 385,000 km while artificial satellites that we can see orbit at a distance of 100-250 km from the Earth.

Our observations back up what our model tells us about gravity. The force of gravity is stronger near the Earth than it is far out in space; and satellites that orbit closer to the Earth travel faster – just as the marbles do when they orbit around a billiard ball in our gravitational model!

Being a Scientist

One hundred years after Einstein finished his work on ***relativity theory***, scientists are still working to design and build experiments to confirm the predictions of Einstein's theories today. One of these experiments is called LIGO, and it is used to detect gravitational waves.

Einstein predicted that if spacetime was indeed a unified fabric, that there should be waves in spacetime just as there are waves in a pond when you throw a stone into the water. Investigate LIGO on the internet – what would anyone do with a 'telescope' that detects gravitational waves?

Following Up

Einstein is famous for being the first man in 250 years to correct or adjust Newton's theory of gravitation. The idea of becoming famous for correcting someone else's work is common in the history of science. What other scientists and astronomers can you find that have become well known for making corrections or improvements in someone's earlier work?

On the other hand, what astronomers or scientists can you find that are famous for doing their own original work? I'll give you a hint… there are some from each group in this book!

Unit 7:

Proving the Heliocentric Model Correct

This unit takes us back to the early 1600's and one of the greatest intellectual battles in the history of science. On one side was Galileo, an Italian astronomer, mathematician, and inventor. Galileo supported the heliocentric (Sun-centered) theory of Copernicus. Galileo believed that his new invention, the astronomical telescope, could help him prove that the Sun was the center of our solar system and that Earth was just one of many planets orbiting our star.

On the other side of the debate was Aristotle, an ancient Greek astronomer who had taught that the Earth was the center or our solar system – and the entire universe! Although Aristotle has been dead for almost 2000 years, his ideas were still at the center of all the ideas and theories of astronomy in the early 1600's. Galileo realized that Aristotle's ideas had never been tested by experiment, these ideas had simply been repeated for so long that everyone accepted them without question.

Galileo did not believe that the science of astronomy was settled. Galileo insisted that all ideas in science should be tested and open to experiment and investigation. Aristotle's ideas had been accepted not only by scientists, but also by the Roman Catholic Church – and powerful men in government and positions of power. Galileo was not only challenging the science of Aristotle, but the people in power who believed in it.

Although the struggle between Galileo and his opponents was monumental, this is not the true focus of our teaching and activities. These activities and experiments can show your students both how and why scientists sometimes alter, even throw out an old theory in favor of a new one. Discarding an old theory is never done lightly. Predictions are made by both old and new theories, innovative and delicate experiments are devised by the challengers, and the outcome hangs on the data alone. No thought or prayer will change it, no belief will alter the results in the slightest. Our experiments ask the questions and nature gives the answers. Let the best model win!

Activity 19:

Modeling the Moons of Jupiter

This activity will allow your students to recreate Galileo's discovery of the four largest moons of Jupiter. Before you embark on this activity, it is a good idea to acquaint your students, and yourself, with the basic features of the old geocentric model of Aristotle and Ptolemy. Many of the features and ideas represented in this model will seem strange to your students, and even contradict things they have already been taught. Children in the 21st century are the beneficiaries of centuries of scientific struggle and learning; never the less, an understanding of the scientific ideas from Galileo's time can be useful in showing our children how science changes and evolves as new facts and ideas are discovered. This is a key idea in STEM culture and thinking.

The geocentric system of Aristotle has the Earth in the center of everything – and it is completely unmoving; it neither spins on its axis each day, nor does it orbit the Sun every year. In fact, in the geocentric system, ***everything orbits the Earth!*** The Sun, the Moon, the various planets, and even the distant stars all revolve around the Earth at different speeds and distances. It was this idea that everything orbits the Earth which was the first crack in the geocentric theory that Galileo would exploit in his quest to prove the heliocentric system correct.

Academic Standards

Science and Engineering Practices

Developing and using models
Analyzing and interpreting data
Constructing explanations
Argument from evidence

Crosscutting Concepts

Cause and effect
Systems and system models

Next Generation Science Standards

Space systems (K-5, 6-8, 9-12)
Gravitation and orbits (6-8, 9-12)

For the Educator

Facts you need to know

1. Earth's Moon is not the only moon in the solar system. Small planets in the inner solar system have two at most, but the giant jovian worlds in the outer solar system have dozens! Jupiter and Saturn both have more than 60 moons, from huge satellites larger than Mercury, to tiny irregular asteroids just a few miles across.
2. The ***Galilean moons*** of Jupiter were a key piece of data that pointed the way to proving the Copernican heliocentric model of the solar system was correct. These were almost the first discovery that Galileo made with his new invention – the astronomical telescope!
3. The Galilean moons are not simple barren rocks, they are complex worlds with volcanoes, oceans trapped beneath giant ice sheets, complex chemistry, and possibly even life.

Teaching and Pedagogy

The whole point of this model is to allow students to see what Galileo did when he first turned his telescope on Jupiter in 1609. Some of this is difficult for children, we have been brought up learning that *moons go around planets* – Galileo had no such advantage! When we teach a lesson such as this one, sometimes it helps children to role play and take on the roles of Galileo and some of his opponents for the day.

In his day, Galileo was taught that ***everything went around the Earth***. The core point of this exercise is to ask students ***to use what they see*** as experimental data and compare it to the predictions made by the ***geocentric model***.

Galileo originally thought that these bright objects near Jupiter were stars, but just a few days' observations convinced him that this could not be true. If Jupiter were moving through space, it would simply pass the stars by, ***but the stars themselves would not move***. These objects were clearly dancing attendance on the giant planet, and it did not take many days before Galileo realized that they were actually ***moons in orbit***. The interesting part was that the old geocentric theory said that "everything circles the Earth" – these new moons clearly did not do that.

Galileo named the new moons individually for lovers and friends of Jupiter (you may know him as Zeus!). He wrote to his employer, Cosimo de Medici about what he had found and said: "I have named this discovery for you – they are the ***Medician Moons!***" History disagreed with Galileo, and today we know them as the ***Galilean Moons of Jupiter***.

Here again, we have a situation where new scientific data conflicts with an existing theory. The geocentric theory of Aristotle and Ptolemy had been around for almost 2,000 years and was as well accepted as any idea you can think of. Galileo challenging this idea was not well received – he was eventually put on trial for speaking against Aristotle's theory and teaching that Copernicus was right!

The popular resistance to Galileo's ideas didn't matter. The fact that 99.9% of scientists of his day ***believed*** in the geocentric theory didn't matter. ***Science is not about belief, it is about data and evidence.***

Galileo's scientific evidence, gathered with the telescope he invented, was very convincing. Galileo eventually wrote a book of do-it-yourself experiments and projects people could try at home to convince them that Aristotle's theory was wrong and needed to be thrown out in favor of the Copernican, sun-centered system.

Your students should be able to see easily that the moons orbit the planet Jupiter. Ask them: "How do we know this? What evidence is in our drawings that these are moons and ***not stars?***" The answer of course, is that the moons of Jupiter never wander far from the planet. Jupiter might pass by a background star and move on, but it would not drag that star along with it!

Student Outcomes

What will the student discover?

1. Like the Earth-Moon system, all of the planets and moons in our solar system operate on the same principles. Gravitation, the force we feel that binds us to the planet's surface, keeps all the planets and moons in orbit. The motions of planets and moons in space and the geometry between the planet, the Sun, and the observer controls what phases of the Moon we can see.
2. Our scientific models are usually constructed using incomplete data. Galileo could not observe the moons of Jupiter consistently 24 hours a day, and our students are not allowed to see the model all the time, either. Never the less, a useful model can be constructed!
3. Although it seems difficult, even impossible at first, we can discover the relative distances of the Galilean moons from Jupiter by looking at how rapidly their positions change!

What will your students learn about science?

1. Galileo's struggle to prove the Copernican model of the solar system correct is one of the most moving and profound examples of science in action we know. Your students will discover that it is ***scientific data*** that settles questions when two competing theories are present. Emotions, beliefs, traditions, or political power have no ability to influence the march of science toward the truth.
2. The evidence we see in the night sky must fit neatly into our scientific theories and models. If the data does not fit, we must adjust our theories – **<u>not the data</u>!** Galileo's dispute with the political and religious powers of his day boiled down to precisely this principle – and Galileo was willing to risk prison and death to stand up for the truth rather than change his data or support a model he knew to be incorrect.

Conducting the Activity

Materials

1. One, 5-inch Styrofoam ball
2. Four, 1-inch Styrofoam balls
3. 4 pieces of craft or piano wire, 24-inches long each
4. Wire cutters and pliers
5. The barrel of a plastic stick pen, cut in half.
6. An 8-inch square of cardboard or foam core board
7. Hot glue, markers, paints, etc.

Building the Jovian Moon Model:

1. Use markers or paints to decorate the large ball as a model of Jupiter. There are plenty of photo references on the internet for this, but don't worry about getting too fancy, the decoration will not be critical for our activity.
2. The smaller balls can be colored if you wish. If you are a stickler for accuracy, use orange/red for the innermost moon (Io), yellow for the 2nd moon (Europa), silver/grey for the two outer moons (Ganymede and Calisto.)
3. Use pliers to make a 90-degree bend in each of the wires about 2-3 inches from one end. Make a second 90-degree bend in each wire so that you have a squared off U-shape. Each U-shape should be wider than the previous on by a few inches so that the

four little moons will be at different distances from Jupiter. Look at the figure below to get a better idea of what the finished wires should look like.

4. Trim both ends of the wires so that they are all the same length and push the small Styrofoam moons onto the wires. You may wish to secure them with a drop of glue.
5. Carefully push the plastic barrel of the stick pen into the North Pole of your Jupiter model until it is flush. Now use some hot glue to secure the South Pole of Jupiter to your cardboard base.
6. Put the wires with the little moons on them into the plastic barrel of the stick pen. This should hold them in place and allow them to rotate freely in 'orbit' around Jupiter. If they are a bit loose or wobble on their own, try putting a small ball of poster putty into the barrel of the pen to hold them in place while students observe them.

Exploring the Jovian Moon Model

1. Place the model across the classroom and set the four moons so that there are two on each side of your Jupiter model. The students will be playing ***Galileo*** and doing what he did! Have the students draw what they see – just a circle for Jupiter and a small dot or star for each moon is enough. They will be making several of these observations – they can draw each one or you can give them a worksheet as shown below.
2. Now have the students close their eyes briefly while you adjust the model. Closing their eyes represents one day passing for Galileo (he could not observer Jupiter during the daylight hours!).

   [Teacher] All the moons should orbit anti-clockwise. The inner moons move closer than the outer ones. Advance each moon as follows:

   Io: The innermost moon advances ½ orbit each day.

   Europa: The second moon out advances 1/3 orbit each day.

   Ganymede: The third moon advances 45-degrees each day.

   Calisto: The outermost moon advances about 20-degrees each day – about 1/8th of a circle.
3. When the moons have been adjusted, have the students open their eyes and draw what they see again. Remind them that this is 'day 2' of their Jupiter observation!
4. Continue moving and adjusting the moons for 5-6 days, then have the students look at their data.

Discussion Questions

1. How did you know that the moons were orbiting Jupiter and not just nearby stars?

   Answer: This very question was asked of Galileo! He was able to show that each of the moons had a particular distance from Jupiter (the size of its orbit), and that each moon had a particular orbital period (the time it took to circle Jupiter). The moons also never left Jupiter, they continually stayed near the giant planet – no stars would do this. These points together were conclusive!

2. How did this discovery challenge Aristotle's ***geocentric theory?***

   Answer: Aristotle's theory stated that all objects in space must orbit the Earth. Obviously the newly discovered moons orbiting Jupiter did not do this! Some scientists said Aristotle's theory only needed to be modified to allow other planets to have moons. As we shall soon see – this was not sufficient to save the old theory!

Supplemental Materials

Going Deeper

Galileo, Herschel, Huygens, Cassini, Hall and others discovered moons of planets by studying these planets carefully with telescopes here on Earth – but most moons are not discovered that way anymore!

Space agencies such as NASA (United States), ESA (European Union), JAXA (Japan) and others send spacecraft and telescopes into space and take high resolution photographs of planets. Independent scientists poor over many thousands of photos looking for specks of light that may be a new moon. Most of Jupiter's 67 moons were discovered by the Voyager and Galileo spacecraft. Similarly, most of Saturn's 62 moons were discovered by the Voyager and Cassini spacecraft – and many more will probably be discovered in years to come by scientists combing through the photos and data sent back to Earth by these robotic spacecraft.

Being an Astronomer

Today we know of more than 65 moons orbiting Jupiter, but the four large Galilean Moons still fascinate observers. As Galileo found, these large moons are easy to see, even with the smallest telescope.

You can observe and draw the positions of the moons of Jupiter easily enough. Try using this simple chart to guide you:

When you look at Jupiter in a small telescope or even a pair of good binoculars (8x or higher), you will be able to see the Galilean Moons. Use this chart to record the position of each moon that you see.

There are a variety of websites and software that will show you the position of Jupiter's moons on any given day. ***Sky and Telescope.com*** has one – search for *A Jupiter Almanac* on their website and you will find it easily. The ***Stellarium*** sky simulator software is also helpful, this is free software available at ***stellarium.org.***

Being a Scientist

Scientists have found that the large Galilean moons of Jupiter are worlds in their own right. Three of the four moons are larger than our own Moon, giant Ganymede is almost as large as Mars!

Each of these Jovian moons has a unique structure, and dynamic surface features that rival anything you would find on Earth! See what you can find out about them on the internet. From giant volcanoes on Io, to ocean geysers on Europa, and frozen craters on Ganymede – there are many things to explore. Which moon is your favorite?

Following Up

The Galilean Moon Europa is very unique. Exploration of this moon by the Galileo Spacecraft has discovered that Europa is an ocean world about the same size as our Moon. We didn't see this ocean world for what it was at first, because the entire ocean on Europa is covered in ice. It was only later experiments and observations by the Galileo spacecraft that confirmed that the oceans on Europa were many miles deep.

One of the things we know about the Earth is that wherever there is water, there is life. Every ocean, lake, and stream is inhabited with many forms of life. Even extreme water environments such as boiling pools in Yellowstone Park and lakes a mile beneath the ice in Antarctica have life in them.

What about Europa? So far, no one has found samples of life beyond the Earth; could Europa be the first place? How would you design a probe to look get through the ice and look for life in Europa’s oceans?

Activity 20:

The Phases of Venus

Our next activity is taking another page from Galileo's book – literally! In 1609, after inventing the telescope, Galileo chose three objects for his first investigations: the Moon, Jupiter, and Venus. The Moon proved to be a rugged place, full of mountains, craters with their rays, and large dark seas of frozen lava. Jupiter was a beautiful world with colorful cloud bands and four brilliant moons of its own.

Although these discoveries contradicted Aristotle's geocentric theory (the moons of Jupiter didn't circle the Earth and Aristotle's moon was supposed to be smooth and flat), they didn't actually contradict Aristotle's central idea – that the Earth, and not the Sun, was the center of the solar system. Galileo's quest to prove the Sun-centered theory of Copernicus correct was not satisfied by his observations of the Moon and Jupiter.

Galileo's observations of Venus were the final piece to the heliocentric puzzle. Observations of Venus through the telescope showed beautiful phases just as our Moon does. A little investigation and thought showed that this was only possible with a heliocentric system such as the one proposed by Copernicus – more importantly, phases of Venus were ***impossible in Aristotle's Earth-centered system***.

This activity will allow us to recreate the observations of Galileo using ping-pong balls as planetary models and prove that Galileo and Copernicus were right about the sun-centered theory of the solar system.

Academic Standards

Science and Engineering Practices

Asking questions and defining problems
Developing and using models
Planning and carrying out investigations
Analyzing and interpreting data
Constructing explanations
Argument from evidence

Crosscutting Concepts

Patterns in nature
Cause and effect
Systems and system models

Next Generation Science Standards

Space systems (K-5, 6-8, 9-12)
Structure and function (K-5, 6-8, 9-12)
Waves and electromagnetic radiation (6-8, 9-12)
Gravitation and orbits (6-8, 9-12)

For the Educator

Facts you need to know

1. Venus is the closest planet to Earth, and almost the same size, mass, and density as our planet; in fact, if you only consider size and mass, Venus could be Earth's twin.
2. Venus (and Mercury) are closer to the Sun than Earth is; this fact will be critical in order for students to understand this activity.

3. When we observe planets with a telescope, planets ***closer to the Sun*** than Earth appear markedly different from planets that are farther away from the Sun than Earth is. Closer planets are called ***inferior planets,*** while those planets farther from the Sun than Earth are called ***superior planets.***
4. Inferior planets ***always show phases*** when you observe them, superior planets never do. This is only possible in a ***heliocentric solar system***.

Teaching and Pedagogy

Planets which are closer to the Sun than the Earth (Venus and Mercury) are called ***inferior planets***; those planets which are farther from the Sun than we are (Mars, Jupiter and the rest) are called ***superior planets.*** Galileo quickly noted that whenever he observed an inferior planet – it always shows phases – but the superior planets never do. Experimenting with models like the one you have just built in your classroom convinced Galileo that only the sun-centered system would make this possible!

Unlike the moons around Jupiter and the rugged surface of the Moon, the phases of Venus went right to the heart of Aristotle's geocentric system. Try as he might, there was no way Galileo could arrange the geocentric model to recreate these observations – but they occurred quite naturally and easily with a heliocentric model!

For your students, once you show them the phases of Venus with the Sun in the center of the model, challenge them to find the same thing with the Earth in the center. (In Aristotle's model, Earth is in the center, then the Moon, the Sun, Venus is farther out from Earth than either the Sun or Moon.) Try as they might, Aristotle's model will never produce the phases of Venus we see in a telescope.

Galileo's book ***Dialogues Concerning the Two Chief World Systems***, showed people how to experiment with models very similar to the ones your students have just built. This showed everyone who cared to look that the old Earth-centered system just didn't work, and the new heliocentric system of Copernicus ***did***.

Student Outcomes

What will the student discover?

1. Different models make different predictions about what we will observe in Nature. The two models we are dealing with – the heliocentric (Sun-centered) and the geocentric (Earth-centered) models, give very different predictions about what we will observe when we look at Venus.

2. If you were to take care and move each model, observing how Venus appears every 15 days, the geocentric (Earth-centered) model would show you only small changes, and Venus never shows a crescent or half-lit appearance.
3. The heliocentric (Sun-centered) model is different. Here Venus moves smoothly from a thin crescent, to a half-lit phase, and finally a gibbous phase. We do not see Venus in new phase or full phase because these line up Venus with the Sun and make observing the planet impossible.
4. On the face of it, either theory seems possible. However when we observe Venus with a telescope, it becomes clear which theory successfully predicts the performance and appearance of Nature.

What will your students learn about science?

1. Once again, different models make different predictions about what we will observe in Nature. Many theories or hypotheses are possible, but unless a theory makes a ***unique prediction about Nature***, the theory is unprovable and therefore valueless.
2. Testing theories with experiments, or with models, can help us decide when we are on the right track in understanding how the Universe works.
3. Our emotional attachment or fondness for one theory or another cannot be a deciding factor in our experiments. Scientists propose theories, but ultimately, Nature is the way it is and wishing will not make it different.
4. Polls don’t count in science. When Galileo was building his telescope and using it to show that Copernicus’ heliocentric theory was actually correct (and Aristotle’s ideas were in fact wrong), 99.9% of the learned scientific minds of the day believed Aristotle was correct. Belief and polls aside, Galileo was right and everyone else was wrong.

Conducting the Activity

Materials

1. Four ping-pong balls
2. Four poker chips (you can substitute sports-drink caps if you like)
3. A can of bright yellow spray paint
4. A can of flat black spray paint
5. A roll of 2-inch wide masking tape

6. A tube of silicone glue
7. Markers or classroom paints
8. A can of clear acrylic or art fixative spray (optional)
9. Three white ping-pong balls per student group – $2
10. Six poker chips per group (you can substitute sports-drink caps if you like)
11. One set of 6-10 powerful magnets (for the teacher's model) – $4
12. Wooden or plastic ruler (actually, almost any sturdy stick will do.)

Building the Model of Venus' Phases

1. Begin by using silicone glue to attach one of the ping-pong balls to a poker chip or bottle cap – this will be the Sun.

   Note: Even if you use bottle caps as bases for the students, the teacher's model should use poker chips – it makes it much easier to attach magnets to the bottom of the teacher's model which will allow you to display the model on any white board for everyone to see!

2. **[Teacher]** After the glue has cured at least 24 hours, set the Sun models out on some newspaper. Use the yellow spray paint to decorate the Sun models. Shake the can well and spray the paint on in thin coats, just a spritz at a time. You will need several coats of paint, and allow at least 30 minutes between coats.

   Be sure you use plenty of newspaper as you will be spraying from all sides. Space the models well apart and only paint in a well ventilated area. An empty garage (preferably with the door at least partly open) works very well. Leave the room immediately when you are done spraying to avoid exposure to fumes and allow the paint to dry completely (30 min or so) between coats.

3. **[Teacher]** The other three ping-pong balls must be colored half-black, and half left unpainted white; the black side will represent night, the white side will be the daytime side of the moon or planet. There are two fundamental ways to do this: one at a time (very neat and precise), or in batches of a dozen or so at a time (less precise, but saves a great deal of time.)

   Both methods begin the same way, by taping off half the ping-pong ball with masking tape. Look for the seam, like an equator running around the ball. Tear off a length of tape and carefully apply the edge to the seam and work your way around making sure the tape is well sealed to the ball. You should now have half a ping-pong ball sticking up from a 2-inch tube of masking tape as you can see below.

4. If you are painting the balls one at a time, place the ball on the end of a ruler (the masking tape will help it stay secure). Hold the ball at arm's length and spray it with flat black paint. Remember, use thin coats and work in a well ventilated area!

   If you are painting in batches, put a dozen or so balls into a cardboard box (a copy paper box works very well). Stand them up carefully on their masking tape tubes toward the center of the box and not too close together. Spray the black paint into the box – don't forget newspapers underneath – particles of paint will float up out of the box and may drift a bit!

   When the paint dries, carefully remove the tape and you should have perfect ping-pong balls – half black and half white!

5. Now it is time to decorate the Earth and Jupiter using markers. There are two approaches to this, the accurate and the creative – you must decide which will work best for your students!

   For an accurate model, use photos or maps of the Earth and draw in continents, oceans, mountain ridges, green prairies, islands, etc. You can even use a bit of white paint (or correction fluid!) to add storms and clouds to your model of Earth. Jupiter has alternating dark and light bands – dark bands are dark brown or grey, light bands are tan or yellow. Start with a light band around the equator and alternate as you go toward the poles. Add a red spot on one of the lighter southern cloud bands!

   For a creative Earth model, have students draw continents, islands, oceans any way they wish. You can even have them name their planet creations.

Venus is the easiest of all – it needs no decorating! Venus is covered in thick, white clouds that never part or reveal the surface underneath. For our purposes, a half-black, half-white ping-pong ball will work perfectly!

When you are done decorating, glue the planets and moons to their bases with silicone glue. After they are dry (24 hours!), a quick coat of clear art sealer will not go amiss (old-fashioned lacquer hair spray works well for this if you can find it!) – it often helps keep marker from coming off again on your student's hands!

6. Your model is now ready to play with and explore!

Exploring the Model of Venus' Phases Model

1. Set up your models on a desktop with the Sun in the center, then Venus a bit farther out, and then Earth. Set Jupiter aside for later!
2. The trick with these models is to remember how they should be displayed. Ask your students why one side of the planet models are colored black? The answer of course, is that this is the nighttime side of the planet, the decorated side is daytime. The daytime side of the planets ***must always face the Sun.*** This will seem obvious to you when you think about it for a moment!
3. Begin with Sun, Venus, and Earth all in a line. Have your students put their eye down at tabletop level and look at Venus ***from the position of the Earth***. Ask them to draw what they see! If their eye is right above the planet Earth, they will see that Venus is in new phase – only the dark side faces the Earth. (Venus is invisible to us in this position – the Sun's glare blocks it from view!)
4. Now advance Venus about 45-degrees in a counter clockwise direction around the Sun. Make sure the bright white side stays facing the Sun at all times! Ask the students to make another observation and draw what they see – they will see a crescent phase!
5. Continue to advance the Venus model 45 degrees at a time and the students will see all the phases; new, crescent, half, gibbous, full, etc. If you have older students who have smart phones, ask them to place their phone just behind the Earth model and take a photo of Venus – these photos show the phases off beautifully!
6. Now that your students have seen the phases of Venus – let's try Jupiter! Set your Sun, Earth, and Jupiter models up on a tabletop or on the floor (this one takes more room!) Place Earth just 5-inches from the Sun, and Jupiter 25-inches away – we do this because giant Jupiter is five times farther away from the Sun than we are! Make sure the bright sides of the planets face the Sun at all times!

7. Once again, have students put their eye down near the Earth and look at Jupiter. We see a full disk (no phases.) Move Jupiter around the Sun in a circle and make a drawing every 45-degrees just as you did for Venus – be sure the decorated side of Jupiter ***always faces the Sun***. (You may want a piece of string or a yardstick to help you keep Jupiter at the right distance!) Your students will quickly notice that Jupiter never shows us any phases – it always looks full and round!

Discussion Questions

1. How does this new discovery of the phases of Venus challenge Aristotle's theory?

   Answer: The phases of Venus can only occur if the Sun is in the center of the model. There is no way to arrange the model with the Earth in the center and still create this effect.

2. How is this activity different from the previous one?

   Answer: The moons of Jupiter only challenge the idea that ***everything orbits Earth***. The phases of Venus make it impossible to believe in anything except a ***Sun-centered model.***

3. Why do you think that so many people got mad at Galileo and even charged him with crimes when he showed that Aristotle's ideas about the solar system were wrong?

   Answer: People become emotionally attached to ideas, just as they do with cherished friends. Being told that you are wrong is never a comfortable experience. Being told that ***everyone else is wrong*** usually provokes a very negative response from people!

Supplemental Materials

Going Deeper

Try this model again with the Earth in the center, the Sun orbiting close to Earth, and Venus farther away. Venus should be several times farther from Earth than the Sun is. Can you make Venus appear in phases? In fact, the Earth-centered system fails dramatically here – Venus never appears to show phases when the Earth is in the center.

There is the additional problem of why Mercury and Venus show phases, but Mars, Jupiter, and Saturn do not. (People in Galileo's time did not know of any planets beyond Saturn!) In the Earth-centered model, all of the planets are farther away from Earth than the Sun is. There is no reason for them to appear different from one another in a telescope.

In the heliocentric model however, Earth is just the third planet – one of many! Planets closer to the Sun than Earth appear different from those which are farther away from the Sun than we are. The heliocentric model of Copernicus and Galileo easily explains things that the geocentric model cannot.

Being an Astronomer

This one is obvious – it's time to go observe Jupiter and Venus! If your school does not have a telescope available, try contacting your local astronomy club for help. You can even ask parents through a newsletter or your PTA – you will be surprised how easily you can find someone with a telescope to share!

Venus is sometimes called the ***Evening Star*** because it is brilliant white – the brightest object in the sky after the Moon – and appears in the sky just after sunset (or just before dawn.) Looking at brilliant Venus, even with a pair of binoculars, will easily show that it has phases! This is a very unexpected thing and surprises and delights young and old the first time they see it. If you find when Venus is visible in the morning, you may be able to bring a pair of binoculars to school and allow all the students to have a look at it first thing in the morning!

Observing Jupiter can be done with an 8x or higher power pair of binoculars, but it is far better done with a telescope. The good news is that almost any telescope will do the job, even a very small one such as those you see on sale at holiday time in department stores. If you do not have access to a telescope or binoculars, this is a great time to check the internet and see if there is an amateur astronomy club near your town. Astronomy clubs often do outreach, and if you explain to them that you and your students want a chance to observe the planets, they will almost certainly help out. Some clubs have regular observing nights or ***star parties*** that students and parents would be welcome to attend; some clubs will even be willing to bring their telescopes and equipment to your school for an evening of observing the planets and the Moon!

Being a Scientist

If you have access to a telescope, observing and recording the changing phases of Venus can be a fun and challenging exercise. Venus appears as a ***morning star*** for a period of weeks during most school years. While Venus is visible in the morning skies, you and your students can observe and record the changes you see by looking at Venus at least once per week.

As you observe Venus and sketch the shape of the phase you see each week, you can also pay attention to how large Venus appears in the eyepiece of the telescope by observing how much of the field of view Venus takes up. You will notice that some phases (the crescent phases) appear quite large. Other phases (particularly the gibbous phases) will appear quite small in the eyepiece.

If you pay close attention, you may also notice that the large crescent phases make Venus appear noticeably brighter in the morning sky, while the small gibbous phases make Venus appear dimmer.

How do we explain this? Have your students go back to their model and see where Earth and Venus are located for the crescent and gibbous phases. You students will quickly notice that crescent Venus is ***much closer to Earth*** than the gibbous phase.

Having Venus more than 100 million miles closer to Earth during crescent phase makes the planet look both larger – and brighter!

Following Up

Galileo's famous book ***Dialogues Concerning the Two Chief World Systems*** was actually written as a play! There are three main characters: ***Salviati*** is a scientist and astronomer who believes that Copernicus' sun-centered system is correct. ***Simplicio*** is a traditional scientist who supports Aristotle and the earth-centered system. ***Sagredo*** is an intelligent fellow who has asked these two famous men to debate so that he might decide which theory is correct.

Have your students do a presentation to the class where someone takes each part. You can even do this as a group project with ***Team Salviati*** and ***Team Simplicio*** doing the debating and ***Team Sagredo*** asking both teams to answer questions. Have your actors use the ping-pong models to demonstrate their points and show why the evidence favors their theory.

Of course, the outcome of our little debate is more predetermined than a pro-wrestling match! Salviati (and Galileo!) will win the day, but having children take the parts and present the evidence can be both fun and enlightening!

Unit 8:

Understanding Big Numbers

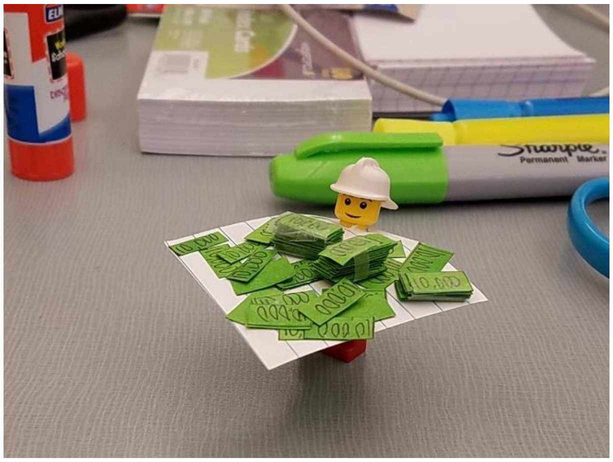
Understanding large numbers is one of the most troubling deficits in the mind of the average adult. Science, not to mention economics, uses large numbers with great regularity, but almost no one in the public eye makes an effort to help the average citizen really understand what they mean.

The late astronomer Carl Sagan popularized the phrase “Billions and billions!” in his science series ***Cosmos*** in the 1980’s. Although Dr. Sagan said this with great excitement and a very melodious voice – he really failed to help us understand what the difference is between million, billion, and trillion. If our children are to understand science – and national finances! – we must help them gain a more fundamental understanding of large and small numbers.

Activity 21:

Million, Billion, Trillion: Big Numbers and Money

If you teach in the K-8 classroom, you may know that most of your students ***will not*** become scientists. Why then is it important to understand big numbers? Although most of us are not professional scientists, very large numbers touch our daily lives in many ways – money is the most common.



When we listen to legislators discuss state or national budgets on the news, or when we see a local bond measure to allocate millions – even billions of dollars to a project like a bridge, highway, or a railroad line, most people don't understand how much money we are talking about. Worse yet, they have no fundamental grasp of large numbers to help them understand the ideas being debated on their behalf.

This activity seeks to correct that deficit by giving students a physical model for the concepts of thousand, million, billion, and trillion – without too much tedious counting!

Academic Standards

Science and Engineering Practices:

Asking questions and defining problems
Developing and using models
Using mathematics
Obtain, evaluate, and communicate information

Crosscutting Concepts:

Scale, proportion, and quantity

Next Generation Science Standards

Space systems (K-5, 6-8, 9-12)
Structure and function (K-5, 6-8, 9-12)

For the Educator

Facts you need to know

1. We normally think of counting, multiplying in powers of 10 – One's place, Ten's place, Hundred's place, etc.
2. Large numbers: Thousand, Million, Billion, Trillion, are ***powers of 1000*** – each one of these numbers is ***one thousand times larger*** than its predecessor.
3. It is this change, from powers of 10 for everyday numbers to powers of 1000 for large numbers that confuses people.

Teaching and Pedagogy

Misconceptions about large numbers are some of the most persistent and troublesome bits of misinformation. Not just children, but a large fraction of adults in our society lack a good understanding of what large numbers are, how much larger a billion is than a million, and much more. Almost no one has a good visual concept of what a million of anything looks like. You can imagine a dozen doughnuts looks like and how large a box you need to put them in – but what does a million doughnuts look like?

When we reach the domain of millions, billions, trillions, and beyond, the names for our numbers now reflect ***powers of 1000***. Psychologists and anthropologists tell us that humans have an ability to easily mentally conceptualize groups of up to five or so, and with a bit of practice (and the help of our fingers!) we can get pretty good at conceptualizing groups of ten. In this way, visualizing 100 as ***ten groups of ten*** is well within almost anyone's grasp. In comparison to this, groups of 1000 are beyond anyone's cognitive grasp. Yes, we handle numbers like these mathematically and numerically; but conceptually, we get lost pretty quickly.

Want proof? Try this mental experiment: Think of ten marbles. Got the picture mentally? Good! Now think of ***one thousand*** marbles. How big is it? How much does it weigh? How large a container will you need to hold them all? If you needed 1000 marbles and you saw a group of 750 marbles, could you tell by sight that you don't have enough? I suppose if you had a job working with boxes of 1000 marbles all day long you might be able to tell, but generally, the answer to all these questions is cognitively beyond our grasp. As human beings, we just don't mentally image or handle large numbers very well without a great deal of practice.

Computers add to the confusion for most students (and adults!) A computer with 200 megabytes of memory (200 million bytes) looks just like the model with 3 gigabytes of memory (3 billion bytes). A USB memory stick with 32 megabytes looks just like a USB stick with 32 gigabytes even though the capacity is one thousand time greater! Newspapers and broadcasters reading the news on television are no better; announcers will jump from one story about a fire causing three million dollars damage to a story about a two trillion dollar spending bill in Congress with no attempt to explain the difference between them. Activities like this one, and a through discussion of the ideas they contain, are essential for your students.

As adults, we are expected to work with computers which routinely use terms like mega (million), giga (billion), and terra (trillion). As voters, we are expected to select candidates for office by listening to their economic and taxation plans involving millions, billions, and yes, trillions of dollars. How can we prepare the children of today to do any of these things successfully if they do not have a fundamental understanding of these concepts? This activity will finally put the ideas of million, billion, and trillion on a solid physical, and visual, foundation.

Student Outcomes

What will the student discover?

1. The fact that large numbers increase in powers of 1000 instead of the usual power of 10 makes them harder to visualize easily.
2. Learning to visualize and comprehend the powers of 1000 in thousand, million, billion, trillion takes practice! We have to try imagining large numbers of various things to become familiar with these scales.

What will your students learn about science?

1. These large numbers are of particular interest in astronomy, where distances and sizes vary so greatly. Our use of powers of 1000 makes it easier to discuss, and understand large sizes and distances.
2. More advanced classes in science and mathematics (high school and college) use something called ***scientific notation*** to help handle these very large and very small numbers. Scientific notation is beyond the scope of this book, but these methods of

writing and calculating with very large and small numbers helps us handle everything from the distance between stars to the tremendously small size of the atom.

Conducting the Activity

Materials

1. A trillion dollars. No? Okay, how about a package of index cards or several manila file folders that we can cut up and color to represent money?
2. A couple LEGO® figures or similar 2-inch toy action figure.
3. Two, 3-foot square pieces of cardboard.
4. Paints and markers (green, of course!), highlighters work well for this.
5. Glue sticks and hot glue.

Building the Big Numbers Model

1. Cut up index cards into ¼-inch wide strips. Cut each strip into ½-inch pieces. You are going to need a lot of these, so if each student does one card, you should have enough.
2. Label five pieces with “$100” and glue them together so that they are fanned out like a hand of cards. When dry, color this stack over with green highlighter. Glue this fanned stack of cash into the hand of one of your small action figures to represent $10,000 – be sure to paint a smile on the little fellow’s face! Remind your students that it takes ***one hundred*** $100 bills to make $10,000 dollars.

3. Now use glue sticks to glue stacks of these cut pieces of index card together – four pieces per stack. Once they are dry, label each stack “$10,000” in pen or black marker and color it over with green highlighter or pale green marker. Each stack now represents a pile of 100, one hundred dollar bills -- $10,000 cash each!
4. Make 100 of these piles. Yeah, each student in your class of 30 is going to have to produce 3-4 of these for you to have enough! Once you have one hundred of these piles – each representing $10,000 – then you have ‘printed’ ***one million dollars***… and you now know how those folks at the U.S. Mint feel! Making money is a lot of work!
5. Make a little cafeteria tray out of a piece of cardboard or plastic from a milk container. Glue this into the second action figure’s hands and stack the $1,000,000 dollars on it. You’ll have to stack neatly, it makes quite a tidy pile of cash, doesn’t it? This is a pretty

good model for the physical size of one million dollars cash in $100 bills! (***BIG*** smile, little guy!)

Exploring the Big Numbers Model

1. Now it's time to go big… it's time to make a ***billion dollars!*** No, we aren't going to need a lot more index cards, a single manila folder and some white glue and markers will do just fine. One billion dollars is a stack of $100 bills that is ***one thousand times larger*** than our million dollar stack. This is a neatly stacked cube of $100 bills that is ***eight feet long on each side.*** Assuming your 2-inch tall action figure is 6-feet tall, let's plan on a pile of play money that is a 2½-inch cube. Take your manila folder and cut out 2.5 inch cube as shown in the diagram below, glue it together and decorate it.

   To give you some idea, our billion dollar pile contains ***ten million $100 bills***. This is like having a solid cube of dense wood 8-feet on a side – it would weigh ten tonnes (10,000 kg), and only the largest industrial forklifts could move it.

2. Okay, big is a relative thing. What about ***one trillion dollars?*** Well, let's consider the standard school soccer field… yes, really. If we took an American school soccer field of 100 yards x 60 yards, we get an area of 6,000 square yards. On the other hand, if we have one thousand cubes of one billion dollars, that make 6,250 yards. That means our stack of ***ten billion $100 bills*** would take up an entire soccer field, plus about 8 feet extra on either end to have room for the goals, and piled it eight feet deep in neatly stacked $100 bills… Yeah, a trillion dollars is a ***LOT*** of money.

3. To keep in scale, we will need an area 10'4" x 4'2" and 2.5" tall. This may be a little much for your class to tackle, but if you want to build it in sections and put them next to each other – it makes a powerful display on the gymnasium floor… especially if you make little soccer goals and use a little gumball for a soccer ball and have several action figures running around on it!

4. If modeling something this big is a little much, consider taking a 3-ft square of cardboard and measuring off and building a cube as shown below. Make it 30-inches long, 18-inches wide, and 1½-inches high. At this scale, your figure is just about ¼-inch tall. I've never seen an action figure or toy this small, I suppose you would just have to draw one on paper and glue it to your soccer field of money (don't forget that big smile!)

5. Oh, and if you want to model the national debt on the scale of our action figure? That's a stack of billion dollar blocks, 10'4" long, 4'2" wide, and 4' tall. That's ***Nineteen Trillion Dollars***… and it's collecting interest!

Discussion Questions

1. You have won the lottery! They offer you your choice: One billion dollars today… or one million dollars a day for a year! Which should you choose and why?

   Answer: A billion is 1000x larger than a million. The year is only 365 days long – you would end up with only 1/3 of the money if you took the million a day!

2. A new highway building project will cost 1.3 billion dollars. How much money does the .3 represent?

   Answer: 300 million dollars!

Supplemental Materials

Going Deeper

Talking about money is fun, but students often don't have a good grasp of money, especially when they are younger. The million-billion-trillion problem can be fun in lots of ways, let's make it about something most every student knows and loves – doughnuts.

You get 12 doughnuts in a 9x9x4 inch box. Now ask your students to figure out the size and space for a larger amount of doughnuts.

1. How many cubic inches in a doughnut box? (Length x width x height)
   a. 324 in^3
2. How many boxes to hold 1000 doughnuts? How many cubic inches is this?
   a. 83.33 boxes, 27,000 in^3 total
   b. This is a 30-inch cube of doughnuts!
3. If a 30-inch cube holds 1000 doughnuts – how big will ***one million*** doughnuts be?
   a. One million doughnuts is 1000 times bigger – our cube must be 10x bigger on each side: 300 inches or 25 feet wide, long, and tall!
   b. This is three 25x25 foot classrooms with 8 ½ foot ceilings – completely full floor to ceiling with doughnuts!
4. How big are one billion doughnuts?

    a. One thousand times bigger! Three thousand classrooms full of doughnuts!

5. How big are one trillion doughnuts?
    a. One thousand times bigger! Three million classrooms full of doughnuts!
    b. Three million classrooms with 25 students each would be 75 million students. This is about the number of students in the United States, Mexico, and Canada combined!

Being an Astronomer

What does million, billion, and trillion mean to an astronomer? Let's consider the size and scale of the solar system to get an idea. One of the most important measurements that astronomers make is distance – how far away in space are planets, moons, and stars from one another?

One thousand kilometers. This is a good scale to measure moons circling planets. Few moons are larger than 1000 kilometers wide; most are between 100 and 1000 kilometers in diameter. Our own Moon is about 3,500 kilometers wide and is one of the largest satellites in our solar system!

One million kilometers. This is a good scale to measure the orbits of moons circling around planets. If you look at all the moons in our solar system (there are hundreds of them!), almost all are within 1,000,000 km of the planet they orbit. Our own Moon circles the Earth at an average distance of about 385,000 km – about one third of a million kilometers away!

One billion kilometers. This is a good scale to measure the distance from a star out to its planets. Our own solar system's outermost major planets are about three billion kilometers from the Sun. The Sun's influence extends only about 20 billion kilometers - farther away than this, the Sun's gravity and magnetic field have no influence at all. Astronomers call this ***interstellar space***.

Only the two Voyager spacecraft have made it this far away from Earth. They were launched 40 years ago in 1977, both probes are now about 20 billion km from Earth and moving away from us at about 60,000 kph. At this rate, they will reach the one trillion kilometer mark in their journey in about two thousand years!

One trillion kilometers. This is a good scale to measure the distances between stars. It takes a beam of light one year to travel six trillion kilometers – this is called a ***light year.*** The nearest star to us is just over four light years away, or about 25 trillion kilometers away!

Following Up

Look for examples in the news that use the terms million, billion, or trillion. It will help if you look for examples that talk about money such as national or state budgets. Science websites that have space news like www.space.com have many stories that deal with large numbers.

Activity 22:

The Thousand-Meter Solar System

My first exposure to models of the solar system was a poster in my third grade classroom which showed a portion of the Sun, and then artistic representations of all the planets. Mercury, Venus, Earth and Mars were all the same size, while Jupiter and Saturn were almost twice as large as the Earth, Uranus and Neptune were a bit smaller than Saturn. All the planets out to Pluto were shown in a neat line with a little paragraph beneath each one telling us something about it. You may remember something similar from your school days; you may even have such a poster in your room now!

Imagine my shock when I learned that almost everything this poster had shown me was wrong! Some of the material was just inaccurate out of ignorance, other things were so badly off that it would be charitable to classify them as anything other than outright lies! We learned in our last activity that big numbers can be a bit deceptive, but if I tell you that Earth is 100 million miles from the Sun, Saturn is a billion miles away, and Pluto is four billion miles out, after doing Activity #21, you probably have a better idea of what that means.

Academic Standards

Science and Engineering Practices

Developing and using models
Analyzing and interpreting data
Using mathematics
Obtain, evaluate, and communicate information

Crosscutting Concepts

Scale, proportion, and quantity
Systems and system models

Next Generation Science Standards

Space systems (K-5, 6-8, 9-12)
Gravitation and orbits (6-8, 9-12)

For the Educator

Facts you need to know

1. Because of the problem with ***big numbers*** (see Activity #21) virtually all models and posters of the solar system you can find for your classroom are deceptive, even blatantly false.
2. We can make an accurate model, but it takes outdoor space and effort! With the Sun the size of a basketball, our solar system is 2 kilometers wide (almost a mile and a half!)
3. We will save space by lining up all of the planets in a row (this happens only once every few centuries.) We will also not try to show the planets' circular orbits – just their distances from the Sun.

Teaching and Pedagogy

Size and scale are solid bits of scientific data, and our children deserve to know – and understand – the truth about these ideas. We will make a real scale-model of the solar system you can use in your classroom… well, on the streets around your school, anyway! Our model will do the things that poster failed to do – it will show the various planets and Sun in their respective sizes in scale to one another, and it will place the planets at the correct distances away from the Sun on the same scale as the size of the planets.

For instance, the Sun is about 100 times wider than the Earth is. The Earth is 100 times farther away than the Sun is wide. Our model will remain true to ***both*** of these facts. One scale mile on our model is always the same whether we are measuring the size of a planet, or its distance from the Sun. You and your students will quickly realize that the solar system is a very big place, and even the largest planets are relatively tiny specks lost in the vast darkness of deep space! So get your walking shoes on and let's get started!

One last thing, none of this "Pluto isn't a real planet" stuff in your classroom please! When we say things like: "Pluto isn't a planet, it's a ***dwarf*** planet!" this is grammatically akin to saying things like "Short people aren't people," or "Billy isn't a real child, he's a ***naughty*** child!" The farther we take this the sillier (and more offensive!) it becomes! Truth is, we classify planets many ways; by size, by composition, by the kind of atmosphere they have, or what their surfaces are made of. We even classify planets by where they are located, in our solar system, orbiting around other stars, or even drifting through space with no star to orbit at all!

As long as a body is large enough that its own gravity has pulled it into a spherical shape (and it's not a star!), it is a planet. If it is shaped like a potato, it's an ***asteroid***. While it is true that we haven't seen some of our minor planets up close enough yet to tell if they are actually spherical or not, we're going to give them the benefit of the doubt here. It is also true that while we may demote some of these to asteroid status someday, we will undoubtedly discover more planetary bodies in our solar system in the future.

Pluto was discovered in 1930 by my late friend ***Clyde Tombaugh***, a great American scientist and astronomer. In 1978, James Christy discovered Pluto's companion ***Charon***, and in 2005, scientists using the Hubble Space Telescope discovered that Pluto-Charon is actually a double planet – a ***binary world*** where two planets of almost equal size are locked face-to-face in an orbit 15 times closer together than the Earth and Moon. The ***New Horizons*** spacecraft from NASA confirmed Pluto-Charon's status as a binary planet with 5 little moons in orbit around it. Pluto-Charon was the first dwarf planet discovered in our solar system – we now know of many more, and our solar system model has room for them all!

Student Outcomes

What will the student discover?

1. The solar system is very vast. As large as planets are, they are tiny specks compared to the great distances between the worlds.
2. Earth is not a very large world. More than a million Earths would fit inside the Sun, even Jupiter is hundreds of times more massive than our planet and more than ten times the size of our world.
3. There is a great difference between the compact ***inner solar system*** (Mercury, Venus, Earth, and Mars) compared to the widely spaced ***outer solar system*** (Jupiter, Saturn, Uranus, and Neptune, plus almost a dozen known dwarf planets.)

What will your students learn about science?

1. Making accurate scientific models take time and effort. All too often our desire to make things easily or simple to understand requires too many compromises and results in an inaccurate model.
2. Accurate models of things that are very large or small requires a knowledge and understanding of how very big (and very small!) numbers work. Without a solid grasp of big numbers, it is impossible to comprehend a model of a solar system.

Conducting the Activity

Materials

1. A package of 25 golf tees
2. A package of craft beads from very small (2mm) to medium size (5mm)
3. A package of glass marbles (mix of large and small)
4. One standard (40mm) ping-pong ball
5. One tube of silicone glue

Note: Silicone glue cures slowly – give it a full 24 hours to dry before you or your students do anything with the models!

6. An emery board or small piece of fine sand paper (See activity #16)
7. One basketball, volleyball, or dodge ball (Any 12-inch ball will do. Larger is better, but exact size and color isn't crucial here as long as it is 10-14 inches in size.)
8. White glue, construction paper, markers
9. Some modeling clay or salt dough to use as stands for a few of our models
10. Pedometer (many free smartphone apps work well)
11. Binoculars or small telescope (optional)
12. Parent volunteer helpers (the more the merrier!)

Building the Solar System Model

1. Let's begin by making a construction paper sign for each of our planets. Once you create the sign, your class can look up some things about the planet and write them on the sign, too. You will need signs for all of these 18 of these listed below! (Yes, Virginia; our solar system has 18 planets… and counting!) Let's include a sign for the Sun as well, just to be complete. Make sure you have signs for all of these:

   Sun, Mercury, Venus, Earth, Mars, Vesta, Ceres, Jupiter, Saturn, Chiron, Pholus, Uranus, Neptune, Pluto-Charon, Quaoar, Haumea, Make-make, Eris, Sedna, and Planet X.

2. Now it's time to make our planets. For the largest planet, Jupiter, we will use a ping-pong ball. Take a look at some photos of Jupiter with its colorful cloud bands and beautiful red spot. Use markers or paints to decorate your ping-pong ball to look like Jupiter. Once you've decorated it, use some silicone glue to attach the ping-pong ball to

a golf tee, then stick the tee in a 1-inch ball of clay that you have flattened a bit to make a good stand. Allow the Jupiter model to dry overnight.

Note: White glue and super glue do not work well on ping-pong balls. From many experiments, I have found that silicone glue works best!

3. Saturn, Uranus, and Neptune are made from marbles, and placed on golf-tee stands exactly the same way as we did in the last step. Uranus should be a green marble, Neptune is blue, and use a larger 'shooter' marble for Saturn (A yellow marble is best if you have one!) Use your emery board to roughen the surface of the marble before you glue it to the golf tee with silicone glue and stand it in its ball of clay to dry.
4. For Saturn, you also need rings! I made mine out of an index card, using a compass to draw a first circle the same size as the marble, and a second circle three times as wide (it will look a bit like a target!) Cut the rings out with scissors and decorate them if you wish. Use a toothpick to put a ring of silicone glue around your marble, then slip the rings on and let them dry. In real life, the rings of Saturn are tipped a bit, so you can glue them at a jaunty angle if you like!
5. Now it is time to make our larger terrestrial planets, Earth and Venus. Use a 5mm bead for these – blue for the Earth and yellow for Venus. I simply turn the golf tee upside down and glue the beads to the pointy tip. If you put a blob of silicone glue on an index card, then dip the tip of the golf tee in the glue, the beads will stick perfectly.
6. For all the smaller planets, we will use the tiny, 2mm beads. These are actually just about right for Mars and Mercury, but quite a bit too big for the dwarf planets like Pluto-Charon, Ceres, and the rest. The correct size for these planets in our model would be a single grain of salt – but this is far too small to work with and cannot be seen easily! Use a red bead for Mars and dark blue or grey beads for everything else.

Exploring the Solar System Model

1. The pieces of our model are complete, but the model hasn't yet been assembled properly! To do this, we will need to go outside – and we will need some room to walk! Parent volunteers are also essential at this point in the exercise.
2. If you want to show the inner solar system – out as far as Jupiter, you can do that on an athletic field, a soccer or football field works well. Begin with the Sun in one corner of the soccer field, then activate the pedometer app on your smart phone and begin walking diagonally across the field. This model is calibrated in meters, but if your app will show yards, that works just as well for our purposes. Don't have a pedometer? Make big steps and just count them off!
3. Mercury is placed 10 m (or 10 large steps!) away from the Sun. Once you get this far, have one student stand at this point and hold the model up, while another student holds the sign that names and tells about planet Mercury.
4. We're going to keep walking to get to the positions of the other planets. We placed Mercury 10 meters (or steps) away from the Sun – now keep walking and counting your steps! Venus is 19 m away – about twice as far from the Sun as Mercury. Have two more students stand here with the model and its sign.
5. Earth is 26 m out from the Sun.
6. Keep walking! Mars is 39 m from the Sun. If you are walking diagonally across a football or soccer field, you should now be about 1/3 of the way across. These four inner planets are referred to as the ***inner solar system.***
7. Vesta, our first dwarf planet, is 65 m from the Sun.
8. Ceres, another dwarf, lies 72 m from the Sun.
9. Jupiter is 134 m away in our model. If you are on a football field, you are now all the way across the field diagonally from where you started! From here, you can see the entire inner solar system tucked in close to our Sun. The signs will help you tell the planets apart – but you are probably too far to read them!
10. If you want to use your telescope or binocular, this is the good place to do this. Place your telescope near the Earth and look at your model of Jupiter through the glass – how much detail can you see? Try looking at the minor planets Ceres and Vesta, can you even see them? Certainly there is no detail to be seen! Ask your students to imagine if they were looking at a salt grain at that distance! This is why astronomers use enormous telescopes – to see tiny and faint objects far out in the vastness of space.
11. If you wish to make a more complete model of the solar system than this, you will probably need to walk down a local street. Start as you did before, but this time, place a

parent volunteer with each pair of students as they hold up the planet and its sign. Alternatively, you can ask parents to hold the planet models and signs and have all the children walk with you.

Having all the students walk with you is the better option if you can do it, because it gives every student a feeling for the real distances in our model – and they get some good exercise, too! Let's pick up where we left off…

12. The next planet is Saturn, this goes 247 meters away from your Sun, almost three football fields away.
13. Chiron is 465 meters out, and dwarfed by the next major planet, Uranus, at 497 m. Uranus is half a kilometer away from our model Sun, about a third of a mile out.
14. Keep walking! Pholus is 774 meters out and great Neptune is 777 meters away. You have now walked half a mile from your Sun model. By this point, your students should have a very solid grasp of the immense size of the solar system compared to the relatively tiny planets that orbit the Sun.
15. The next four planets are out beyond the 1-km mark: Pluto-Charon at 1014 m, Quaoar at 1109 m, Haumea at 1114 meters, and Make-make at 1182 meters. Look how far away and tiny the Sun looks from out here! Pluto-Charon and the others are sometimes called ***Kuiper Belt Objects*** after Dutch-American astronomer Gerard Kuiper who predicted their existence half a century before most of these outer bodies were ever seen.
16. If you are willing to make the effort, Eris is out at 1756 meters, and tiny Sedna is at 2220 meters, more than a mile and a half away from our Sun. If you walked this far with students, it probably took you 45 minutes or more to get here!
17. The new 'Planet X' some scientists are talking about has been detected, but little is known about it. Scientists think that it is about the size of Uranus (10x more massive than Earth and about 4x as wide.) Even so, on our model, this outer giant would be 12,600 meters away from our Sun model – that's almost 8 miles away! Only dedicated Scouts and hikers would want to make this journey!

Discussion Questions

1. Why do we need a telescope to study planets if they are in our own solar system?

   Answer: The planets are tiny compared to the distances that separate them. Without a telescope to magnify the images, planets appear as bright stars, not disks like our Moon.

2. What things are ***not*** included in our solar system model?

   Answer: Like all scientific models, we've left out lots of things!

   i. The Asteroid Belt (and all the asteroids!)
   ii. The comets
   iii. The moons around the planets (Jupiter & Saturn have over 60 each!)
   iv. Planetary surface features!
   v. Dozens of spacecraft!
   vi. All the ***undiscovered stuff!*** (We should never be so arrogant as to think we've found ***everything***!)

Supplemental Materials

Going Deeper

Like so many good science activities, this one is about discovery! If you tackle this activity with the help of some parents, you are sure to see some smiles on parent's faces when you hear: "Are we there yet?" The scope of the solar system is truly vast. We are taught to think of planets as enormous objects, but we rarely teach children about the tremendous empty spaces between them. Models, diagrams, posters, illustrations in books, even video clips from reputable television programs distort the vastness of space rather terribly.

Once you get all the planets in place, it is very worthwhile to have a telescope and a pair of binoculars with you. Set up where the Earth is and ask children to look at the planets with binoculars. How many can they see? (Probably out to Saturn, maybe Neptune, but certainly no further.) Try again with the telescope, can they see any surface features on the planets or the rings of Saturn? This is quite challenging! Ask the students how large a telescope they think they would need to see the surface of Mars, of Jupiter, or of Pluto!

Being an Astronomer

If you have a telescope, or you can make it to a meeting of a local astronomy club, try your hand at observing some of the planets. Jupiter and Saturn make delightful targets – you can see colored cloud bands, a number of moons, and the rings of Saturn will amaze you! Think about how far away these planets are! Jupiter is half a billion miles away and Saturn is over a billion miles out – its ring system is about the same size and the orbit of our Moon!

Don't have a telescope? Check on Google or your local yellow pages for local astronomy clubs. Every club member I've ever met has been thrilled to offer interested people a chance to look through the eyepiece. Many clubs have outreach programs and would be willing to have their members bring their equipment to your school some night and provide a ***star party*** for your students, parents, and faculty. I've hosted many similar events myself and often had hundreds of excited children and parents show up for a few hours of star gazing out on the athletic field behind the local school.

Encourage your students to make a drawing of what they see in the telescope – you will be amazed at what your young astronomers can do!

Being a Scientist

Choose a planet that is your favorite and imagine what it would be like to play your favorite sport there! You cannot choose Jupiter, Saturn, Uranus, or Neptune – these are ***gas giants*** and have no solid surface you can land and walk around on! The giant moons of these planets are small worlds of their very own, you can choose one of them if you like!

What is your favorite planet like? Is it colder or hotter than Earth? Is there an atmosphere there? Would you need a space suit, or perhaps just an oxygen mask!? Differences in temperature, gravity, and atmosphere change everything. If the gravity is lower than Earth, you will be able to jump and throw much farther than you can on Earth. In the thin atmosphere of Mars, throwing a curve ball would be essentially impossible, but the wind would never blow a home run ball back into the park either!

If you can kick a soccer ball farther, would you need a larger field? More players? If you can jump three times higher on Mars, would you have to change Martian basketball hoops and make them higher? Think how much air, gravity, and temperature affect the games you play, then write a story or draw a picture showing how your favorite game would be different if it was played on another planet!

You might not think of this imaginative exercise as 'real science', but in fact it is! Science has a powerful imagination component; we rarely stumble on an important discovery by chance. Instead, many scientist imagine how the Universe might work and build creative models to show their ideas to others. Careful experiments show which models are valid, and which must be discarded.

Following Up

One of the best things about this activity is the wonder that it generates in the students who participate in it. Although everyone is impressed by the size of the solar system and the relative insignificance of the planets that orbit in the vast deep of space, take a minute to remind your students that each of these planets ***circles the Sun*** at these distances. This would be a great place to take out your Earth-Moon model, stretch it out in the playground, and then have someone chalk in the circle of the Moon's orbit again. If you go out to the orbit of Sedna (2220 meters out in our model), you would need a square field 2.5 miles on a side (that's 4000 acres!) just to chalk out the circle of Sedna's orbit.

Like the ***Million, Billion, Trillion*** activity, this solar system model is all about beginning to appreciate the real scale of large numbers. Remind everyone that this model is true to scale – the planets and Sun are modeled on the same scale as the size of the orbits. Although the planets are very large compared to a human being or a small spacecraft, one can easily see that navigating a spacecraft across such vast distances and trying to arrive at such small targets is very difficult. In fact, the reason that we haven't stopped at any planet farther out than Saturn is that by the time we get a space vehicle going fast enough to get to these distant places in any reasonable amount of time, it is difficult to slow down enough to enter safely into orbit.

Space craft travelling to Mars, Jupiter, or Saturn often fly through the planet's atmosphere like a meteor or shooting star and allow the air friction slow them down. The trip to Mars takes about six months, flying to Jupiter takes at least a year. NASA went 'economy class to Saturn – it took about 7 years for the ***Cassini*** space probe to get there. But the real long-distance champ is ***New Horizons***, which was launched in 2005, and arrived at Pluto-Charon in 2015 – a ten year trip!

New Horizons is the fastest spacecraft ever built, flying at over 85,000 mph, far too fast to stop at essentially airless Pluto-Charon! This spacecraft performed a ***flyby***, whizzing through the Pluto-Charon system in just a few days, taking as many photos and measurements as it could while the spacecraft went zooming past the tiny binary planet and its moons. We will still be getting new photos and data from New Horizons for at least another year, and the data sent back will fascinate scientists for many decades to come.

Unit 9:

Orbital Dynamics:
Planets and Moons in Motion

It is perhaps odd, but quite true that when you ask most people to picture a planet, a moon, or the entire solar system, they tend to visualize a series of bodies frozen in place in a neat line as you might see on a classroom poster or a textbook illustration. Almost no one pictures moons and planets racing around in orbit, moving like horses careening around a track.

Even so, ***motion*** is one of the most fundamental qualities of our successful models of the solar system. Motion involves distance, time, velocity, and acceleration; it may be linear, circular, or even elliptical in nature. We're going to skirt around all the math and physics that are implied in this and focus on one thing – movement! Our goal will be to get your students to incorporate ***movement*** into their fundamental mental picture of the solar system.

Activity 23:

A Working Model of the Lunar Phases

We have looked at lunar phases before; this was one of our first activities, but we found that this model had flaws. While the Moon is round, our old clay model of the phases was completely flat. We also noted that while the old model predicted what was going to happen next with lunar phases, it was noticeably deficient in explaining how the phases worked or why they changed as they did. This helped our students to recognize that all scientific models have flaws and are incomplete in places.

Now it is time to create a new model, one that takes into account both the shape of the Moon, and its motion as it orbits the Earth. Our new model will also take light into account. The lunar phases are obviously a play of sunlight and shadow, so we will include the light from the Sun in our new model as well. It might seem at first glance that adding shape, motion, and the effects of a distant light source into our model would make it far too complex to understand easily – not so! The power of a good scientific model to explain and simplify is often greatly underestimated – as your students will soon show you!

Academic Standards

Science and Engineering Practices

Developing and using models
Analyzing and interpreting data
Constructing explanations
Argument from evidence

Crosscutting Concepts

Patterns in nature
Cause and effect

Systems and system models
Stability and change

Next Generation Science Standards

Space systems (K-5, 6-8, 9-12)
Structure and function (K-5, 6-8, 9-12)
Waves and electromagnetic radiation (6-8, 9-12)
The Earth-Moon system (6-8, 9-12)
Gravitation and orbits (6-8, 9-12)

<u>For the Educator</u>

Facts you need to know

1. Planets and moons are all in motion. Okay, this one seems obvious, but the implications of what that means when you are observing the cosmos from a spinning, orbiting platform are not as simple as they may seem.
2. Adding motion to our model of the Earth – Moon system will finally answer the “How do phases work?” question that has been nagging us throughout this book.
3. It is the very motion of the planets, and the invention of the astronomical telescope by Galileo, which allowed him to prove that the Sun-centered model of Copernicus was in fact correct, and the Earth-centered model of Aristotle and Ptolemy were wrong.

Teaching and Pedagogy

One of the more profound and difficult tasks we face when we start teaching students using physical models is making the transition from a static model to a dynamic one. Consider that many students today learn science from ***looking at pictures*** in a text or on a screen. It is rather shocking when one realizes how little ***activity based science*** occurs in most schools. We could endlessly ruminate about the causes of this state of affairs, but the point is that students (and many teachers) are completely unfamiliar with dynamic models.

A dynamic model in motion often helps create a wonderful ‘A-ha!’ moment that lifts an idea from the page and makes it part of a child’s everyday reality. Once again, ***play*** will be an important part of our teaching. Children may stare vacantly at a photo or a video, but I have yet to meet a child who plays with a toy by simply looking at it.

The student’s urge to pick up a model and play with it should be gratified. As teachers, our job at this point is not to stop the child from ‘playing with the science equipment’, but rather to guide the child to make useful observations and discoveries during play. This is a different model of teaching than I grew up with to be sure, but it has been a powerful and effective pedagogy in my own classroom for many decades!

Student Outcomes

What will the student discover?

1. Students will discover how the phases of the Moon actually work. This is not only a matter of angles and simple geometry, but of perspective and where you stand to view the cosmos.
2. ***Motion*** is a critical part of any solar system model. Until we incorporate the movement of planets rotating on their axes and revolving in their orbits our models will be incomplete.
3. The point of view of the observer is a critical factor. The phases of the Moon that we see are not a universal phenomenon, they are dependent upon our privileged position as we observe from the surface of the Earth. If we view the moons of Mars, Jupiter, or Saturn, we will see no such phases.

What will your students learn about science?

1. How did Galileo actually prove Copernicus' ideas were correct? How does *any scientist* prove that their ideas are correct and the old ideas are wrong? This is a theme we will continue to develop throughout this book!
2. How do the phases of the Moon actually work? What mechanical process creates them and causes them to change as they do? Exploration of the ***How does that work?*** question in science is a fundamental one. We generally begin a scientific investigation with ***What is that?*** and later progress to ***How does that change over time?*** But eventually, those nagging ***How does it do that?*** questions must be addressed!
3. Our new model is very different. It hypothesizes a number of things that we take for granted, but historically were not always clear to thinking men and women. First, our model supposes that the Moon is actually round, a spherical body like the Earth. Second, it says that the Sun is the only source of light, and that it shines on Earth and Moon equally and with identical effect (half the globe is always lighted, half is always in darkness.) Third, this model hypothesizes that it is the motion of the Moon around the Earth (and the changing angles between Sun, Earth, and Moon) which causes the changes in the lunar phases that we see.

4. The final thing we learn about science in this activity is most important. By making these new hypotheses about the shape and motion of the Moon affecting lunar phases, we have in fact developed an ***entirely new scientific model***. Our tests show us something new, how the phases of the Moon actually work and how the Moon's shape and orbital motion create them. But our model does something more – ***it reconfirms what we already knew***. When your students drew the lunar phases on paper as they moved their model Moon around in orbit, they confirmed the lunar phase model that we began with, and reconfirmed the evidence of their own eyes when they looked up in the sky and observed the lunar phases change from night to night.

5. Our new model both taught us something new and reconfirmed what we had already discovered. This is the grand sweep and majesty of a ***scientific theory***. A scientific theory explains everything we already know about a subject. Our theory answers old nagging questions, sometimes questions that have puzzled thinking men and women for centuries! Our theory also points us on the way to new knowledge and helps us frame new questions that we didn't even know how to ask before.

6. A scientific theory, such as the one we just explored about the shape and motion of the Moon causing the familiar lunar phases, is often a work of genius and the product of a lifetime of diligent work and struggle. We remember the men and women of discipline and genius who developed these theories and often name these theories after their discoverers. When Newton said: "If I see farther than other men, it is because I stand upon the shoulders of giants!", he was referring to those people of science who had come before him and made his work possible.

7. At this point in my class, I often ask students if they have ever heard someone say: "You don't know that for a fact, ***it's just a theory!***" Many of them have, and after this activity it is easy for them to see how unscientific this statement actually is. Our goal as STEM educators is to help students understand the difference between facts, hypotheses, and comprehensive scientific theories.

Conducting the Activity

Materials

1. Three white ping-pong balls per student group
2. Six poker chips per group (you can substitute sports-drink caps if you like)
3. One set of 6-10 powerful magnets (for the teacher's model)
4. One tube silicone glue
5. One tube super glue (optional)
6. One can flat black spray paint
7. One can gloss yellow spray paint
8. Roll of 2" wide masking tape
9. Wooden or plastic ruler (actually, almost any sturdy stick will do)

Building the Lunar Phases Model

1. You can reuse your Sun model from Activity #20 again here.
2. **[Teacher]** Your two remaining ping-pong balls must be colored half-black, and half left unpainted white; the black side will represent night, the white side will be the daytime side of the moon or planet. If you wish to save time, you can reuse the Venus model from Activity #20 as your Moon model here. As we explained in Activity #20, there are two fundamental ways to paint ping-pong balls half-black: one at a time (very neat and precise), or in batches of a dozen or so at a time (less precise, but saves a great deal of time.) See Activity #20 for more details.
3. Now it is time to decorate the Earth and Moon using markers. There are two approaches to this, the accurate and the creative – you must decide which will work best for your students!

For an accurate model, use photos or maps of the Earth and Moon and draw in continents, oceans, mountain ridges, green prairies, islands, etc. You can even use a bit of white paint (or correction fluid!) to add storms and clouds to your model of Earth. The Moon will have no color, make it all grey and white (paler shades will work best). Draw in the maria and prominent craters and make the model as accurate as you can!

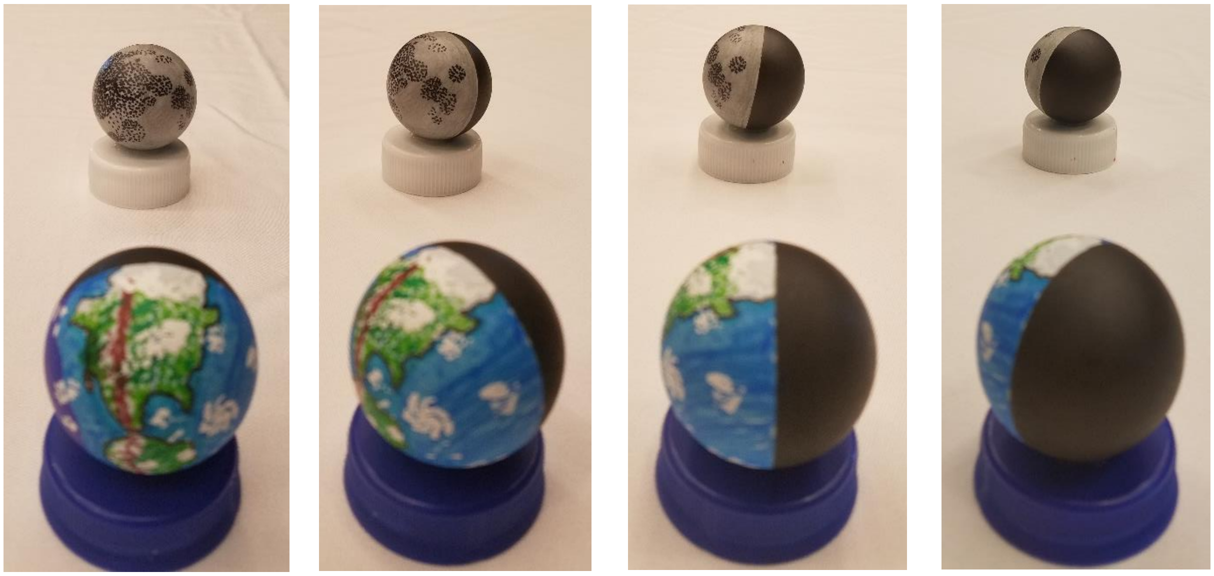
For a creative model, have students draw continents, islands, oceans any way they wish. You can even have them name their planet creations. A creative moon may have maria, mountains, craters, etc. Some moons even have oceans, although they are not always filled with water!

For the purposes of our model, it will not matter which approach you take. Alien worlds with unexplored moons still have phases the same way, and for the same reasons, that we have them here on Earth with our Moon! When you are done decorating, glue the planets and moons to their bases with silicone glue. After they are dry (24 hours!), a quick coat of clear art sealer will not go amiss (old-fashioned lacquer hair spray works well for this if you can find it!) – it often helps keep marker from coming off again on little hands!

4. Your model is now ready to play with and explore!

Exploring the Lunar Phases Model

Now that students have made their models, it is time to have some fun with them. In spite of the desktop scale of this model, working with it is an active experience for students, and one that will help them appreciate our perspective of standing on the Earth and looking out into space in a new way. This is one of my favorite activities, the delight that it brings to young and old alike is refreshing and contagious!



If you have made a set of ping-pong planet models for yourself, go ahead and attach magnets to the bottom of the bases with some superglue or silicone glue. Don't use cheap rubbery refrigerator magnets, they won't do. Models made with these weak magnets slide right down the slick whiteboard surface; this is frustrating for the teacher and often seems quite funny to the student. A magnetized set of models on the class white board can help students to position their models and understand what they are to do; a visual model to follow can be especially important for ESL or special needs students in your classroom.

Since this model only works when you look at it from the right perspective, you must take care that the students understand ***how*** to look at the model. When using magnetized models, I often use a large colorful arrow on the white board (also held on with magnets) to show students exactly how (and from what direction) to look at the model.

1. Begin by having students place the Sun, Earth, and Moon on a piece of large construction paper on the table in front of them as shown here. Be sure the 'lighted' sides of the Earth and Moon face the Sun (obviously!) and the dark, unlighted side faces away.

   I usually ask a sort of trick question at this point; "What do we call the lighted side of the Earth that faces the Sun?" The answer, of course, is "Day", which elicits both groans and laughter. It does serve the remind students that there is both a cosmic and pedestrian perspective to this model!

2. Now have students move the Moon around in orbit, reminding them to keep the lighted side of the Moon always facing the distant Sun. Where are the lunar phases? The answer to this relies on where your eye is relative to the model! From the perspective of the model Earth and Moon, your eye high above the desktop (your viewing position)

is millions of miles out in space above the North Pole. Although no human has ever been this far out in space, if ***you were there***, you would not see the Moon cycle through lunar phases either! Students at this point may be a little frustrated, but fear not, all will be revealed in the next step!

Depending on the age and sophistication of your students, this may be a good time to remind them of the scale of things from the 1000-yard solar system (activity #18). Our model is 'lying' about the distance between Earth and Sun, as well as the relative size of Earth and Moon, but these little inaccuracies will not affect the experiments we are about to do, or the truth of what we are learning about.

3. Now ask the students "Where do we see the Moon from?" Okay, another tricky question, but we see the Moon ***from the surface of the Earth!***

   Have the students put their eye down near the Earth model and look over the Earth toward the Moon – now ask them what they see! Remember that colorful arrow on the whiteboard? This is where it comes into play! (This arrow is especially helpful with younger students.)

   Your students will see a ***full moon phase!*** Have them draw a full moon phase (an empty circle) at this position where the Moon is sitting on the paper and label it. You may wish them to trace out a circle with a coin or a sports drink cap to keep things neat.

4. Advance the position of the Moon anti-clockwise in orbit by 45 degrees as shown below, remembering to keep the lighted side of the Moon facing the Sun. Have the students put their eye near the Earth and once again look ***over the Earth toward the Moon***. If they have kept everything lined up correctly, they will now see a ***gibbous moon phase***. Once again have them draw a circle near the Moon's position and shade in and label the phase as they see it.

5. Very likely, the students will be way ahead of you now and able to continue advancing the Moon 45 degrees each time, then looking past the Earth and drawing the phase as they see it. In no time at all, your students will have recreated the familiar map of the lunar phases which we began this book with in activity #1. This is not repetitive, instead it has great pedagogic value as we will soon see!

Discussion Questions

1. How is this new model different from our clay-circle lunar phase model?

   Answer: The Earth and Sun are shown in this model.

   Answer: The Earth, Moon, and Sun are shown as round in this model.

Answer: The Moon moves in this model.

2. What does the Sun do in our model? Why did we include it here?

   Answer: The Sun model reminds us where the light comes from and shows us the directly from which it shines.

3. What do you think causes the phases of the Moon to change as they do?

   Answer: The motion of the Moon in orbit around the Earth.

   Answer: The changing angle between Sun, Earth, and Moon.

4. How is this model different or better than our previous model of lunar phases?

   Answer: This model shows how the phases work – not just what happens next.

   Answer: This model includes Earth, Moon, and Sun working together to create the lunar phases – the old model just showed the Moon.

   Answer: This model includes motion and time – it is not a static model like a picture or drawing.

5. Draw a picture and use it to explain to your seatmate how the lunar phases work!

Supplemental Materials

Going Deeper

You can tell students "The angle between the Sun, Earth, and Moon creates the lunar phases!" all you wish, and have them study diagrams in textbooks or on posters, but nothing I've ever done in a classroom has been as powerful as this simple activity for helping students understand that it is the motion of the Moon around the Earth and the geometry of the lunar orbit combined with our unique perspective here on Earth the creates lunar phases.

If you really want a victory for STEM science in your classroom, have your administrator come to your room after this activity is over and ask your students to ***teach the Principal*** how the lunar phases work. Your students will be delighted to show off their knowledge and expertise to your boss, and the model is so impressive that young and old find delight in it.

Everyone seems to learn something new the first time they try it for themselves. If you have a back to school night or parent's night at your school, this is an easy and powerful was to demonstrate exciting and active learning in your classroom. This activity never fails to impress; in fact, when I came to interview for my current position as Professor of

STEM Education at my university, this is the lesson that I chose to present to my boss and future colleagues!

Being an Astronomer

If you have a telescope or an active relationship with the local astronomy club, it is an excellent time for another peek through the eyepiece. If you don't have access to a small telescope, try looking at high resolution photos of the Moon online.

If you are lucky enough to be able to see the Moon in the first quarter phase, look along the ***terminator***, the dividing line between light and darkness; this is the place where sunrise is happening on the lunar surface and shadows are the longest and most dramatic. Look at the shadows that lie inside craters near the terminator, then gradually sweep your view into the more lighted portion of the lunar surface.

If you look carefully, you will see that as you sweep away from the terminator and into the light, the shadows inside the craters become smaller – this is because ***the Sun is higher in the sky*** in these locations! You are actually seeing how shadows change when the angle of the Sun in the sky changes, and this is exactly how the lunar phases work! The changing angle of the Sun shining on the Moon as seen from our perspective on Earth causes the changing patterns of light and shadow which we call the ***phases of the Moon***.

Being a Scientist

If we examine our lunar phase model carefully or take photos of it with a cell phone, you will notice that the ***terminator***, the line that separates light from darkness on the Moon's surface, always stretches from one lunar pole to the other.

The reason for this is simple, looking down on the Moon from high above the lunar equator, we astronomers on Earth can see ***both poles at once***. When asking students to draw phases of the Moon outdoors in my astronomy classes, I noticed something curious, very few students drew the terminator shadow stretching from one pole to another.

Can you verify this curious fact in your own observations of the Moon? It is not difficult, all you need to is take time to look at the Moon with your naked eye, or through binoculars if you have them. See if you can extreme ends of the terminator lie 180 degrees apart on opposite sides of the Moon as the model suggests they must do!

Following Up

Lunar eclipses are much more common than solar eclipses, and usually far easier to see! If you and your students have the opportunity to observe a lunar eclipse, you will get to see an entirely different type of shadow move across the Moon's surface.

Lunar phases occur because we can see both the illuminated (day) side of the Moon and the dark side (night) at the same time. During the normal phases – there is ***no shadow*** on the Moon – we simply get to see both day and night at the same time.

Eclipses are different – here the Moon is moving into the shadow of the Earth and there is no connection to the day and night sides of the Moon itself. As a result, the Earth's shadow ***does not stretch from pole to pole*** as the lunar terminator does. This proves that an eclipse is a completely different phenomenon than the Moon's normal phases.

Can you make careful sketches or take photos of the Moon during a lunar eclipse that prove this hypothesis?

Activity 24:

Aristotle's Flat Moon

There is an ancient theory – sometimes attributed to Aristotle - that accounted for lunar phases in a different way than we do today. This theory held that the Moon was in fact flat (or perhaps bulged out on one side rather like a warrior's shield). One side of the Moon was silvery-white, the other side was black, and it was the orbiting of this half-black, half-white Moon around the Earth that caused the lunar phases.

Why did they say that the Moon was flat? It is very difficult, if not impossible, to actually ***see*** the spherical shape of the Moon. If you look at a ball at arm's length, or even across the room, there are many subtle clues of shading and shadow that allow us to see that the ball is in fact round. This is not true of the Moon! The full Moon looks perfectly flat – just like people in Aristotle's time, we claim to see what we are taught to see!

If this seems silly to you, let me remind you that the most common misconception ***among adults*** about the lunar phases is that they believe that the Earth's shadow falling on the Moon somehow causes or creates the lunar phases! Maybe that Aristotle fellow wasn't as silly as he appears at first glance! In any case, let's test Aristotle's theory as Galileo did and see what happens.

Academic Standards

Science and Engineering Practices

Developing and using models
Planning and carrying out investigations
Analyzing and interpreting data
Constructing explanations
Argument from evidence

Crosscutting Concepts

Patterns in nature
Cause and effect
Systems and system models

Next Generation Science Standards

Space systems (K-5, 6-8, 9-12)
Structure and function (K-5, 6-8, 9-12)
Waves and electromagnetic radiation (6-8, 9-12)
The Earth-Moon system (6-8, 9-12)
Gravitation and orbits (6-8, 9-12)

For the Educator

Facts you need to know

1. The Moon is actually round, not flat. (Okay, you already knew that one!)
2. A model makes predictions – we record these predictions and test them against what we see in Nature. Good models make accurate predictions!

Teaching and Pedagogy

This activity teaches much more about the process of science as a cultural activity than it does about the Moon. There is no controversy today about how the phases of the Moon work, how far away the Moon is, or what the Moon is shaped like – but this was not always true!

We have areas of science today which have powerful controversies swirling about them. Theories about global climate change, how (and if!) vaccines work, the evolution of species, and life on other planets are just a few of these that students may have seen in the news.

When students see one group of adults shouting that “the science is settled!”, or “96% of scientists agree with our theory!” on one side of the issue. On the other hand, there are those who insist just as vehemently that the prevailing theory is wrong; the climate never changes, species do not evolve, and vaccines cause autism but do not actually protect people from disease.

Many students (and adults!) find these arguments very disconcerting. I have had hundreds of students and adults approach me as a scientist and ask, “Which one of these is true?”, or even more to the point, “How do we know which one of these ideas is correct?”

Science isn’t about votes or polls of course, and ***people do not decide*** which theory is valid. Real scientists use experiments and data to decide these things, and Nature cannot be argued with! Even so, sometimes the experimental results are not clear to us; more often, we simply do not know how to interpret and understand what the experiment is telling us.

Never the less, sometimes we do get definitive results; powerful experiments can show us that a theory is clearly wrong. At this point, no matter how fond we are of a particular idea or theory, it is time to discard it in favor of more accurate and powerful ideas. Teaching students how we decide between theories, keeping one and casting the other aside, is a powerful lesson about science that armors children against future misconceptions and manipulation.

Student Outcomes

What will your students discover?

1. Data from an experiment does not always support our hypothesis! This is an important idea. Teachers almost always have students ***perform experiments that work***. Why would you waste precious class time doing an experiment that you knew would fail?

   The reason that we need to do an activity like this occasionally is that ***experiments do fail.*** Not every hypothesis is correct, and many more incorrect hypotheses are tested than correct ones. Every reputable scientist knows this – but very few students do.

2. The Moon is not flat. (Seriously – that is what we were testing with this activity!)

What will your students learn about science?

1. Your students will learn that theories are fallible, human creations that are subject to error and misinterpretation. We too often see theories held up as gospel-like and infallible in the media and in classrooms. Students need to know that theories are always open to question and inquiry.
2. Theories are beneficial only when they make definite, testable predictions. A theory that makes no testable predictions at all is scientifically useless.
3. If a theory makes predictions that are demonstrated to be false, then that theory must be revised or discarded. There is no room for sentiment, desire, or political correctness in science – we must be humble before the facts.

Conducting the Activity

Materials

1. A ping-pong planet model of the Earth, Sun, and Moon (See Activity #19)
2. Three poker chips, one white, two black. (You can paint these the necessary colors if you don't have ones of the correct color. Painted coins may also be substituted.)
3. Epoxy, hot glue, or super glue

Building the Flat Moon Model

1. Glue one black and one white poker chip together face to face. This will serve as Aristotle's black-and-white Moon.
2. **[Teacher]** Epoxy or glue the double chip from step #1 on edge on the second black chip as shown below. I filed a flat spot on the edge to make the gluing easier. You can use hot glue or epoxy for this, I have found that silicone glue isn't strong enough for this edge-on application, and superglue needs more surface to grip effectively. Regardless of what glue you use, be sure to hold the edge-on chips in place until the glue is completely hardened.

Exploring the Flat Moon Model

1. Now it is time to try a version of Activity #23 (Modeling Lunar Phases) using Aristotle's flat Moon instead of a round one. Let the students play with this model, and ask them to see if they can get anything that looks like the familiar lunar phases out of it.
2. Try as they might, they will not be able to do this successfully. There is no position that works and shows us the familiar gibbous, quarter, and crescent phases. The flat Moon with one white face and one black face conflicts with everything we know about the Sun lighting planets and creating day and night.
3. Because this model of the flat Moon ***does not show us what we see in Nature***, we must reject this model. The model may be interesting, but it becomes clear that Nature does not work this way, so our model is useless to us as scientists.

Discussion Questions

1. What does this activity show about Aristotle's theory?

   Answer: Aristotle's ideas about the lunar phases were incorrect. His theory did not make correct predictions and did not support or explain the facts we already knew.

2. Why do we, as scientists, decide to keep one theory and throw out another?

   Answer: When a theory cannot explain new facts, it must be modified to account for the new information. When new information conclusively proves that predictions made by the old theory were wrong – then that theory is incorrect. It must be substantially modified, or discarded all together in favor of a new theory which works better.

3. What happens when we have two different models that make similar predictions? How do we decide between them?

   Answer: Sometimes we find out that what we thought were two different models are actually the same when we look at them in another way. Other times, we simply do not know enough about the models to design an experiment that would decide which model is true and which is not. This sort of disagreement often indicates that we do not know enough about the subject and that we need to keep studying and learning more about the Universe before we can decide between our competing theories!

Supplemental Materials

Going Deeper

While it may seem strange to set students to trying out an experiment that is quite unworkable and doomed to failure, this activity does serve an important purpose. Aristotle's idea of a flat Moon were simply accepted based upon the thinker's great name and left untested for centuries. These untested (and incorrect!) ideas were taught in colleges, written down in books, and accepted without question for almost ***two thousand years!*** It was Nicholas Copernicus who developed the first modern ***heliocentric model*** of the solar system, but he never promoted his ideas during his lifetime and in fact held back the publication of his work until almost his dying day.

Galileo was cut from a different cloth altogether. He marveled at Copernicus' Sun-centered theory, and set out to test it. Galileo not only invented the modern astronomical telescope, he single-handedly gathered the needed experimental data to prove Copernicus' ideas were correct. Galileo developed many simple activities much like those in this book and wrote about them in simple language so that everyday people could try these experiments for themselves and see that Copernicus' theories of how the solar system worked were superior to those of Aristotle. Galileo fought for the acceptance of these ideas and stood fast, refusing to give up in the face of terrifying opposition.

Galileo's fight for scientific truth cost him his job, his fortune, and even landed him in jail for the rest of his life, but he never relinquished the truth. Galileo's stubbornness freed us from the tyranny of false ideas and launched the modern scientific age. Every time we ask for data, and not blind belief, we too stand fast and support the truth. When the data demands it, Galileo taught us that we must abandon old established ideas in order to move forward. We do not throw out theories because they are unpopular or uncomfortable, we do not accept them because our teachers or civic leaders tell us to do so. We stand fast and support the truth, backed by sound scientific data and successful experiments.

You may have guessed by now that Galileo is something of a hero of mine, I hope he will become one for you and for your students as well. Go ahead and find a picture of the old gent and hang it up in your classroom. Even better, ask the children to draw their own pictures of Galileo and write a bit about what he did and what we owe him for his stubborn stance and determination to protect and promote scientific truth!

Following Up

Sometimes teachers are uncomfortable about teaching scientifically controversial subjects and choose to avoid them – other times teachers present these subjects as though they are not controversial at all; the phrase "The science is settled" springs to mind here.

I believe that both of these pedagogical models do a disservice to the student. When we avoid controversial topics all together, we teach students to think of controversial issues as unpleasant and to avoid them when possible. There is also an underlying current of disrespect, an implicit claim that the student is not capable of dealing with or understanding the issues at hand.

On the other hand, when we stoutly proclaim that there is no controversy, that ***scientists know the Truth***, we implicitly lie about the nature of science. In the time of Copernicus and Galileo, 99% of the educated populace agreed that the Sun revolved around the Earth which was itself the center of the cosmos. Galileo was dismissed as a dangerous crank – today Galileo is also venerated as one of the greatest heroes in scientific history.

We ***can teach controversial subjects.*** We can teach them, if nothing else, as an example of how science works, how men and women challenge each other's ideas, and struggle to gain a better understanding of Nature. We can teach that science is never 100% certain, and that no idea is above criticism or challenge. Einstein became famous in 1905 because he was the first scientist in 250 years to challenge Newton's ideas about gravity. One hundred years later, scientists are still busily engaged in designing and carrying out experiments to prove (or disprove!) Einstein's ideas and predictions.

Unit 10:

War of the Worlds: How Impacts Build Planets

How was the Earth formed? How did the Moon get here? Are all planets formed in the same way? Deep questions like these often seem unanswerable, especially in the elementary school classroom! But as we have seen, simple models can convey concepts and ideas with a power and scope that few people appreciate.

Don’t worry, we won’t create entire worlds from scratch, but we are going to use models and activities to demonstrate how the active environment of a solar system shapes and changes the surface of planets both suddenly, and gradually over long periods of time. The theory that things usually change gradually over time, but occasionally are radically transformed by titanic events is called ***punctuated equilibrium***. There is a lot to learn about how the surface of the Earth and Moon got the way they are today, so let’s go exploring!

Activity 25:

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***[8]. 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.

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[8] 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.

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.

Teaching and Pedagogy

Once the model is made, there is still quite a lot to be learned! The largest craters and maria the students made represent some of the oldest features on the Moon. These maria were formed more than three billion years ago when the Earth and Moon were quite newly formed. These huge impacts were some of the last major objects to strike the Moon, and they give us a clue as to how the entire Moon (and the rest of the planets) were formed. Smaller objects smashed together and stuck to each other, creating a new larger object. The original impacts were wiped out as one asteroid after another struck the growing moon – but some of the last major impacts were preserved because nothing larger has wiped them out in their turn… yet! The interior of the young Moon was much more molten than it is today, and the last impacts fractured the lunar crust and allowed floods of lava to reach the surface.

Just like the real Moon, our model landscape preserves a record of both the size, and timing of the impacts. Does one crater overlap another – it must have happened ***later in time***! Are there craters on the lava flows filling a maria? This tells us the lava flow happened first. It's not always easy to read the rugged lunar surface in real life, but your students can get an idea of how astronomers date the features of a planetary surface in chronological order. Rays tell us about time as well. These lines of powdery material are very transitory, they disappear in just a few million years. Only the newest craters on the 4-billion year old lunar surface have them. This might also be a good time to remind students of the difference between a few million and a billion – the Moon is really old!

Those lines we pressed into our model with string? This can be your student's introduction to longitude (vertical lines marching east to west) and latitude (horizontal lines). Not only do the lines help your students draw an accurate map on paper, they can be used to find the location and document it on your map. On your clay model, choose a location to be point (0,0) You may wish to put a little toothpick with a sticky note flag there to mark the spot!

Horizontal (latitude) lines above this point are numbered +10, +20, +30, etc. The lines below this are -10, -20, -30, and so on. Vertical (longitude) lines to the right of this point are numbered +10, +20, +30, but lines to the left of this point are numbered 350, 340, 330, etc. Remind your students that longitude lines run around the whole globe – 360 degrees worth! Our piece of the lunar surface is just that – a piece and not the whole Moon!

Have your students use their system of latitude and longitude to find the location of the center of some of the major craters. You can have them record them on their maps, or just make a list of the names with the locations shown next to each name. Wait… did someone say GPS? Yes, that's right! These latitude and longitude lines are precisely the same at the latitude and longitude measurements that help our GPS devices tell us where we are, and keep us on the correct road when we are travelling.

Student Outcomes

What will the student discover?

1. Impactors can reshape the surface of a planet in sudden, and cataclysmically violent events. These tremendous impacts leave large scars on a planet's surface we call ***craters***.
2. The largest impactors can punch deep into a planet's interior, releasing floods of lava on the surface. Sometimes these lava floods fill the giant craters left by an asteroid impact. These seas of frozen lava are visible as dark features on the surface of our Moon; Galileo named them ***maria***, from the Latin word for 'seas'.
3. Impactors leave records of their size and composition, their direction of travel, and the amount of energy of their impact in the craters that scar the surface of moons and planets. We can learn a great deal about these asteroids from studying the craters they leave behind, even if the impact happened ***billions*** of years ago!

What will your students learn about science?

1. Science knowledge sometimes comes from the most unlikely places! Our current models about how large impactors can change not only a planet's surface, but its climate and the evolution of life came from a father and son team, Luis and Walter Alvarez, who were studying layers of dinosaur fossils!
2. Science sometimes gives us a call to action. Occasionally, scientific study reveals a process or action that may be a particular threat to both our civilization and our species.

Such evidence is not to be taken lightly, nor is it to be acted upon without clear thought and careful planning.

Scientific evidence tells us that a great asteroid impact destroyed the dinosaur species which had been the dominant form of life on Earth for over 250 million years and cleared the way for the development of mammals and eventually human life. Could such an impact happen again? Is there anything that we humans can do to prevent such a disaster?

3. How do scientists study evidence that is millions, sometimes billions of years old and determine anything worthwhile and interesting in today's world? Can ancient evidence really last for so many years? What conditions are necessary to preserve this evidence in any sort of useful form for the skilled scientists of today, and the young scientists of tomorrow?

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 the baking pan. 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 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. 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. Now you can start with marbles and beads, pressing small craters into the surface as you like. Make lots of them and don't worry about using them in 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

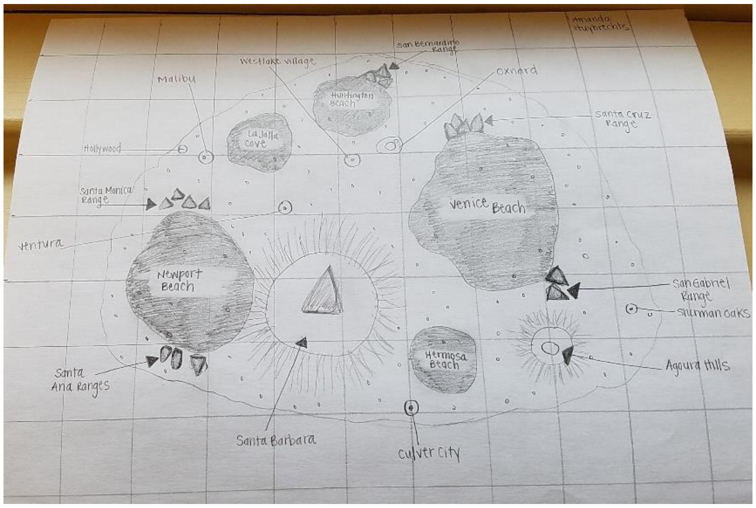
ignore the dark maria surface! Maria have almost as many craters covering them as the rest of the Moon does!

7. 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.

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.

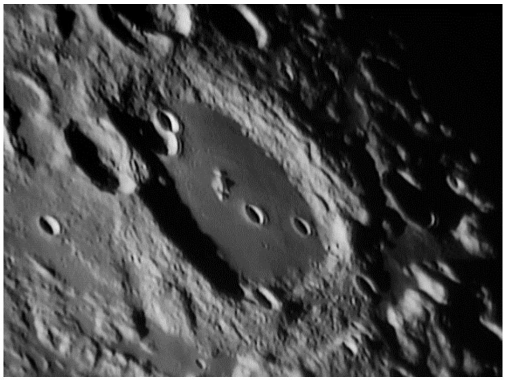
   

   Have the students name the larger craters on their maps using a theme. Will they choose U.S. Presidents? Rock bands? Favorite cartoon characters? Have fun with this!

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!



Discussion Questions

1. We have made yet another model of the Moon! How is this model different from the previous ones?

   Answer: This model is intended to show surface features instead of phases.

   Answer: This model shows only a part of the Moon close up instead of the entire thing from space.

2. What does this model show us about the Moon?

   Answer: The Moon's surface was created over many millions of years. The process of asteroids impacting the surface (we used various size balls pressed into the clay to show this) created most of the surfaces features we can see.

3. How are maria different from other craters on the Moon?

   Answer: The maria are particularly big craters that were so deep that they filled with lava. This lava hardened into dark-colored stone which is why we see dark markings on the lunar surface today.

Supplemental Materials

Going Deeper

Mapping is an important technology, but reading a map is not as easy as it seems. Find a close-up photo of the Moon on the internet and print it out. Now let's take a look at a ***lunar atlas,*** you will find an excellent one online at www.fullmoonatlas.com. Find the area that matches your photograph and see how many features you can recognize and name. This may not be as easy as it seems, your photograph and the atlas may be different magnifications, and the photos may be taken from different angles or under various lighting conditions.

Being an Astronomer

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.

Being a Scientist

In astronomy, scientists often work from photographic evidence. Very few scientists have traveled to the Moon, and none have gone to Mars, yet we learn new things every day from scientists who study photographic evidence gathered by distant spacecraft.

This time, we will use a high-resolution photograph of the Moon – or a portion of its surface. Your students will construct a timeline from photographic evidence. Think of a large number of footprints in the snow outside a busy store; which footprints were their first? Which were placed later?

We can determine our timeline for craters (or footprints!) by looking for ***things that overlap.*** If one crater overlaps another, it must be ***newer***. Have your students begin by looking at the largest craters first. Those that are overlapped the most must be older. Those craters which have nothing overlapping them must be newer.

Brightness is also an indication of newness. Craters that are bright and prominent are generally very new – less than 100 million years old! Craters that are dull and show no evidence of bright interiors or bright streaky rays around them must be older.

Erosion is another line of evidence. Is the crater rim fresh and shows a complete circle? This complete crater must be relatively new. Some craters show rims that are thinner and more worn down, sometimes they are even incomplete. These features indicate very old craters, often more than 2 billion years old.

Have your students make a timeline, showing major craters from youngest, to oldest. Have them present their findings to the class and cite the evidence that supports their ideas!

Following Up

Geology is much more than a science that names different kinds of rocks! Geology is a dynamic science, but it generally acts over enormous scales of time and wide geographical regions. One advantage of looking at the Moon from so far away is that we can see the entire surface in one view and zoom down into features that interest us without losing ourselves in irrelevant details.

The lunar surface lacks many things that we would miss if we were there, like air, water, weather, plants, and oceans, just to name a few. The Moon even lacks an active geology, there are no active volcanoes or earthquakes on the Moon. Some people might think they wouldn’t miss earthquakes, but quakes and volcanoes are part of an active geology which recycles minerals and materials that help to make life on Earth fertile and abundant.

Even so, it is the very things we might miss that make the Moon such an excellent place to study geology. With no air, water, weather, or active geology, the lunar service doesn't change very much on any sort of human timescale. Even the most casual features on the Moon such as a crater the size of a baseball, or an astronaut's footprints, will last for millions of years. With no wind to erase those footprints, or water to wash them away or fill them with silt, and not even an earthquake to cause a landslide to cover them up – what is left? The only active weathering that happens on the lunar surface is the steady rain of dust and rocks from outer space.

It would take a rock the size of an egg to obliterate an astronaut's footprint, hundreds of such rocks strike the Moon every day, but the surface of the Moon is really quite large compared to a single footprint. If you want to see even a portion of that footprint erased, you are probably going to have to wait a very long time! But on the day it finally happens, a future geologist will be able to say for sure that the footprint happened first. Geology gives us timelines in stone!

Activity 26:

Dynamically Modelling The Moon’s Surface in Flour

This activity is larger, messier, and a lot more fun that the clay model we made in Activity #25. In the last activity, we pressed various size balls into a clay surface to make ‘craters’, depressions that were smooth and round, but not very exciting or dynamic. We’re going to take this up a notch and let kids see the crater making process as it happens! By dropping weights into pans of flour to look at the resulting craters, plus the ***ejecta*** – material which is blasted out of the crater on impact.

Academic Standards

Science and Engineering Practices

Developing and using Models
Planning and carrying out investigations
Analyzing and interpreting data
Constructing explanations

Crosscutting Concepts

Cause and effect
Systems and system models
Energy flows, cycles, and conservation

Next Generation Science Standards

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

For the Educator

Facts you need to know

1. As large and impressive as craters may be, they change the landscape in a matter of seconds. The Barringer Crater near Winslow, Arizona has as much volume at 400 professional football stadiums; even so, it was excavated in under 5 seconds.
2. Craters average between 10-20 times as large as the asteroid that created them. Crater Tycho on the Moon is over 90 kilometers wide, it took a 6-10 km wide rock to create it. This mountain-sized impactor is about the same size at the Chixulub impactor which killed the dinosaurs.
3. Craters are typically a bowl-shaped depression with a raised rim around them, they also sometimes feature a raised ***central mount*** in their centers.
4. ***Ejecta*** includes all the material blasted out of the crater at impact time. There is an ***ejecta blanket***, a bright layer of material that surrounds the crater. There are also ***rays***, streaks of material radiating away from the center of the crater. Rays can be very long, sometimes more than ten times the diameter of the crater itself.

Teaching and Pedagogy

If you don't want to fool with dying corn meal, you can cover your flour surface with black spray paint instead. This method is quicker and you can stir the flour after the experiment and use it again immediately.

Flour covered with paint is a reasonable analog for the lunar surface. Almost waterless, the lunar rock pulverizes into dust when an asteroid of any size strikes the surface into a fine powder very similar in consistency to flour. The sunlight darkens the surface of the Moon over time in a process called ***radiation darkening***, we've used paint to simulate this. When the light colored rock is blasted out of a crater, it falls back onto the surface making a sunburst or splatter shape we call ***rays***. Can you see evidence of rays on any of your craters? Have the children draw what they see here.

How far do the rays go out from the central crater? Can you measure this? Is the ratio of crater diameter to ray length the same for all craters of any size? This is an interesting investigation to do; it takes patience and a little measuring, but the math is very simple. Make a chart showing the size of the crater, the size of the rays, and the ratio between them. You may find that your larger craters blasted flour right out of the pan and onto the floor! Don't worry about that (you did use that plastic tarp, right!?), use the smaller craters for your investigation and see what you find!

Want another example or the ray-making process in action? Toss a water balloon high up in the air and let it splatter on the dry pavement of a parking lot or play area – you will see the same splatter pattern with ‘rays’ of water streaking away from the center of the impact!

Impact craters on the Moon also have ***raised crater rims***. These are areas where the blast force has pushed the rock back from the center of the impact, causing it to pile up like snow in a freshly plowed parking lot. This happens because the solid rocky surface of the Moon forces the blast energy to turn 90-degrees, from straight down to horizontal. Look at your lunar-flour surface, can you see evidence of raised crater rims? See if you can measure the height of the rims above the flat surface. Is there a relationship between crater size and rim height? Another chart can help you settle this question!

Want to do it again? Just stir the flour well with a spoon, add a little more as needed and then re-smooth and repaint the surface. You can do this activity many times! If you want to keep the flour in the pan and try again tomorrow, I strongly recommend putting a cover of plastic wrap or aluminum foil over the pan to protect the flour from moisture and insects!

You can also save the flour in large zip-shut plastic bags or plastic jars and save it for salt dough art projects! Don’t forget to sift the flour to get the pebbles, marbles, and other “asteroids” out of it before you use it! Do you find that the black paint has tinted the flour a bit? Don’t worry, a little paint won’t hurt the salt dough at all – just don’t reuse it for cooking!

Student Outcomes

What will the student discover?

1. Crater making is a dynamic, violent process. The Moon’s surface may look static and unchanging, but it is in fact a record of titanic collisions and explosions. Impacts of the size that killed off the dinosaurs (100 km craters) are just large enough to be detected on the Moon’s surface with the naked eye. Most of the impact sites you can easily see are far larger than this!
2. Craters change the landscape not only by scooping out huge, bowl-shaped depressions in the ground, but by burying the surrounding landscape in tons of rock and debris we call ***ejecta.***
3. The ratios between the size of the impactor, the size of the crater, and the size of the ejecta blanket are remarkably consistent. This indicates that the crater making process is a consistent and understandable physical process.

What will your students learn about science?

1. Processes that happen on distant moons or planets can help us understand the forces that have shaped our own planet. This is one of many reasons why space exploration is both valuable and important to those of us here on Earth!
2. It is not possible – or safe! – to recreate the crater making process here on Earth because the process is too dangerous and destructive. We can recreate these processes in miniature to help us understand for forces that shape every moon and planet in our solar system.

Conducting the Activity

Materials

1. 10 lb bag of flour.
2. A deep dish pie or cake pan
3. A 2 lb box of corn meal
4. Several bottles of dark blue/black food coloring, or a bottle of black ink
5. A large 12-ft square tarp or plastic sheet. Check the paint department of your local home improvement store for this, sometimes sold as a 'plastic drop cloth' for protecting floors and furniture while you paint.
6. A roll of masking tape to hold the plastic sheeting securely down on your floor and prevent tripping.
7. An assortment of small pebbles, marbles, etc. Nothing larger than 1-inch diameter.

Building the Impact Crater Model

1. Dilute two bottles of dark food coloring in ½ cup of water. Put the corn meal in a large bowl, add the colored water and stir for several minutes until well mixed (a kitchen blender works well if you have one.)
2. Spread the corn meal out on cookie sheets or aluminum foil and allow to dry. You can put the cookie sheets in a low (180 degree) oven for an hour or so if you wish to speed the process. Once dry and cool, return the corn meal to a bowl and stir thoroughly to insure all granules are separate. Store in original box or in a zip-shut plastic bag.

3. Lay the tarp or drop cloth out on the floor and tape it down securely – you're going to need a large area for this so you may want to push the desks aside!
4. Put the large pan or box-top in the middle of the tarp and fill with flour to the top. You can overfill a bit and use a yard stick to strike off the top to make a smooth, flat surface.
5. Sprinkle a thin, even layer of dark corn meal on top of the flour.

Exploring the Impact Crater Model

1. Have everyone gather round and pick up an edge of the tarp; most should stand well back to keep splattering flour off shoes and clothes.
2. Choose a lucky student to drop a pebble or marble into the flour from a height of about 1 meter.
3. Students can now inspect, photograph, and sketch the crater they have created. Have your students look for the crater basin, crater rim, ejecta blanket, and rays.
4. Measure carefully and see how large the crater was compared to the impactor that made it. How about the size of the ejecta blanket compared to the crater? How far do the rays extend away from the crater?
5. Want to try again? (My students always wanted to do this multiple times!) Try using different size pebbles, comparing the effects of large and small weights. Don't let children ***throw*** their pebble, as that can make a real mess!

Discussion Questions

1. How was this model different from the clay model you made last time?

   Answer: This model shows the crater-making process as it happens instead of just modeling the shape of finished craters.

   Answer: This model is ***dynamic***, we see it in action as it is being created.

2. What does this model show you that the other clay model did not?

   Answer: The crater formation process (asteroid impacts as they happen!)

   Answer: Crater rims and crater rays.

3. What have you learned about the size of the impactor compared to the size of the crater and the ejecta blanket that surrounds it?

Answer: Craters are always significantly larger than the impactors that create them. The size of the ejecta blanket and rays are truly enormous compared to the impactor. A 100 meter impactor (the size of a football field) could throw ejecta material more than 25 kilometers from the impact site!

Supplemental Materials

Going Deeper

How are craters discovered? From our work here, you might think that you just have to look for a crater to find them. On the Moon, finding craters is fairly easy, but not so on our own Earth!

Craters on the Moon are visible to anyone with a pair of binoculars; if you have access to a telescope, you can see thousands of craters. The Moon is a unique environment, there is no air, no water, and almost no erosion on the surface at all. Unlike Earth where rain, wind, and even earthquakes and volcanoes disturb and reshape the surface, our Moon is ***geologically dead***, there are no active reshaping processes there. The only weather and erosion on the Moon comes from rocks falling from space to strike the surface.

If you could go back in time 100 million years, the Earth would look very different. Apart from dinosaurs, even the continents would be in different locations! Mountains that look old and rounded now would have looked new and rugged then; some mountains that we are familiar with would not even have been formed then!

Our active Earth wears away, buries, and destroys most craters in just a few million years. Most of the known craters on Earth have been discovered from space, either from the space shuttle (1981 – 2011) or from the International Space Station.

Being an Astronomer

Telescope time again! Now it is time to take another good look at some craters on the Moon's surface. Can you see the features we discussed such as crater rims, ejecta, rays, and central mounts in lunar craters? Can you find overlapping craters where one impact destroyed evidence of another earlier impact?

You will find that some craters appear bright – these are relatively new, less than 100 million years old! Other craters show eroded rims indicating they must be a billion years old, or even older. You may also find ***maria***; dark, circular basins filled with dark colored lava. These maria are impacts so tremendous that they cracked open the Moon's crust allowing lava to flow in from deep within the interior. The Moon's interior is all frozen solid today so no impact, no matter how large, could cause a maria to form in modern times.

Being a Scientist

Sometimes the size and scope of the damage that an impact event can create are hard for students to imagine. If you have older students (6th grade and up), you may wish to have them investigate what an impactor could do if it struck the Earth.

Purdue University in Indiana has a wonderful website called *Impact Earth!* (www.purdue.edu/impactearth) which allows students to enter data on the size of an impactor, its speed, angle, and the type of terrain that is struck. Once you enter the data, your students can indicate how far away they are and see how the impact effects them.

The *Impact Earth!* website shows blast damage, heat damage, ejecta damage, and seismic damage from the impact and describes in detail what the impact would be like for the observer on the ground.

Following Up

Earth, Mars, Venus, Mercury, and the Moon all show substantial impact damage from asteroids striking their surfaces, but larger planets like Jupiter, Saturn, Uranus, and Neptune do not.

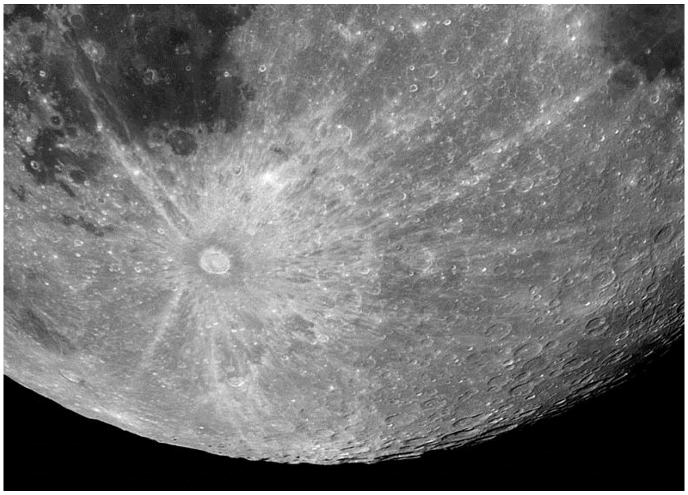
Investigate these planets and compare them to our own Earth and Mars. Why would our inner planets all show impact damage but these large worlds do not?

Answer: These larger worlds are ***Jovian planets***, sometimes known as 'Gas Giants' – they have no solid surfaces at all. Asteroids may impact them, but they easily penetrate into the planet's interior without leaving a mark on the gaseous surface.

Activity 27:

Exploring Crater Rays in Detail

Many students are fascinated by crater rays. Once you've seen one of them on the Moon's surface, you just can't help looking for them like shamrocks among the clover. Ray systems occur in almost all craters on the airless Moon, but they are virtually unknown on the Earth – why do you think that is?



The answer has to do with our thick atmosphere – and the Moon's complete lack of air. On Earth, if an asteroid is large enough to strike the surface and make a crater, the blast will look rather like a mushroom cloud from a nuclear test explosion. The extreme heat creates a rising column of hot air that carries pulverized rock high aloft into the stratosphere. If you look at the rising plume from a large volcanic eruption in a photo or a video, you will have an idea of the amount of energy such an impact can release.

Things are completely different on the Moon; with no air, it doesn't matter how much heat the impact generates, there will be no plume of dust and smoke because there is no air to rise and carry it aloft. Pulverized rock dust sprays out more like water from a hose, flying in perfect parabolic curves with no wind to disturb or distort its path. Modeling a single impact on Earth in your classroom requires a little ingenuity, but we can do it easily!

Academic Standards

Science and Engineering Practices

Developing and using models
Planning and carrying out investigations
Using mathematics

Crosscutting Concepts

Cause and effect
Scale, proportion, and quantity
Systems and system models
Energy flows, cycles, and conservation

Next Generation Science Standards

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

For the Educator

Facts you need to know

1. Rays are made of pulverized material ejected from the crater during an impact. The reason we see streaks of material is because the irregularities in the rim alternately block and channel the flow of material flowing outward.
2. Ray material is often as fine as sand, or even flour in real life.
3. Earth's atmosphere stops rays from forming. The dust is suspended in the air as a dust cloud which drifts away on the wind. On the airless Moon, or nearly airless Mars, rays are distinct and easy to see.
4. Rays stand out because the finely powdered material is bright and more reflective than the darker ground on which it lies.
5. Rays on the Moon are easiest to see in the days just before and after the full moon.

Teaching and Pedagogy

Rays on the Moon are made of very finely pulverized rock that is as fine as flour. Jagged edges along the irregular crater rim channel the explosive power of the impact and help create the streamers of powdered rock we call ***crater rays***.

One of the most famous crater and ray systems on the Moon is from Crater Tycho. Tycho is almost 90 miles wide and 4 miles deep – it is a virtual twin of the impact that destroyed the dinosaurs here on Earth 65 million years ago, some scientists even hypothesize that the Crater Tycho on the Moon and the Crater Chixulub on Earth were made from two pieces from a single asteroid that broke apart and fell into the inner solar system at about the same time.

The rays from Crater Tycho run for more than a thousand miles across the surface of the Moon and are easy to see with any small telescope on a full moon night. It is likely that the rays from your crater went out much further than your students expected them to! In fact, if you were skeptical about why I asked you to put down a 5-ft wide spread of craft paper, you probably aren't any longer!

Rays and crater volume are both a good measure of ***impact energy***. It requires energy to excavate a crater and lift out all the rock and soil that used to be where the crater is now. The famous ***Meteor Crater*** in Arizona has a volume about 400 times larger than a football stadium, and this huge crater was excavated in just a few seconds.

Rays are also a measure of impact energy. Like excavating a crater, it takes energy to first pulverize the rock, and then to lift and throw it over great distances. The rays from great craters like Tycho are rarely more than an inch thick, but they extend over vast distances. These rays represent thousands, even millions of tons of rock that was smashed to powder and then thrown across tremendous distances! How much larger was your ejecta blanket than your actual crater? What was the size ratio between the crater and your ray systems? All of these things represent impact energy from the asteroid smash that created your crater!

Student Outcomes

What will the student discover?

1. You can learn a lot from looking at a rock! We tend to think of rocks as hard, virtually indestructible things, but on a planetary scale, rock is soft enough to record the scars and impacts that have formed all the planets in our solar system, including the Earth and Moon.
2. The Earth is quite different from the Moon, geologically active with earthquakes and volcanoes, scoured by wind and rain, these things tend to erase the record of early impacts that formed our Earth billions of years ago. The Moon with its airless, waterless environment has virtually no erosion. The Moon's interior is also almost completely solidified, any molten material remaining is so deeply buried that it can never affect the lunar surface again with volcanic eruptions or earthquakes – we say that the Moon is ***geologically dead*** and almost completely unchanging.
3. It is this very lack of geological and environmental activity that makes the lunar surface such a perfect record of events both ancient and modern. To the scientist, the shapes of the lunar landscape as well as the types and age of the rocks there tell a story that

stretches back over four billion years to a time when the Moon was newly formed and still molten on the inside.

What will your students learn about science?

1. You often hear people challenge scientists, saying: 'How do you know that?' or 'What evidence do you have?' But in the case of the Moon and its ancient and violent history, the evidence is right in front of us. We see it every time we look up at the man in the Moon.
2. This insight into how the scientist looks at the commonplace things around us and sees more than their neighbors do is quite valuable. It is sad, but true, that the adults in a child's life often shut down the myriad of questions that a child has when they see something new.

   When we teach young children about science, we need to give them a different message; we need to remind them to keep asking those questions, and to cherish and pursue the most difficult ones. It can be the beginning of a lifetime of adventure!

Conducting the Activity

Materials

1. Flour and black spray paint (See Activity #22.)
2. Two pieces of 5-ft long x 30-inch wide black or dark blue craft paper (any color will work here as long as it is as dark as possible.)
3. A 10-inch spring form cake pan – $10 (You may get paint on this, so don't bring a nice one from home!)

Building the Crater Ray Model

1. Tape your two pieces of black craft paper down to the floor – this should give you a nice 5-ft square area to work in.
2. Put your spring form pan ring down on the paper (don't attach the bottom!) and carefully fill it with flour to the top. Use a ruler to strike off the excess and sweep it away carefully with a soft paint brush. Try not to leave any stray flour on the black paper.

3. Lift the ring straight up. The flour will slump a little around the edges and leave you a nice mound about 2-½ deep in the center. Spray black paint over the mound of flour keeping the can at least 18-inches away from the surface.

   If you would rather not work with paint in the classroom, try putting some black or dark blue food coloring into a bowl with about 2-3 cups of flour. Keep stirring the flour with a whisk and gradually add food coloring until the flour is a dark, uniform color. You can then put the dark flour in a sifter and sift a dark surface layer over your pile of white flour. The color is only for contrast, and this works just about as well as paint.

Exploring the Crater Ray Model

1. You are now ready to drop a weight into the flour pile. If you have access to some disk-shaped weights common to science labs, these work wonderfully. If not, a large marble or slightly flattened 2-inch ball of clay will work well. Drop the weight from about 2-feet up; if you are using disk weights or flattened balls of clay, be sure to drop them so they land flat against the surface!
2. The impact on your pile of flour will not only make a satisfying crater, but a very dramatic system of rays spreading out over your black paper surface. It is often advisable to photograph the crater and its rays with your smartphone camera before children start to measure and explore!
3. Measure the ***crater diameter*** from one edge of the rim to the other and record this.
4. Measure the ***ejecta blanket*** from one edge to the other and record this. The ejecta blanket is the more or less continuous circle of material thrown out of the crater at the time of impact.
5. Measure the rays spreading out from the crater from the crater's rim out to the tip where the ray disappears. Measure enough of them so that you can get a good average. If there are enough rays, each child can measure one or two. Record the shortest and longest rays, and calculate the average length of rays for your crater.

Discussion Questions

1. What did this activity show you about craters that the last activity did not?

   Answer: Rays are awesome! Crater rays extend for great distances – much farther than most people might think.

2. What does this activity show you about the energy of asteroid impacts?

Answer: When we remember that crater rays are made of ***powdered stone***, we begin to realize how much energy it must take; first to pulverize solid stone into a powder, and then to blast this powder hundreds of miles across the lunar surface.

3. Why don't craters made on Earth have any rays?

Answer: The powdered stone would be carried away as smoke or dust on the wind instead of falling in neat lines.

Answer: The powdered stone would be washed away by rain and wind in a relatively short time. Any rays created on Earth would not exist just a few years after the impact crater was created!

Supplemental Materials

Going Deeper

We haven't always discussed "impact craters" on the lunar surface. When I was young, we were taught that almost all the craters on the Moon were volcanic in nature, and that the idea of something large enough to strike the Earth or Moon and make a large crater was a ridiculous idea.

The discovery of the true nature of impact craters is tied up with two men, and one giant impact crater in northern Arizona. Daniel Barringer purchased what became known as ***Barringer Crater*** in 1903, hoping to mine the site for tons of meteoric iron he assumed must be buried there. Barringer published many articles in scientific journals claiming to prove that the crater was made by a giant meteorite striking the Earth. Although the scientific community never accepted Barringer's work as conclusive – the Barringer family steadfastly claims that he discovered the meteoric nature of impact craters before anyone else.

Gene Shoemaker first came to Barringer Crater in the late 1950's and continued to study the site into the early 1960's. Shoemaker's analysis of shocked quartz proved that the crater had to be of meteoric origin. Shoemaker was slated to be an Apollo Astronaut, but a heart ailment kept him from flying. Never the less, his work on impact craters was verified by the Apollo astronauts, and today we all know that almost every crater on the Moon was caused by the impact of asteroids from space – not volcanic explosions!

Being an Astronomer and Scientist

We combine the astronomer and scientist sections for this activity because they are so closely interwoven. If you have a telescope, so much the better, but if you do not then a high quality photograph of the full Moon will serve.

1. At or around the full moon, take your telescope an hour or so after sunset when the Moon is well above the horizon. Viewing the Moon at 80-100x, scan for craters with bright ray systems.
2. Have your students draw a crater and a ray system as accurately as they can, paying attention to the crater diameter and ray length. If you can determine the extent of the ejecta blanket, add that to your sketch!
3. After sketching, measure the size of the crater and compare it to the length of the rays and extent of the ejecta blanket.
4. Calculate the ratio of the sized of the crater compared to the ejecta, and to the rays. Compare these ratios among the students – can you find a consistent relationship between crater size and ray length?

Following Up

A class visit to Barringer Crater (also known as Meteor Crater) in Arizona might not be possible for your class – however there are many videos that will take you there without leaving the comfort of your own school room. As with all videos on the web, be sure to preview them to insure that the content is age appropriate for your students.

Activity 28:

Dynamically Modeling The Lunar Surface in Plaster

This is a fascinating (and messy!) activity which always seems to delight children. The fact that the asteroid impacts which shape the worlds and moons in our solar system are violent and sudden affairs is easily brought home to everyone with this exciting activity! This activity will take a bit more preparation, and practice, than anything else we have done before. The practice involves timing, because wet plaster hardens quickly and if you start too soon, impacting rocks will simply disappear as though you've tossed them into a bucket of water – but wait too long and they will just bounce off the surface without affecting anything! You will need to try this on a small scale by yourself before you do the larger activity with students!

Academic Standards

Science and Engineering Practices

Developing and using models
Planning and carrying out investigations
Analyzing and interpreting data
Using mathematics

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)
History of Earth (K-5, 6-8, 9-12)
The Earth-Moon system (6-8, 9-12)

For the Educator

Facts you need to know

1. Working with Plaster of Paris takes practice. Plaster can be a messy medium and your best choice will be working outdoors. Likewise, plaster can damage clothing and shoes – children will need to wear old clothes and shoes if possible for this activity!
2. You may wish to ask your custodians for help with this project. You will be mixing and pouring heavy materials, and chances are that your custodial team has more experience working with mortar than you do! The custodial team at my school loved working with me on these projects, I'm sure yours will be happy to help too!
3. A permanent model offers many advantages over a temporary clay or flour model. Permanent models can be touched, painted, measured, photographed, and displayed for parents and administrators.

Teaching and Pedagogy

Your new plaster model of the lunar surface has quite a few features that other models lacked. The dark painted surface contrasts very well with the ***ejecta blanket*** material (white plaster) so you and your students can clearly see that material was ejected from the craters as they were formed.

You may wish to measure the size of the ejecta blanket (calculating the approximate area of such a feature can be an interesting geometry problem for older students!) Is there a correlation between the size of the crater and the size of its ejecta blanket? Modern geologists and astronomers are investigating questions like these even today!

No doubt you will also notice that later events (the small rocks) made marks ***on top of*** older features. This is exactly what happens on the lunar surface as we have discussed before. Your model shows you geological timelines forming in action! Have your students map your landscape on a piece of construction paper and name the major craters. Can they construct a timeline that shows when these craters were formed?

The maria made of dark plaster also offers areas for investigation. If you took photos before and after the maria was formed, how many features were obscured by the lava flows as the original crater filled and became a maria? How does this formation relate to our timeline? Can your students notice ripples or inconsistencies in the lava flow now that it has hardened? These features still exist on the Moon today billions of years after these lava flows hardened into stone.

You may also have noticed that our model lacks some features that the others possess. Our flour models showed beautiful rays, but our plaster model shows none. Ask your students why not? In fact, our flour model was made of powdery material that was perfect for forming rays made of streaks of fine powder grains. Our plaster model was made wet – and our little rocks could in no way strike the surface hard enough to pulverize it into a powder again!

Student Outcomes

What will the student discover?

1. We tend to learn about things like continental drift, earthquakes, and mountain building that take millions of years to change the surface of a planet. Impact craters are titanic events that change the surface of a planet in minutes – and sometimes extinguish much of the life on the surface and even deep in the oceans.
2. Craters come in all different sizes – and all different impact energies! The smallest craters on the Moon were found in small beads of glass; these microscopic craters were made by granules much smaller than a grain of sand. The largest know crater in the solar system is called Aitken Basin – it is 2200 km wide (larger than Germany) and is up to 15 km deep!
3. Craters not only disturb and shape the surface of a planet – sometimes they affect the interior as well. Maria on the Moon are examples of craters so deep that they allowed lava from the Moon's interior to flow to the surface and fill these giant basins.

What will your students learn about science?

1. Taken together, these various models show us something unique about the scientific process. Specifically, even though each model was quite good, none of them showed every feature and fact that we already know to be true about the lunar surface. Modern science tries to build models to help us understand how nature works, but we are limited by are time, money, tools, and even by things we haven't yet discovered or don't understand.
2. Scientists often build multiple models to help them understand various aspects of nature. Some of these models are physical, rather like the ones you have made in your classroom. Other models may be much farther removed from the actual processes, others may be entirely mathematical and have no physical components at all!
3. When we see that scientists have multiple models of something, or even multiple explanations for a single phenomenon, that doesn't mean that the scientists are 'doing a bad job' or that they don't understand what is going on. Science is a rich activity, full of nuance and subtlety.

4. When we are modeling something as wonderful and complex and forming the surface of an entire planet, it can take a series of models to help us understand nature more completely. Sometimes a single model cannot show us everything we want; and some things, like asteroid collisions, are so tremendous in their energy and size that we simply cannot model them completely in our laboratories or classrooms.

Conducting the Activity

Materials

1. 25 lb bag of plaster of paris – (See your local home improvement store for this, the paint department usually has it!)
2. 25 - 50 lb bag of "play sand" – Play sand is finer than builder's sand and does a better job for us with this project. The biggest problem is lugging the stuff around, but it can be used for lots of classroom projects!
3. A very large dish pan or cafeteria pan and a large metal spoon or garden trowel to mix the plaster. A wheelbarrow can also be used if your custodian has one.
4. Can of flat black spray paint (any dark color will do.)
5. The top from a case of copy paper
6. A roll of duct tape
7. A quantity of black, water-based classroom paint (about ½ cup.) Black food coloring can also be used for this if available.
8. Large trash bag or aluminum foil for lining the box top
9. Assorted rocks and pebbles from fingernail size up to egg size. Use only <u>one</u> of the largest size (2-inch) rocks, 5-7 of the 1-inch size, and everyone else gets a smaller size.
10. Large tarp or drop cloth, ***at least*** 12 x 12 ft. (See Activity #22)

Building the Lunar Landscape Model

1. **<u>Everyone</u>** wears old clothes for this. The plaster may splatter about a bit, and it will not really come out of clothing or off of shoes. The tarp will help, but just be aware of this issue.
2. Reinforce all the corners of the box top with strips of duct tape. Be sure you use enough, the plaster mixture will be heavy and if it bursts out of your box, the activity will be ruined!

3. Lay out the tarp and the cardboard box top from the copy paper and line the box with a large trash bag or a generous layer of aluminum foil. Have all your materials at hand, pre-shake the can of spray paint, and make sure everyone has a rock to throw.
4. In your large dish pan (even a wheel barrow works well!) mix 2 parts dry plaster to one part dry sand. It is fine if you have extra sand, but too little will not do, be sure to make enough! If you end up with more wet plaster than you need, the extra can be dumped onto a plastic trash bag to set and then thrown away when hardened.

   Follow the directions on the bag, but mix the plaster **wet**, add just a bit more water than strictly needed. The mixture will be like cake batter when mixed properly. Make sure you use the spoon to dig into the bottom and corners of the pan so that all the plaster is mixed in. If you feel you've made it a bit too runny, you can add another cup of plaster in – don't worry, it **will** thicken up and harden!
5. When mixed, pour the plaster into your cardboard box mold, filling it to the top. Immediately spray paint the top of the plaster. This is an excellent time to have a volunteer rinse out your dish pan thoroughly with a garden hose!

   If you have some extra plaster, pour it into a paper cup as a tester. Poke into this mixture with a stick – if the plaster is no longer runny and the stick leaves any sort of permanent mark, you are ready to begin. This won't take long, perhaps a not even a minute.
6. Have your students each hold the edge of the tarp and lift it up in front of themselves as an apron or splash guard. (Don't lift up the box of wet plaster and spill it!) Begin with the student holding the largest rock, toss it vigorously into the middle of the box. After this, the students with mid-sized rocks can toss them in one at a time. Don't drop them, you must throw them down into the plaster to make a large enough impression. Finish up with all the smaller rocks. If you have 30 students, you will have an excellent landscape – if fewer, some students can toss an extra rock or two.

Exploring the Lunar Landscape Model

1. Allow the plaster to harden for at least an hour before you move it, then carry it inside. It will be heavy, get some help with this! Be sure you display it on a sturdy table where it will not fall!
2. Now it's time to fill in the maria! You may wish to take a photo of the landscape before and after you make the maria for comparison! Put a couple of cups of plaster (no sand this time) in a large mixing bowl, add ½ cup black paint or squirt a whole bottle of dark blue or black food coloring into the required water. Mix the plaster and make sure it is thin and runny! Pour this plaster carefully into the largest crater in your landscape –

your maria is filling with lava! If some of the dark plaster-lava overflows the maria and runs out onto the surface, that is excellent – just like it happens on the Moon!

You will notice that some of the craters are filled in and obliterated by the lava flow, point this out to the students as it happens!

3. For extra realism, you may wish to toss in some very small rocks (less than ¼-inch) to make small craters on the maria floor.
4. [Optional] You can use a ***chalk snap-line*** to mark lines of longitude and latitude on your model. Ask your custodial staff about this, chances are good that they may have one which you can use already; if not, one of them will probably know how to use it and be able to help you with this.

   If you do not have a snap line – you can use colored builder's twine (available at any home improvement store.) Leave your model in the cardboard box and cut notches every inch along the edges of the box. Thread the twine back and forth through the notches – first lengthwise, then crosswise. The twine will mark out lines of longitude and latitude that will help your students draw and map the landscape they have made!

Discussion Questions

1. How is this model better than the flour models we made earlier?

   Answer: This model gives us a permanent record that is easier to study over a period of days and weeks after we made it.

2. Why doesn't this model show crater rays like the flour model did?

   Answer: The plaster in our new model starts out as a liquid and splashes on impact. The flour is already ground to a powder and is capable of being blasted out of the crater much like pulverized stone from a real crater!

3. What did you notice when your teacher started to fill the maria with dark-colored plaster?

   Answer: This dark plaster is like lava coming from deep within the lunar interior. The plaster fills the maria, making a smooth, level surface. The plaster also fills, covers, and destroys some of the smaller craters as it flows across the surface.

Supplemental Materials

Going Deeper

Map making is one of the oldest mathematical activities. Maps make visible, physical representations of sizes, distances, and spatial relationships that transcend language. This is why map making is one of the most powerful techniques a science teacher has for effectively teaching the ESL student.

Once you have put longitude and latitude lines in place on your model, have students make a grid on a piece of construction paper. Have the students map the features of your lunar model onto their own paper – this makes a great activity station for group work day.

Tell the students how many miles or kilometers each square represents, then have them use the grid to determine things like x-y location of various craters, sizes of craters and maria, and the distances between various features using the Pythagorean theorem or just by measuring with a ruler.

Being an Astronomer

Another night at the telescope looking at the Moon? Sure! The Moon is beautiful and mysterious and worthy of a lifetime of study. If you have been doing these lunar surface activities through a semester, your classes will be bringing more knowledge to the eyepiece each and every time they look.

When we come to the telescope with a mental model of the Moon, its craters and maria fresh in our minds, then we come prepared to explore and discover new things. In short, we are primed for learning – not just seeing.

If your students have another opportunity to study the Moon through a telescope, have them look for evidence of geological processes such as lava flows, landslides inside the walls of giant craters, even geological erosion of ancient crater rims.

Being a Scientist

Craters, in spite of their great age, tell us a lot about the ***impact energy*** of the asteroid that made them. Larger craters obviously indicate more energy, but how to measure this? With your plaster model, you have a fun and easy way to investigate this. By filling a plaster crater with water to the very brim, you can measure the volume of the crater quite precisely; more volume indicates that more surface material was blasted away, and hence more impact energy!

To measure the water, you will either need a ***graduated cylinder*** (a very precise measuring cup of sorts), or a scale that can weigh in grams. A graduated cylinder is measured precisely to allow you to record how many milliliters of liquid are inside. Start with a cylinder with 100 mL of water, and after you have filled a crater you have 13 mL left – then you have used 87 mL of water to fill the crater – this is the crater's volume, and a direct measure of the energy that created the crater in the first place.

A bottle of water and a digital scale work just as well. Weigh the full bottle in grams, and weigh it again after you have filled the crater. If your bottle weighs 1000 grams full, and 835 grams after filling the crater, you have used 165 grams of water to fill the crater. Interestingly, this means your crater volume is 165 mL. This exact correlation between grams and mL of water is not a coincidence – French scientists designed the metric system with water in mind so that 1 mL of water was defined to be exactly 1 gram of mass.

One thing your students will notice is that they cannot directly measure the volume of the maria you have created because you have filled them with plaster 'lava'. Scientists and astronomers on Earth have the same problem when studying the Moon! Have your students measure and record the diameter of the craters alongside their volumes. Can you find any correlation between energy and diameter? Try graphing your craters with energy on the vertical axis and diameter on the horizontal axis!

After naming, mapping, and measuring the volume of the craters, record the crater energy (volume in mL) on their maps. Make a list of the craters on your map and classify the size of the impacts. This little adventure into a more mathematical analysis of your lunar landscape can be both exciting and fun.

Following Up

Craters are everywhere in our solar system. Take some time on the internet to search for photos of Mars, Mercury, even Pluto, these bodies are loaded with craters! Try searching for images of 'Moons of Saturn', or 'Moons of Jupiter' – there are more than 120 of these moons for you to explore, and all of them have craters.

How large are these craters compared to the little moons themselves? Take a look at a crater named Stickney on the Martian moon Phobos. This crater covers a substantial portion of the surface of the Martian moon. How large a crater do you think a moon or planet can have without being destroyed? Scientists debate and study this issue today!

Unit 11:

The Four Seasons: Two Competing Models

The change of the seasons through the year are one of the more obvious, and more puzzling aspects of our world. Throughout history there have been many theories as to how and why the seasons change in regular cycles as they do – some of these were quite insightful, others were simply preposterous. We will take a look at two competing theories, one is actually correct, and the other is a very common scientific misconception, mistakenly believed by a great many people! Your students will use the skills they have learned about building a model, playing with it, seeing what predictions the model makes, and then comparing these predictions with actual observations in order to decide which model is correct!

Activity 29:

The Elliptical Model of the Seasons

This model predicts that the elliptical planetary orbits discovered by ***Johannes Kepler*** are indeed the cause of the seasonal changes. In this model, the Earth's axis stands perpendicular to its path in orbit, and the change in distance from the Earth to the Sun causes the change in the weather of the seasons as we move through the year. Our ping-pong models of the Earth, Moon, and Sun from Activity #23 are built on this premise. We've built our model with the Earth's South Pole glued to the poker-chip base, and the North Pole stands straight up. The Earth's axis is ***not tilted*** in this model. This activity works best with students working in groups of 2-3.

Academic Standards:

Science and Engineering Practices

Developing and using models
Planning and carrying out investigations
Analyzing and interpreting data
Constructing explanations
Argument from evidence

Crosscutting Concepts

Patterns in nature
Cause and effect
Systems and system models
Energy flows, cycles, and conservation
Stability and change

Next Generation Science Standards

Space systems (K-5, 6-8, 9-12)
Waves and electromagnetic radiation (6-8, 9-12)
The Earth-Moon system (6-8, 9-12)
Gravitation and orbits (6-8, 9-12)

For the Educator

Facts you need to know

1. Every planet's orbit is ***elliptical*** in shape, rather like an oval, and the Sun is not located at the center. This means that every moon and planet is sometimes closer, sometimes farther away from the object they are orbiting.
2. The Earth's axis is tilted by about 23 degrees, but that axis stays pointing at the same point in space throughout the year as the Earth orbits the Sun. From mid-summer to mid-winter, the change in the tilt of the Earth relative to the Sun is 47 degrees.
3. Changes in the amount of solar energy we receive from the Sun cause the change in the seasons. When we receive more solar energy, we have spring and summer; when we receive less, we have fall and winter.

Teaching and Pedagogy

While working with this model, students will almost immediately notice that the Earth gets much closer to the Sun at some times of year, and many will quickly make the connection between winter and summer and the distance between the Earth and the Sun. As you discuss this, ask the students to mark the orbit to indicate Spring, Summer, Autumn, and Winter.

Marking the orbit in your model this way constitutes an ***hypothesis***, but is it correct? On the positive side, we see that our model indicates that we should have the seasons, and they are in the correct order! Having our model match what we already know to be true is an important step in accepting it scientifically!

In science, when we make a model or hypothesis, we must investigate further to determine what predictions that our model makes. If our model hypothesis is a valid one, it should ***make predictions***, tell us things we do not know or have not yet tested. These predictions allow us to design experiments to see if our model continues to be valid. The answers the experiments give us indicate whether we should keep this particular model – or throw it out as unsatisfactory.

Now it is time to go back to our model with another piece of string. Start with your model in the summer position (Earth closest to the Sun.) Stretch a piece of string from the equator of the Earth to the center of the Sun, and note the angle; this represents the angle of the Sun above the horizon at noon. Continue to move the Earth around its orbit and try again with the string, your students will quickly notice that the angle never changes – ask them why they think this is true? It won't take long for someone to note that the angle never changes ***because the Earth's axis is not tilted.***

This is the prediction we have been waiting for! Write this prediction down and put it up on your white board or on your wall somewhere. This is important! Your students have just taken the first steps down new roads by formulating predictions based upon a scientific model! This is what the adult scientists do in laboratories and in the field the world over. ***This*** is science – and your students are doing it! In our next activity, we will build and test the ***tilted Earth*** model and see what predictions it makes!

Student Outcomes

What will the student discover?

1. There are competing models for everything, the causes of the change of the seasons is no different. Your students will see two models for the change from summer's heat to winter's cold; the elliptical model where the Earth moves closer to the Sun in summer and farther away in winter, and the tilted axis model where the tilt of the Earth's axis causes the angle of sunlight to change from summer (more direct) to winter (more oblique).
2. One of the least appreciated concepts in science is that competing models or theories make different predictions. We've touched before on the idea that theories make predictions and show us where to look for new knowledge, but we haven't seen specifically how that idea is used to help us decide which theory is correct – and which theory we should discard.
3. The Sun's changing path through the sky as we proceed through the seasons of the year is caused by the tilted axis of the Earth. This might seem like a slow and ponderous movement that would be all but untraceable with simple equipment in the classroom. In fact, your students will discover that they *can* track the movement of the Sun across the sky, and its changing path from week to week.

What will your students learn about science?

1. Predictions in science are not a matter of guesswork, they arise from the testing and experimentation that we do with scientific models. Sometimes these predictions are a surprise to us, they emerge spontaneously as we work with a model. Other times, we suspect that we know how a model will function after we are finished building it. When the model confirms our intuition, then we proceed to verify these predictions with independent experiments.
2. It is the process of theorize, predict, experiment, and confirm (or reject!) that allows science to progress methodically. A scientist isn't predicting experimental results the

way a gambler chooses a winning horse in a derby race! An hypothesis is never an ***educated guess!*** Scientific models create predictions as they function, we test these predictions with experiments.

3. For instance, we have seen that only one side of the Moon ever faces the Earth. If you play with your ping-pong models and look at the Earth from the Moon's perspective, you would see that the Earth would never move in the lunar sky. Our *model predicts* that for someone standing on the Moon, the Earth would never move across the sky, but remain spinning in just one place. This was a hypothesis, but there was no guesswork involved! And the Apollo astronauts confirmed this hypothesis in six trips to the lunar surface!

Conducting the Activity

Materials

1. Enough string to make a 16-inch long loop.
2. Two unsharpened pencils with fresh erasers
3. One ping-pong Earth model and one ping-pong Sun model (See Activity #23)
4. Construction paper (light colors work best)
5. Markers, rulers, pencils, tape, etc.

Building the Elliptical Model of the Seasons

1. Fold your construction paper in half the long way, and again the short way. This will mark the center of the paper for you.
2. Place the paper on the desk top and tape it in place at the corners.
3. Use a ruler and measuring out from the center on the long axis, mark two points, each 2-inches from the center. These points will be the ***focal points*** of our elliptical orbit. Mark these points carefully with a marker.
4. Have one student hold the two pencils, erasers down, on the focal points with the loop of string around them.
5. The second student puts a pencil inside the loop, and keeping the loop taught, they will draw an ***ellipse*** on the construction paper. If the ends of the ellipse do not meet perfectly, that is okay, have the students sketch over the pencil with marker and smooth

out the discrepancies. Younger students may need some help with this (some of my high school and college students did!), but everyone should soon get the hang of it.

Exploring the Elliptical Model of the Seasons

1. The drawn ellipse represents the Earth's orbit. Put the Earth model on its orbital path and put the Sun model on one of the focal points. Have the students move the Earth around the Sun in an anti-clockwise direction. Remind them that one orbit is the same as one year (and its seasons!) Ask the students to write down whatever they notice as they work with this model.
2. If younger students are having difficulty with imagining how the elliptical orbit affects the seasons, ask them to think about what happens when they stand closer to a fireplace or stove, and then they move farther away. The connection between distance and warmth will quickly become clear.
3. Another way to explore this model works well with a cell phone camera. Start with the Earth at ***perihelion,*** its closest point to the Sun when we would expect summer weather. Place the cell phone ***directly behind the Earth*** and snap a photo of your Sun model.
4. Try this again with the Earth at Fall, Winter, and Spring positions – always keeping the cell phone directly behind the Earth model when you photograph the Sun.
5. Review the four photos, what do you notice? Most students will notice that the Sun is closer in summer, farther away in winter – but what about the apparent size of the Sun? In a substantially elliptical orbit, the Sun would look noticeably larger in summer, likewise it would appear smaller in the winter. This is a ***prediction or hypothesis*** that our model makes. Ask the students to think about whether this is true or not. How could they test this prediction?

Discussion Questions

1. What did you notice about the position of the Earth in its orbit relative to the Sun?

   Answer: The Earth comes substantially closer to the Sun at some times of year than at others in this model. This change in distance *would* account for the change in temperatures from summer to winter.

2. If the Earth came substantially closer to the Sun at some times of year, what would you expect to observer in the sky? (Use your model to make a prediction.)

   Answer: If this puzzles your students, take a ball of any type and move it slowly closer, and then farther away from them. They should notice that the ball appears larger as it gets closer, and then smaller again as it moves away. Does this match what they see in the sky from summer to winter?

3. What did you notice about the angle between the equator and the Sun as your Earth model moved around its orbit?

   Answer: The angle does not change at all. Again, this does not match what we see in our sky. Ask students to take a look at their solar clock/calendars – has the Sun remained at a constant angle all year?

Supplemental Materials

Going Deeper

Could we use photographs to prove or disprove the idea that the Sun appears larger in the sky in summer, and smaller in winter? Challenge the students to think about this before you begin exploring photos. What ideas do they have? What reasons do they have to back up their ideas?

Often, we educators are too quick to jump in and correct a student when they are on the wrong track. I don't believe that this is always helpful. Remember that we do not do science to prove we are right, but rather to become right! Allow students to flesh out their ideas and think about them. Guide them to test these ideas and see where their ideas lead.

In the case of using photos to prove or disprove our idea of the Sun changing size in the sky, we won't make much progress. Look at landscape photos, sunset photos, etc. You will find that the size of the Sun changes dramatically ***based upon the camera***. Things such as zoom lenses can make a big difference in how large the Sun or Moon appear.

Could we use a camera to prove or disprove our ideas? Yes, but scientists take great pains to insure that everything else is the same such as same camera, same lens, same zoom setting, same location, and having the Sun at the same position in the sky.

We do this so that any changes we might see in the size of the Sun in the sky are actually a change in the Sun – not in our camera or photo! This is called ***controlling and limiting the variables.*** It is one of the most important ideas in science!

Being an Astronomer

Did you build the solar clock and calendar from activity #1? If you did, and if you have kept adding data to your solar calendar through the school year, you will now be poised to make another discovery!

Our ***elliptical model*** of the seasons shows no tilt of the Earth's axis. We actually found that there should be no change in the angle between the Sun and the horizon at any time during the year. What would this mean for our solar calendar?

If there were no change in solar angle on our solar calendar. This means that the shadow should never be closer to or farther from the base of the gnomon stick. The most we would expect to see is the dots forming a horizontal line across the page.

Of course, if you have done this experiment, you will find that the dots representing the tip of the shadow are tracing out a figure-8, or ***analemma*** on the paper. Your patient recording of data several times per week has ***proved the Earth's axis must be tilted.***

We often find that this is true – the results from one experiment give us sudden and dramatic insights on a totally different theory or hypothesis!

Being a Scientist

We talked about using a camera to prove or disprove the idea that the Earth gets significantly close to the Sun in the summer than the winter. If you, or your students, have access to cell phones, let's start taking photos!

Recess or lunch time is ideal for this, find a place where everyone can stand and take a photo that will show the Sun in the sky relative to some trees or buildings. Be sure that your camera isn't using a zoom function!

Take a photo once or twice per week and save them. After 4-8 weeks, compare the photos one to another and look for changes in the Sun's size in the sky. Of course, you won't find any real change – and this data indicates that the elliptical model is false.

Following Up

Some students get frustrated with this activity: "Why are we studying something that is wrong!?" The answer, of course, is that we are not seriously studying the elliptical hypothesis of the seasons as much as we are studying the methodology of science itself.

If we always study what is correct, how will we ever know how to recognize an incorrect theory when we see one? How will we know how to proceed and how to recognize the signs that a theory is invalid?

Science is a ***self-correcting process***, and an essential part of that process involves what we do when we make an error. Far too many students (and adults!) have the impression that 'the science is settled'; that science is a collection of truths and facts that are not open to investigation and debate. It is also just as dangerous to see science as a collection of opinions, choices open to our individual taste or desire.

Science is none of these things. But students must see ***science in action*** to appreciate the process and culture of science for what it is.

Activity 30:

The Tilted Axis Model of the Seasons

The tilt of the Earth's axis is one of those 'gradual discoveries' that have their origins in antiquity and crop up independently in many cultures. Study of the ***ecliptic*** – the path of the Sun across the sky each day, and the observation of the zodiacal constellations are just two ways in which can discover the tilt of the Earth's axis. One can also do this with nothing more than a vertical stick and a bit of string, observing the angle created by the shadow cast by the stick and how it varies through the year. These observations from cultures around the world date back at least 3000 years, if not more.

Discovering that the Earth's axis it tilted is quite different from discovering how that fact fits into a coherent model of the solar system. Copernicus was the first modern scientist who discussed how the tilt of the Earth's axis fitted into a scientific model of the solar system. It wasn't until Tycho Brahe made extremely precise measurements of the position of the Sun, Moon, and planets in the sky and Johannes Kepler put those observations into the context of an exact mathematical model that we understood, and measured, the tilt of the Earth's axis with modern precision.

Academic Standards:

Science and Engineering Practices

Asking questions and defining problems
Developing and using models
Planning and carrying out investigations
Analyzing and interpreting data
Using mathematics
Constructing explanations
Argument from evidence

Crosscutting Concepts

Patterns in nature
Cause and effect
Systems and system models
Energy flows, cycles, and conservation
Stability and change

Next Generation Science Standards

Space systems (K-5, 6-8, 9-12)
Structure and function (K-5, 6-8, 9-12)
Waves and electromagnetic radiation (6-8, 9-12)
The Earth-Moon system (6-8, 9-12)
Gravitation and orbits (6-8, 9-12)

For the Educator

Facts you need to know

1. The Earth's axis is tilted 23.5 degrees with respect to the Sun's equator which is also the plane of the solar system.
2. The direction in which the Earth's axis points in space ***does not change***. We can tell this because the location of ***Polaris***, the northern pole star, does not change in the sky.
3. Since the direction of the Earth's axis in space does not change, we find that sometimes our hemisphere is ***tilted toward the Sun***; while at other times of the year, our hemisphere is ***tilted away from the Sun.***
4. It is the ***change in solar angle*** which causes the change in the seasons and our weather – not the distance between the Earth and the Sun.[9]

Teaching and Pedagogy

It was known from ancient times that the ***ecliptic*** – the line in the sky which describes the path of the Sun, the Moon, and all the planets as well as the constellations of the zodiac – was tipped at an angle to the line of the celestial equator. There were numerous different explanations for this, none of them particularly noteworthy. Only with the modern idea of the spinning Earth put forward by Copernicus was the proper explanation of the ***celestial poles*** and the ***celestial equator*** arrived at. The cosmos has no natural pole or equator – it is the spinning Earth that defines them for those of us who live here. If you lived on another planet like Mercury or Mars, there would be different pole stars and a different celestial equator!

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[9] The Earth's orbit ***is elliptical***, meaning that the Earth is sometimes closer to the Sun, sometimes farther away. Even though the Earth's orbit is elliptical – the orbit is almost circular – the difference in the distance from Sun to Earth is very small, less than 1%, this change has virtually no effect on our weather. In fact, in the northern hemisphere, the Sun is closer to the Earth in the winter than in the summer!

The modern concept of the Earth's tilted axis being a primary cause of the seasonal changes was developed after Copernicus published his heliocentric theory in 1543. When Copernicus realized that it was the spinning Earth that in effect created the celestial poles and equator, it was a short leap to realize that all the planets orbiting the Sun in the same plane creates the ecliptic. Our solar system is essentially flat, with all the planets orbiting essentially in the same plane. This is not a coincidence and physics gives us good reason to expect that this should be so, but we must leave that explanation for another time!

In effect, it is the motions of the Earth, both spinning on its axis and orbiting the Sun, that make the motions of all the objects in the sky appear as they do. The brilliance of Copernicus was that he was able to look at the sky with just his eyes and deduce what the motions of the stars, Sun, and Moon told him about how the Earth moves and spins through space. One must learn a good bit about astronomy to appreciate the genius of Copernicus! For your classes, the important part to remember is that Copernicus hypothesized that it was indeed the tilt of the Earth's axis that caused the change in the seasons – not the change is the distance from the Earth to the Sun! This next activity will focus on modeling that idea and seeing what predictions our new model makes.

Student Outcomes

What will the student discover?

1. This is yet another occasion where we see what seems to be a reasonable hypothesis turn out to be wrong. The idea that summer weather happens when Earth is closer to the Sun seems reasonable and sound, but in fact it isn't true.
2. It is important to help guide your students' thinking here. The children may be frustrated with finding their idea was not correct. It is important to emphasize that the ***process of science*** is working, even if the hypothesis does not.

What will your students learn about science?

Our two models of the changing seasons have done something new and amazing. Our models have advanced our knowledge in a new way by helping us to decide between two scientific theories. This point cannot be emphasized too strongly! We had two perfectly interesting models of how the solar system worked. Each of these models made predictions. A single experiment proves that one model's predictions are correct while another model's predictions are false.

As a result of what we have learned through experiments, we now know that one model should be kept while the other must be discarded. There is nothing here about politics, nationalities, fairness, beauty, simplicity, or even what we may or may not like; this is ***all about the data***. We do not do science to ***prove we are correct***; rather, we do science to ***become correct***.

One of our models correctly explains nature to us, it has more to teach us, and we should be able to continue to modify it and add new features to it as we learn even more. The other model cannot continue to lead us in the right direction, it cannot tell us new and interesting things. It is a misstep, a scientific misunderstanding; quite simply, it is incorrect and must be discarded.

There have been many times that learned men and women have become attached to a particular theory or model. The favored model is what people learned from their teachers when they were in school. As adults, these people may have taught young students about their favorite model with complete confidence for many years.

Sometimes models are beloved because they fit well into our culture, or our religion, other times leaders favor one model over another because it fits better with their political ideas about the world. In the end, none of these things matter, but the ***truth*** does matter. This is why Galileo was willing to go to prison rather than abandon the scientific model of Copernicus and the Sun-centered solar system.

At his trial, Galileo was given the alternative of a horrible tortuous death, or life in prison. In order to escape a terrible death, the Inquisition made Galileo kneel and publicly renounce everything he had learned about the solar system. Galileo was made to say that Copernicus was wrong, that the Earth was the center of the solar system, and that it was fixed in place and unmoving in the heavens. When his guards helped the old man rise from his knees to lead him away to prison, Galileo was heard to say: ***"Eppur si muove"***, (And yet, it moves.) With his last breath as a free man, Galileo paid homage to the truth; *si muove*, indeed.

Conducting the Activity

Materials

1. One ping-pong ball and poker chip
2. One large paper clip
3. One round toothpick
4. A length of string – about 12-inches.

5. Super glue
6. Wire cutters (The type known as diagonal cutters work best. Check with your custodian first, if they do not have one, your local home improvement store will.)
7. Regular pliers
8. One large sewing needle
9. Emery board or fine sand paper
10. Ping-pong Sun model
11. Construction paper (light colors work best)
12. Markers, paints, etc.

Building the Tilted Axis Model of the Seasons

1. Have your students decorate another ping-pong Earth model using paints or markers, but this time, we include the entire planet instead of just half of it. A coating of clear sealer will probably be helpful after they are finished.
2. **[Teacher]** Put a dot at the north and south poles of each model Earth. Hold the needle with the pliers and heat it well with a candle flame, then poke a hole in the ping-pong ball at the north and south poles.
3. Unfold your paper clip so that it is bent almost at a 90^o angle, then the teacher uses the wire cutters to cut the paper clip as shown to make an axis for your model. Use super glue to attach the axis to the poker chip.
4. Use the wire cutters again to snip the last ¼-inch off of a round toothpick. Sand the cut end flat and glue it onto your ping-pong Earth wherever you live. This will indicate not only your location on the globe, but it will point to the zenith (straight up) in your location.
5. Slip the Earth model onto the paper clip axis you have prepared for it – your tilted Earth model is now complete.
6. Now trace a large circle on your construction paper to represent the Earth’s orbit. You can do this with a classroom compass or simply trace around a plate or a bowl. While it is true that all planetary orbits are elliptical, Earth’s orbit is so nearly circular that our distance from the Sun varies by less than 5% at any time of year!

Exploring the Tilted Axis Model of the Seasons

1. Place the Sun in the center of your circle and the Earth on its circular orbit with the axis pointing toward the Sun. This represents the ***summer solstice*** and longest day of the year, June 21st; label this point on Earth's orbit as ***Summer***.

2. Advance anti-clockwise 90-degrees in orbit (¼ of the way around the Sun) and mark this position ***Autumn***, another 90-degrees brings us to ***Winter***, and the last position will be ***Spring.*** Label these locations on your construction paper orbit.

3. The important thing to remember when using this model is that the Earth's axis ***always points in the same direction***. We know this is true because the ***North Star*** never changes – if Earth's axis always pointed at the Sun, the pole star would change from month to month as our axis pointed to different directions out in space!

   If students do not understand why the Earth's axis stays pointed in one direction, it may be helpful to demonstrate the concept to them using a toy ***gyroscope***. When you spin the gyroscope, it will balance on the tip of your finger; move your finger how you will, the axis always points in the same direction, just as the Earth's axis does in real life!

4. After the students have had a chance to familiarize themselves with the model and see how the little toothpick representing their location spins on its axis, it is now time to use our piece of string to look at something important – the solar angle.

   Begin in the ***Summer*** position (the Earth's axis is pointing ***toward the Sun***) and spin your Earth model so that the toothpick also points toward the Sun. Your model now represents noon on mid-summer's day.

5. With your eye down near the table level, stretch the string horizontally from the Earth to the Sun; the string represents our horizon. Now look at the angle ***between the string and the toothpick***, this represents how high the Sun is off the horizon at noon on mid-summer's day. Make a note of this angle; older students may wish to estimate the angle using a protractor or cut a wedge of construction paper that fits this angle.

6. Now move your Earth around to the Winter position and use the string to measure the angle of the Sun off the horizon once more. The angle between the Sun and the horizon is ***significantly less!***

   Our tilted Earth model has just made a new prediction: The angle of the Sun on the horizon should change with the seasons.

Discussion Questions

1. This model makes a very specific prediction about the distance between the Earth and the Sun – what is it? How do we know if this is true or not?

   Answer: A circular orbit predicts that Earth's distance from the Sun will not change through the year – and the size of the Sun's disk in the sky will also be consistent. We do not see the Sun changing in size in the sky from winter to summer indicating that this model is probably correct!

2. What actually does cause the change in the seasons?

   Answer: The tilt of Earth's axis causes seasons to change. In the northern summer, our hemisphere is tilted toward the Sun, while in the winter months we are tilted away from it.

3. We hear that the seasons in the southern hemisphere are reversed from our northern hemisphere, winter in July, summer in December! Could our tilted axis model account for this?

   Answer: Yes. When the northern hemisphere is tilted toward the Sun, the southern hemisphere must be tilted away. This effect accounts for the reversal of the seasons. This was first discussed in writing by Herodotus, a Greek historian in about 450 BC.

Supplemental Materials

Going Deeper

Can we add actual sunlight to our model? This little addition to activity #30 can be done in two simple ways, both amount to the same thing. Perhaps the easiest way is to use a flashlight. Darken your room a bit, and place the flashlight on the table so that it shines horizontally on the tilted Earth model – the flashlight will stand in for the Sun in this case. Adjust your model so that the Earth's axis is tipped directly toward the flashlight and rotate the Earth model slowly in an anti-clockwise direction. You will notice that the toothpick rotates gradually into the light (sunrise) and travels across as the Earth rotates until it disappears back into the darkness (sunset). Note how far you have to rotate the Earth between sunrise and sunset, this represents the hours of daylight that you experience.

Now adjust your Earth model so that the axis is tipped directly away from the flashlight. This represents the axis of the Earth tilted away from the Sun during the winter months. Once again, rotate your Earth model and see how far you must rotate the Earth to go from sunrise to sunset. If you have done everything carefully, you will notice that the length of the day in the winter months is significantly shorter that those in the summer months.

Ask your students how early it gets dark around Christmas time, and how long the night is before Christmas morning. Then ask them how long they have to wait to see fireworks on the 4th of July! They will quickly realize that the predictions of the model fall in quite nicely with their own experiences – and explain how these changes in the length of daylight and darkness happen as we move through the year!

If you do not have a flashlight or do not want to dim the lights in your room, you can do this activity another way. Take a 3x5 index card (a piece from a manila folder will do) and cut out a U-shape just large enough to fit over the Earth model (and the attached toothpick!) and allow it to rotate freely. The cardboard represents the boundary between daylight and darkness. The side of the Earth that faces the Sun model is in daylight, the portion of our model on the other side of the card represents darkness. When the toothpick moves past the card onto the sunlit side, it is in daylight, and when it passes back onto the far side of the card, it will be in darkness. The change in the hours of daylight will be seen just as easily.

Being an Astronomer

Remember the ***Solar Clock and Calendar*** we built way back in Activity #1? Have you been keeping up with your observations? If you have, you are in for a wonderful experience! Any line from the tip of the gnomon stretched down to the tip of the shadow, shows the precise angle of the Sun in the sky. You can demonstrate this with one of the small student sundials and a flashlight in the classroom. Shine the light so that the pencil casts a shadow down onto the edge of the cardboard. Hold the light steady and stretch a string from the tip of the pencil down to the tip of the shadow – you string points directly back to your light source!

Have the students take their sundials and stretch a string from the pencil tip down to the first dot made back in September, then stretch the string to each dot in succession. The angle gets shallower until mid-December, then begins to increase again as you move into the spring months. Your solar clock and calendar ***proves by experiment*** that our tilted axis model of the Earth is correct. The prediction made by the tilted axis model (the Sun's angle will change through the seasons) has been confirmed, while the prediction made by the original model (the Sun's angle will not change through the year) has been disproved.

Being a Scientist

Can you measure the angle of the Earth's axis with as much precision as Tycho Brahe and Johannes Kepler did in the 17th century? Potentially, all you need is a vertical stick and a protractor. If you know how to do some trigonometry, you can do this with just a vertical stick and a tape measure?

You will need to measure the angle of the Sun by measuring the angle between the tip of the shadow and the top of the vertical stick. You will need to do this on two different days, and at the ***same time*** of day. The required days are the ***winter solstice*** (December 21st) and the ***summer solstice*** (June 21st).

One these days, when the shadow falls perfectly along a north-south line, the Sun is crossing the ***meridian*** or center line of the sky. On the winter solstice, the Sun will be at its lowest angle above the horizon; while on the summer solstice, the Sun will be at its highest angle in the sky.

These two angles represent the extremes in the Sun's angle above the horizon. Keep in mind that in summer, we are tilted ***toward the Sun***, while in the winter we are ***tilted away from the Sun.*** By calculating the difference between these two angles – and then dividing the difference in half – we will measure the tilt of the Earth's axis.

The tilt of the axis measured by Tycho and Kepler is 23.5 degrees – meaning that the total difference in the solstice angles is 47 degrees. How close did your students come to this measurement?

Following Up

There are many good documentaries on Copernicus, Tycho, and Kepler. Find one of these videos to show in your class!

Unit 12:

Safely Observing the Sun

Warning: NEVER look directly at the Sun! Not with sunglasses, not through a camera, definitely not with a telescope or a binocular, not even through a welder's mask. **NEVER LOOK AT THE SUN DIRECTLY!**

These warnings sometimes make people (especially teachers!) shy away from solar observation activities – please don't let this be you! Observing the Sun is fun and wondrous and can show students many interesting things, especially if you have the opportunity to observe a full or partial solar eclipse! Don't let this terrific opportunity pass you by!

More than 40,000 students observed the Great American Eclipse in 2017 using the activities and curriculum from this book – and more importantly, ***everyone observed the Sun safely!*** You and your students can observe the Sun in perfect safety, too!

How can we observe the Sun safely? The trick is to ***project an image*** of the Sun onto paper, and look at that image instead of looking directly at the Sun itself. There are three easy ways to do this, we will look at the low-cost version first, then the high-tech version, then the no-cost version!

Activity 31:

The Pinhole Camera

Pinhole cameras have been known for centuries – actually long before the invention of photographic plates and film! The revelation that light shining through a tiny hole can create an image of what lies beyond is an exciting revelation that your children are sure to enjoy!

The pinhole camera used to be a more popular activity in the past when cameras were expensive and relatively rare. Miniaturized digital cameras are now on phones, and appear in the most unlikely places, taking away some of the awe and mystery of the camera. Even so, few people understand how a camera actually works, so making one of your own is a profound experience.

Academic Standards

Science and Engineering Practices

Developing and using models
Planning and carrying out investigations
Analyzing and interpreting data
Argument from evidence

Crosscutting Concepts

Systems and system models
Structure and function

Next Generation Science Standards

Space systems (K-5, 6-8, 9-12)
Engineering and design (K-5, 6-8, 9-12)
Waves and electromagnetic radiation (6-8, 9-12)
The Earth-Moon system (6-8, 9-12)

For the Educator

Facts you need to know

1. The Sun emits three basic kinds of light that reach the surface of the Earth: ***infrared light*** which we call heat, ***visible light***, and ***ultraviolet light*** which is essential to our health in small doses but can damage skin and eyes if we are not careful. The trick when observing the Sun is to separate the visible light out from the rest! Fortunately, this is easier than it may seem.
2. Any time we shine sunlight through a small hole or a lens, we create a round ***image of the Sun***. The bright circle of light isn't round because the hole through which it shines is round, nor because the lens we use is round; the image is round because the Sun itself is round! This also means that during an eclipse, when the Sun's image is <u>not</u> round, we should be able to observe this phenomena in action!

Teaching and Pedagogy

This lesson is as much about technology as it is about observations and data. One thing that you can focus on is what the pinhole camera is ***actually doing***. In fact, there are several things going on at once! The aluminum foil is completely opaque – no sunlight passes through this thin layer of metal at all. By taking the light from the tiny hole and allowing it to expand into an image several inches across, you have eliminated almost all of the infrared and ultraviolet light and reduced the brightness of the visible light by several thousand times! This makes our image not only safe, but fun and easy to study and enjoy.

The image of the Sun also has much to tell us. If you can discern tiny dark dots on the solar image – sun spots! – then you will be very fortunate. These cool spots (really!) on the Sun's surface are up to 1500 degrees colder than the surrounding areas. Cooler means that they shine more dimly, and thus appear dark to us. As it turns out, these sunspots are caused by ***magnetic storms*** on the surface of the Sun which allow extra energy to escape, cooling that region off substantially. The magnetic structure of the Sun is a bit beyond the scope of our STEM activities in this book, but it is fun to introduce children to these new ideas!

Student Outcomes

What will the student discover?

1. The image of the Sun contains many exciting details that are normally hidden from us because we are blinded by the brightness of the solar disk. By cutting down on the amount of light, these details can be revealed with marvelous precision!
2. Solar and lunar eclipses really do look very much the same. The bright object in the sky, whether the Sun or Moon, is gradually blotted out as a dark circle proceeds to cover it. This covering activity takes several hours, but with a solar eclipse, the time when the disk of the Sun is completely covered is very short indeed.

What will your students learn about science?

1. Sometimes our scientific curiosity leads us into dangerous places or situations. Often times, the scientist's answer to this is to create an instrument or mechanism that will allow us to observer and record what is happening in complete safety.
2. Observing the Sun is our introduction to this important technique! Looking directly at the Sun is dangerous! Instead we will use instruments to filter out the light we want, and eliminate the more dangerous light we do not want so that we can observe safely!
3. ***Safety First!*** This is the most important motto for the experimental scientist. Every responsible science teacher stresses – and teaches – safety as part of every lab activity. Every professional scientist thinks about safety as they plan and design experiments, no matter how big or how small.

Conducting the Activity

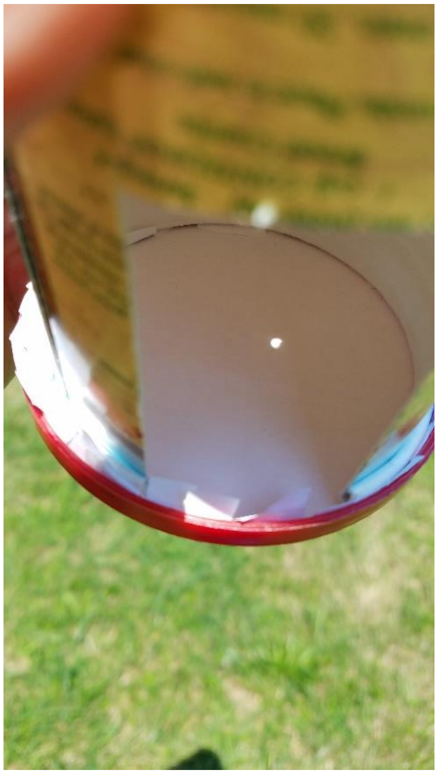
Materials

1. A cardboard container. An oatmeal container works well.
2. Scissors and hobby knife
3. Lightproof tape (electrical tape or duct tape works well)
4. White glue
5. Aluminum foil
6. Sewing pin

Building the Pinhole Camera Model

1. Begin by cutting some holes in your cardboard box with scissors or a hobby knife. For the oatmeal box, cut a square opening about 5-inches on a side in the middle of the box; then cut a 1-inch square hole in the center of the box lid.

   If you are using a copy paper box, cut an 8-inch hole in the lid a bit closer to one end; next, cut a 2-inch square hole in the center of one end. Tape over any seams in the box with duct tape to be sure they are light-proof.



2. Cut a piece of white paper out that fits properly and glue it in the bottom of the oatmeal box. Once this is done, put the lid on and tape in in place with duct tape.

   If you are using the copy paper box, you can use a full sheet of paper and glue it in the end opposite the 2-inch hole. Once this is done put the lid on – the hole in the lid of the copy box should be closer to the end where you glued in the paper. Tape the lid in place securely with duct tape.

3. Cut a square of aluminum foil large enough to completely cover the end of the oatmeal box and tape it over the end securely with duct tape, this will keep all stray light out of the box for you. Once this is done, puncture the foil carefully with a sewing pin. For the copy paper box, a 3-inch square of foil will be sufficient.

   Make as small a hole as you can! Smaller holes give dimmer, but sharper images. Larger holes make brighter, but somewhat fuzzier images. If the hole is too large, or if it gets damaged, you can always replace the foil easily. If the hole is too small (image is too dim to see), poke the needle into the hole again and enlarge it just a bit.

   Your pinhole camera is now ready to use!

Exploring the Pinhole Camera Model

1. Hold the box over your head with the large opening in the side facing down, and the foil covered end facing the Sun. If you are doing this correctly, you should be able to look inside the box and see the white paper inside.

2. Carefully adjust the direction you have the box pointed until you see a circle of light projected on the paper – this is the image of the Sun!
3. Study the solar image carefully, you may see tiny black or grey dots on the solar surface – these are sunspots! With a separate piece of paper, try and map the sunspots you can see.

   Be aware that the Sun does not have sunspots every day! The solar activity cycle (more active means more sunspots) peaked in 2014 and has been declining. This cycle is 11 years long, and according to astronomers, we are in a period of weak solar activity anyway. Never the less, careful and patient observers will generally be rewarded with the sight of a few sunspots if they observe carefully once a week or so.
4. If you have the opportunity to see a partial or complete solar eclipse, you are in for a treat! Your pinhole camera will show you the solar disk clearly, and when the eclipse begins, you will see a black "bite" being taken out of the Sun! As the eclipse progresses, the 'bite' will become larger; if you are lucky enough to see a total eclipse, the entire disk of the Sun will go dark!

Discussion Questions

1. How does the pinhole camera make it safe to view the Sun?

   Answer: The pinhole cuts out almost all the light.

   Answer: We never look directly at the Sun – only at its image projected on paper.
2. Why is the image of the Sun round in a pinhole camera?

   Answer: Because the Sun itself is round!

Supplemental Materials

Going Deeper

You can find many interesting and fun to build designs for pinhole cameras on line, these are also called a ***Camera Obscura***. Many of these designs show how to make a camera with a piece of translucent plastic for a screen.

You can actually project images of trees, landscapes, buildings, almost anything as long as it is well lighted.

Explore some camera obscura designs in your classroom and see what your class can discover about light and images.

Being an Astronomer

If you have the chance to observe an eclipse with a pinhole camera, try drawing a 0.5 cm grid on your projection screen with a fine, permanent marker. As you observe the progress of the eclipse, use the grid to estimate what percentage of the Sun or Moon is obscured by the eclipse.

One easy way to do this is to count the number of squares in the total image of the Sun or Moon (you only need to do this once), then count the number of squares that are darkened. The ratio between these two numbers will give you the percentage of the eclipse at that moment.

If you see a partial eclipse, try to estimate to greatest extent of the eclipse by percentage. Official values for eclipse percentage are often published for solar eclipses and are specific to your location. How close to you get to the official predictions?

Being a Scientist

Modern cameras use lenses to focus light. Find a simple magnifying lens and see if you can get it to project an image of a light bulb onto a piece of paper. How is this similar to your pinhole camera?

See if you can measure the distance between the lens and the focused image in millimeters – this is the ***focal length*** of the lens.

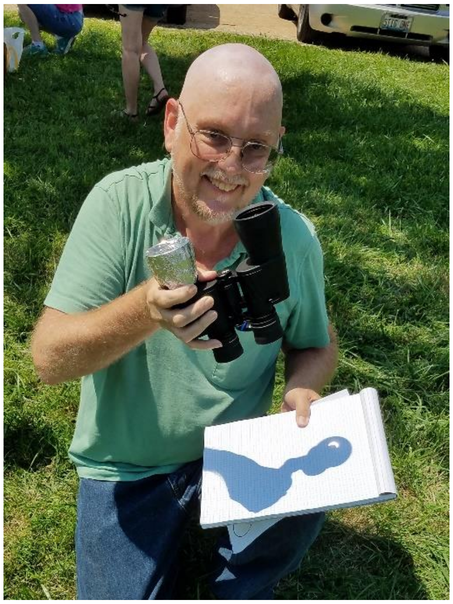
Measure the diameter of the lens in millimeters; this is also called the ***aperture***. Now divide the focal length by the diameter of the lens, this is the ***focal ratio*** of the lens.

Following Up

Every modern camera and projector system uses lenses to focus and control light. How many examples of lenses in use can you find in your classroom? How about around your school?

Activity 32:

The Binocular Projector



This activity does the exact same thing as our pinhole camera – it allows us to examine the surface of the Sun safely by looking at a projected image. There are some important differences however! Unlike the pinhole camera, the binoculars do not dim the brightness of the solar image – instead they concentrate the light and brighten it substantially. The binocular projector is easier to use, there is no construction needed and it becomes very easy to draw or photograph the image which we have seen. The increased brightness makes it more difficult to make out subtle features like sunspots on the solar disk, the glare of the intense image tends to obscure them. For eclipse viewing however, this is an excellent method requiring almost no setup time.

Academic Standards

Science and Engineering Practices

Developing and using models

Planning and carrying out investigations
Analyzing and interpreting data
Argument from evidence

Crosscutting Concepts

Systems and system models
Structure and function

Next Generation Science Standards

Space systems (K-5, 6-8, 9-12)
Engineering and design (K-5, 6-8, 9-12)
Waves and electromagnetic radiation (6-8, 9-12)
The Earth-Moon system (6-8, 9-12)

For the Educator

Facts you need to know

1. NEVER look at the Sun directly!
2. Using ***only one pair of binoculars*** which remain in the teacher's hands at all times, this activity is perfectly safe for all ages.
3. We will use the binoculars to project an image of the Sun on paper.
4. The projected solar image will be large enough and bright enough for an entire class to view it at once.

Teaching and Pedagogy

Once again, every science teacher ***teaches safety first!*** This activity makes safe observation virtually automatic. When you use the binoculars to project a solar image onto a piece of paper, students must stand ***with their backs to the Sun*** in order to view the projected image.

Using a pair of binoculars to project a solar image is simple in principle, but it requires practice to learn how to line up the binoculars, the Sun, and the paper. You will need to practice this activity several times before you do it in front of your students!

Take the binoculars and focus them for a distant object such as a tree or building at least 300 meters away. Remember to keep one side of the binocular covered, and start with the binoculars just a couple inches from the paper, then pull the binocular back until you get a large, sharp image of the Sun!

The Sun is different every day, sunspots and other features move slowly across the Sun. If you have a chance to try this activity during a lunar or solar eclipse, the effect is quite spectacular!

Student Outcomes

What will the student discover?

1. A solar eclipse is a rare and wonderful event that is not to be missed. For many students, this will be a once-in-a-lifetime experience – do not allow them to miss it!
2. The new Moon will at times be perfectly lined up to allow it to pass in front of the disk of the Sun, causing an eclipse.

3. In order to see a ***total*** eclipse, you must be in ***exactly*** the right spot! The shadow of the Moon on the Earth's surface is usually not more than 50 miles wide, and the shadow traces a path across the Earth called the ***path of totality***. You must be inside this narrow path to see a total eclipse!
4. Most people will not see a total eclipse, instead we get to see a partial eclipse because we are on one side or the other of the path of totality. This is still a wonderful event and worthy of our observation and study.

What will your students learn about science?

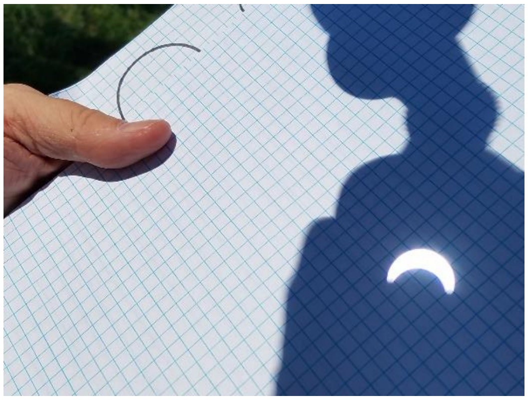
1. People have been predicting solar eclipses for several thousand years. Scientists and mathematicians today predict these events with marvelous precision.
2. Predictions are still just that – predictions made using a scientific model much as we have been doing throughout this book. Modern predictions of the timing and extent of a solar eclipse are not exact. This is a chance for students to see the precision – and the uncertainty – of modern science in one magnificent activity.

Conducting the Activity

Materials

1. One pair of binoculars. Larger binocular work better for this, a pair of 7x50 binoculars work perfectly.
2. A sheet of white paper on a notebook or clipboard.

Exploring the Binocular Projector



1. Check the binoculars on a tree or building to see that they are focused correctly.
2. Put one of the lens caps on the binoculars so light only passes through one side. If lens caps are missing, use a piece of aluminum foil to tightly cap one side of the binoculars.
3. Point the large end of the binoculars toward the Sun and hold the paper underneath the eyepiece. The paper may be anywhere from

1-4 inches away to give you the best image, this varies with styles and models of binoculars, so you will have to adjust this until you have the best view.

4. You should now be able to observe the solar disk, sunspots, even an eclipse just as you can with the pinhole camera. The advantage of this method is that working with a partner, your students can easily draw directly on the paper they are observing and copy down what they see!

Discussion Questions

1. How does the binocular projector make it safe to view the Sun?

   Answer: We never look directly at the Sun – only at its image projected on paper.

2. Why doesn't the Sun look the same every time we look at it like the Moon does?

   Answer: The Sun has no solid or permanent surface. The sunspots we sometimes see are magnetic storms on the solar surface, they appear and disappear as conditions change on the Sun's surface, much as thunderstorms appear and disappear on Earth.

Supplemental Materials

Going Deeper

The binocular projector is also an excellent method to use when trying your hand at imaging the Moon. Take your binoculars out on a night when the Moon is at least half-full and try setting up to project the image on a piece of paper just as you did with the Sun. You will need a dark place to do this properly, yard lights and street lights will interfere with the image substantially. You will find that the projected image is substantially dimmer than the solar image, and this makes it much easier to pick up things such as dark maria and even some of the larger craters in addition to the shape of the lunar phase that night!

If you have a chance, try this activity with both a telescope and a binocular. You will find that the binocular projects an image just as you see it in the sky, while the telescope flips the image from side to side or even upside down! (This depends upon the type of telescope you use.) Optics are fun and mysterious – something your students will have the chance to explore further as they get older and enter higher grades in school!

Being an Astronomer

There are dedicated solar telescopes which allow you to look directly at the Sun and see many amazing features on the solar surface. Solar telescopes are specially built, single purpose machines, and quite expensive – even for telescopes!

Once again, it is time to contact your local astronomy club and ask for their help. Many clubs have a member with a special interest in the Sun who may own their very own solar telescope; some larger clubs purchase one of these specifically for the club to take out to schools and outreach events. If your local club has such an instrument, your students are in for a real treat!

Being a Scientist

If you are lucky enough to observe a solar eclipse through a binocular projector, you will find that the image is bright and well-focused enough to be easily photographed.

If you are able to take a photograph of the Sun every 5-10 minutes during an eclipse, the pictures can be combined into a GIF or time-lapse video to show how the Moon moves in front of the solar disk and put the Sun into eclipse!

Following Up

There have been many famous eclipse events in history and literature. Columbus' eclipse during his exploration of the New World and Mark Twain's *A Connecticut Yankee in King Arthur's Court* both come to mind. How many others can you find?

Activity 33:

The Tree Projector

Yet another method to project an image of the Sun safely during a solar eclipse. My students were able to observe and photograph the images of the Sun in eclipse using this method during the Great American Eclipse of 2017. Some were even able to use a kitchen colander to project multiple images of the Sun and photograph them!

Academic Standards

Science and Engineering Practices

Developing and using models
Planning and carrying out investigations
Analyzing and interpreting data
Argument from evidence

Crosscutting Concepts

Systems and system models
Structure and function

Next Generation Science Standards

Space systems (K-5, 6-8, 9-12)
Engineering and design (K-5, 6-8, 9-12)
Waves and electromagnetic radiation (6-8, 9-12)
The Earth-Moon system (6-8, 9-12)

For the Educator

Facts you need to know

1. NEVER look at the Sun directly!

2. Observing a projected image of the Sun on the sidewalk, this activity is perfectly safe for all ages.
3. We will use the leaves in the trees – and the spaces between the leaves – to project an image of the Sun on paper.
4. The projected solar image will be large enough and bright enough for an entire class to view it at once.

Teaching and Pedagogy

This one sounds a bit weird, but it really works! If you have a chance to see an eclipse, find a shady tree. Ideally, there should be some spots of sunlight shining through the tree onto the ground or a nearby wall. These spots of sunlight are actually ***projected images of the solar disk!*** As the eclipse progresses, you will notice that they are no longer "spots" of sunlight, instead they have become spots with a bite out of them! If the eclipse progresses far enough (more than 50%), you will see hundreds of bright crescents projected on the ground beneath the tree! This makes a beautiful and mysterious photograph if you can manage to capture it!

While in principle, this should also be possible with the Moon when it is lit more than half way, I have not been able to accomplish it. This could be an interesting challenge for your students to try!

Student Outcomes

What will the student discover?

1. A solar eclipse is a rare and wonderful event that is not to be missed. For many students, this will be a once-in-a-lifetime experience – do not allow them to miss it!
2. The new Moon will at times be perfectly lined up to allow it to pass in front of the disk of the Sun, causing an eclipse.
3. In order to see a ***total*** eclipse, you must be in ***exactly*** the right spot! The shadow of the Moon on the Earth's surface is usually not more than 50 miles wide, and the shadow traces a path across the Earth called the ***path of totality***. You must be inside this narrow path to see a total eclipse!
4. Most people will not see a total eclipse, instead we get to see a partial eclipse because we are on one side or the other of the path of totality. This is still a wonderful event and worthy of our observation and study.

What will your students learn about science?

1. People have been predicting solar eclipses for several thousand years. Scientists and mathematicians today predict these events with marvelous precision.
2. Predictions are still just that – predictions made using a scientific model much as we have been doing throughout this book. Modern predictions of the timing and extent of a solar eclipse are not exact. This is a chance for students to see the precision – and the uncertainty – of modern science in one magnificent activity.

Conducting the Activity

Materials

1. You need an eclipse, and a leafy tree.
2. A flat surface for the solar image to fall upon – a sidewalk works very well. If the Sun is low during the eclipse, you may find that the image will be nicely projected on the side of a building such as a house or garage.
3. If you have no convenient flat surface around your tree, a flat piece of cardboard that has been painted white will do. A pizza box of something similar works very well.

Building the Tree Projector Model

1. This model requires no preparation – you simply use the landscape to your advantage.

Exploring the Tree Projector Model

1. I know of no other activity that inspires such wonder and amazement in children and adults alike. Watch and photograph the hundreds of solar images during the eclipse as they shimmer on the ground.
2. As the eclipse progresses, the shape of the solar image on the ground will change. First you will see a small 'bite' out of the solar disk, then a large section will disappear, finally you will see only a thin crescent – hundreds of them – projected on the ground just before the Sun goes completely dark during totality!

Discussion Questions

1. How does the tree create these images of the Sun?

   Answer: The spaces between the leaves on the tree act just like the small hole in our pinhole camera.

2. Why don't we see solar images under the trees every day?

   Answer: We do! The 'dappled sunlight' under a tree is hundreds of round images of the Sun. We take these round images for granted, not realizing what we see every day. Only during an eclipse, when the shape of the Sun changes dramatically do we see hundreds of crescent suns and stare in wonder!

Supplemental Materials

Following Up

Let all your parents know about your Tree Projector project. Encourage the parents from your class, and your students, to take as many photos of these delightful images as they can and post these photos in your class after the eclipse!

Unit 13:

Solar and Lunar Eclipses

Warning: NEVER look directly at the Sun! Not with sunglasses, not through a camera, definitely not with a telescope or a binocular, not even through a welder's mask. **NEVER LOOK AT THE SUN DIRECTLY!**

Solar and lunar eclipses are the stuff of legends. The spectacle of the Moon going dark and then becoming blood-red for hours at a time, or the horror of the Sun being devoured until the world stood in darkness at midday was enough to chill the blood of any ancient or primitive soul that witnessed them. Columbus himself is supposed to have used a solar eclipse prediction to convince the Native Americans that he had great mystical powers and should be left to his business; Mark Twain incorporated this story in his book ***A Connecticut Yankee in King Arthur's Court***.

But why do eclipses happen? Some students may know that the eclipses have something to do with the shadows of the Earth and Moon, but if that is true, why don't they happen every month? In this unit, we will not only investigate the phenomena of lunar and solar eclipses, we will see once again that we can take an existing model of the solar system, and add new features to it that will not only increase its richness, but also improve its usefulness and allow us to make even more testable predictions!

Activity 34:

Modeling a Solar Eclipse

Solar eclipses are wonderful events, but it is quite rare to see one. The eclipse is only total along a very narrow line called the ***path of totality.*** If you are not on this narrow line at exactly the correct time and the weather is not clear – you will miss your total eclipse. Partial eclipses are easier, but they do not visit any particular continent or region very often – you may wait decades between opportunities, or have to travel thousands of miles to see one.

Since we cannot expect the Sun and Moon to cooperate and give you a wonderful solar eclipse of your own (and conveniently during school hours, too!) we must do the next best thing by modeling the solar eclipse in our classroom.

This activity will take our Earth-Moon system model to new levels of detail. In order to do this, we are going to have to make a new model on a different scale. Like so many scientific models in astronomy, this one will fib a little bit when it comes to the real scale of the solar system. As we've seen in Activity #3 (Making a Scale Model of the Earth-Moon System), the distance to the Moon is very large, and that would make our model rather impractical for us.

Students will do better with this activity if we confine our model to a desktop, so that they can see all the parts working together properly. We won't put the Sun in this model either, it is sufficient that we know where the Sun is supposed to be and in which direction the sunlight is shining (this tells us which way the shadows must go!) We can accomplish this simply by putting a construction paper arrow on the desk to indicate the direction of the sunlight!

Academic Standards

Science and Engineering Practices

Developing and using models
Using mathematics
Constructing explanations
Argument from evidence

Crosscutting Concepts

Patterns in nature
Cause and effect
Systems and system models

Structure and function
Stability and change

Next Generation Science Standards

Space systems (K-5, 6-8, 9-12)
Structure and function (K-5, 6-8, 9-12)
Waves and electromagnetic radiation (6-8, 9-12)
The Earth-Moon system (6-8, 9-12)

For the Educator

Facts you need to know

1. The Earth and the Moon cast shadows just as any object on Earth does when it lies in direct sunlight. These shadows stretch many thousands of miles off into space but are not visible to us unless a sunlit object passes through them.
2. Because the Earth is roughly 4x larger than the Moon, its shadow is four times wider and four times longer than the lunar shadow. This larger shadow is easier to hit, so to speak, which is one of the reasons why a lunar eclipse is much more common than a solar eclipse.
3. The Moon's orbit is tilted by just over 5^{o}. This may not seem like much, but over the large distance from the Earth to the Moon, it becomes quite significant. Because of the tilt of the Moon's orbit, the Earth and Moon dance now above, now below these shadows in space and prevent an eclipse from happening. Only when Earth, Moon, and Sun are perfectly aligned on a level plane can we have an eclipse!

Teaching and Pedagogy

This is an interesting exercise in solid geometry! Students working with their models will tend to make several mistakes, let's look at them one at a time. Your students may want to tilt the shadow rather than keeping it perfectly horizontal. This doesn't work in real life, the Sun is so far away that the shadow always points perfectly horizontally (in the plane of the solar system.) Remind your students what we learned using the solar clock and calendar – the angle of the shadow always points back to the Sun!

Some students may want to point the shadow in the wrong direction; the shadow must always point in the same direction as our sunlight arrow. This is really just another version of the same problem. Shadows are stubborn things, they always point directly away from the light source, and once again our experiences with the solar clock and calendar point this out to the student.

The real solution, as you see in the photo below, is to rotate the Earth-Moon model so that the Earth, orbit ring, and the Sun all line up precisely. If you think about that tilted orbit of the Moon, there are only two places where the orbit actually crosses in front of the Earth instead of being either above or below it. These points are called ***nodes***; when the Moon is on a node – and that node lies directly between the Earth and the Sun – then an eclipse is possible.

Did you notice that for this model to work, you had to position the Moon between the Earth and the Sun? This is the ***new moon phase*** when the entire near side of the Moon is in darkness. If you wish, you can draw a new moon on the lunar orbit ring in this position with a marker and draw a full moon on the orbit ring on the opposite side of the Earth! It can be fun to have the children fill in the phases on the orbital ring to refresh them on the lunar phases again!

You will also notice that only the point of the shadow touches the Earth! In reality, this shadow point is never more than 50 miles wide! The combined rotation of the Earth and the orbital motion of the Moon during an eclipse cause the shadow to draw a thin, gracefully curving line hundreds of miles long across the Earth's surface. Combine this with the fact that the ***total eclipse*** lasts only a few minutes, and you will see why a total eclipse is such a rare event! To see this celestial wonder, you must be precisely on that thin line (and looking up!) at the exact time of day when the eclipse occurs. The relatively tiny size of the shadow, the motions of Earth and Moon, and the precise geometry required in space make this one of the rarest observational events!

Safety Note: Staring at the Sun is **NEVER** a safe activity! You can damage your vision permanently without realizing it (the eye has no pain receptors!) If you have the opportunity to observe a solar eclipse, get in touch with a local astronomy group – they can show you many safe and fun ways to observe this wonderful celestial event! See Activity #29 below for more information on this!

Student Outcomes

What will the student discover?

1. Solar and lunar eclipses are diverse and delightful events. Solar eclipses are visible only in precise places on Earth and for just a few minutes at a time, and only on the day of the new moon. The next solar eclipse visible across much (but not all!) of North America occurs April 8th of 2024. Only those lucky few who stand along the ***line of totality*** will see the full solar eclipse in all its glory.

2. Lunar eclipses are visible to at least ¾ of the globe when they happen, they are the ‘people’s eclipses’, so to speak. These events occur on full-moon nights, and you don’t need a telescope or a binocular to enjoy them, just a lawn chair and a thermos of hot chocolate to keep you warm as you watch the celestial show!
3. The explanation for how eclipses happen is deeply embedded in the ideas of a moving Earth and Moon, revolving in their respective orbits. It is only when we understand how the moons and planets function in their orbits that we can understand the theory that explains how these events happen.

What will your students learn about science?

Once again we will see the wonderful interplay between theory, prediction, and experimental data. This is the drama of modern science in action! We have developed a marvelous scientific model that explains the Earth-Moon system; it features a heliocentric system with the Earth as a planet rotating on a tilted axis as it orbits the Sun. Our model also includes a lop-sided Moon that forever turns one face to the Earth and keeps the other side hidden, along with changing phases and an elliptical orbit.

When we see an eclipse, this rare event begs to be explained! Can we adjust our model and add new features that will explain these rare and beautiful events without destroying the usefulness of our existing explanations? This is the challenge of the scientist in a nutshell, and we will take up that challenge together as we pursue this activity, and the next!

Conducting the Activity

Materials

1. One rubber T-ball
2. One large marble
3. 24-inch square of foam-core board
4. Sharp hobby knife
5. 4 wire coat hangers & sturdy wire cutters or 4 15-inch pieces of sturdy piano wire (a craft or hobby store should be able to help you with this.)
6. An empty soup can
7. Poster putty

8. Hot glue
9. Sheets of black (any dark color) and yellow (any bright color) poster paper
10. Can of light blue spray paint
11. Markers, tape, etc.

Building the Solar Eclipse Model

1. Spray paint your rubber T-ball blue, and set on the soup can to dry. You can actually set the ball on the soup can and spray it over a sheet of newspaper, allow it to dry and rotate it between coats to be sure that the color is even.
2. When the ball is completely dry, have the students use markers to make this into an Earth model as we did with the ping-pong balls. As before, the exact shape and placement of continents and ocean won't matter much for our demonstration, so don't worry about making a perfectly accurate map!
3. **[Teacher]** Use a string compass and draw two circles on the foam core board. The first circle should be as large as the board itself, the second should be about 2-inches smaller. Trim the outer circle with the hobby knife, (have some cardboard beneath your project to keep from scratching the table!) Trim the inner circle next, this should leave you with a 2-inch wide ring, 2-ft in diameter. The exact width of the ring isn't important, but making it too thin will make it fragile.
4. **[Teacher]** The four wires must now be inserted perpendicularly along the equator of the Earth model, so they form a neat cross the same size as our foam core ring. It is usually easier to puncture the ball with the hobby knife first, and then insert the wire into the ball (you may wish to wear gardening or work gloves when you do this step to protect your hands.)
5. **[Teacher]** Once you have all the wires inserted and you are sure they are correctly in place so as to match the size of your foam core ring, a drop of super glue will help hold them firmly in place. Next use hot glue to firmly attach the wires to the foam core ring; it is often helpful to set the Earth model on the soup can (North Pole <u>down</u>!) while you do this to keep it from rolling around! When the hot glue has cooled completely, flip your model over – it is now ready to use.
6. Cut out a large arrow from yellow construction paper (use the whole length of the paper!) Draw and label a smiling sun at the base of the arrow, and label the pointed end 'Sunlight'. Tape this arrow to your desktop.

7. Set the empty soup can on the center of your sunlight arrow and set the Earth model on top of it. Adjust the position of the Earth so the Moons orbit (foam core ring) is tipped a bit. The ring should be tipped enough so that the highest point of the ring is well above the top of the t-ball Earth. Secure the rubber ball Earth model in place on the can with some hot glue or a bit of duct tape.
8. Use some poster putty on the marble so that you can put it on the ring and make it stay put. Attach this carefully so that you don't damage the ring! Try moving the marble moon around the ring orbit, notice that the Moon is sometimes above the Earth, and sometimes below it.

Exploring the Solar Eclipse Model

1. Now it is time to model the Moon's shadow. Use black construction paper to make a cone shape. Its widest point should be the size of the moon marble, and it should be just long enough to reach from the orbit ring to the t-ball Earth model. This will take a little bit of practice and adjusting! When you get it just right, tape the cone together and secure it to the marble moon with some silicone glue.
2. It is finally time to make a solar eclipse! The rules are simple:
    a. You can turn the soup can around, but you cannot adjust the angle of the foam ring – it must stay tilted as it is. (This is why we secured the Earth model to the soup can!)
    b. The Moon's shadow must remain horizontal, and point in the direction of the sunlight arrow.
    c. When you find a place that allows the Moon's shadow to touch the Earth – you've done it! Use your poster putty to secure the Moon and its shadow in place!

Discussion Questions

1. What does the black paper cone represent in our model?

    Answer: The shadow of the Moon being projected onto the surface of the Earth.

2. Why do we need to be in such an exact location to observe a total solar eclipse?

    Answer: Because the size of the lunar shadow is very small by the time it reaches Earth. This shadow is seldom more than 50 miles wide and you must stand directly in its path to see the total eclipse.

3. Why don't we have a total solar eclipse every time there is a new moon?

Answer: The Moon's orbit is tilted – most of the time, the Moon is either above or below the Earth during a new moon.

Supplemental Materials

Going Deeper

The prediction of eclipses requires complex mathematics – far beyond the scope of your class whether you teach 1st or 12th grade! Even so, there are a number of excellent video resources that will help your students to picture, and imagine what happens during a solar eclipse. One of the most interesting of these are a series of short videos taken from the International Space Station looking down upon the Earth as the Great American Eclipse of 2017 happened in real time.

Being an Astronomer

In spite of dire warnings to the contrary, **it is possible** to observe the Sun safely as long as you do not look directly at it. While this may seem like a contradiction in terms, allow me to assure you that it is not. We have examined three methods in our previous unit of observing the Sun, one using cardboard boxes that fits in nicely with our low-cost science program, the second requires a pair of binoculars; the third requires only a convenient tree, all of these are easy and fun!

Being a Scientist

Being a scientist and observing a solar eclipse is difficult because the solar eclipse is such a rare phenomenon. Still, if you get a chance in your lifetime to observe a total solar eclipse – I urge you to take advantage of it!

Following Up

Use the internet and search for the next upcoming eclipses. Even if the eclipse is too distant for you to travel to and observe, there is often live video available from scientists who have made the journey to observe and record this magnificent event.

Activity 35:

Modeling a Lunar Eclipse

At first glance, our lunar eclipse activity will look much like the solar eclipse (Activity #34), but there are subtle differences worth noting. We will use the same rubber T-ball model Earth and foam core lunar orbit ring that we used last time, but this time we will be using a paper cone to represent the Earth's shadow instead of the Moon's shadow.

Academic Standards

Science and Engineering Practices

Developing and using models
Using mathematics
Constructing explanations
Argument from evidence

Crosscutting Concepts

Patterns in nature
Cause and effect
Systems and system models
Structure and function
Stability and change

Next Generation Science Standards

Space systems (K-5, 6-8, 9-12)
Structure and function (K-5, 6-8, 9-12)
Waves and electromagnetic radiation (6-8, 9-12)
The Earth-Moon system (6-8, 9-12)

For the Educator

Facts you need to know

1. Lunar eclipses are far easier to observe than solar eclipses, this depends upon two facts:
    a. First, the Earth's shadow is far larger than the Moon's shadow. The Moon's shadow tapers down to just a few miles wide by the time it strikes the Earth in a solar eclipse. The Earth's shadow is large enough to engulf the entire Moon by the time it travels the same distance.
    b. Because the entire Moon is covered by the Earth's shadow, and the eclipse takes several hours to finish, at least 75% of the globe can witness every lunar eclipse.
2. Lunar eclipses are colorful – and different every time. The Earth's atmosphere bends the light as it passes through the atmosphere, and filters out all the blue and green portions of the spectrum. We see this when we enjoy colorful sunsets! It is these 'sunset colors' that illuminate the Moon during totality making the Moon appear anywhere from a pale orange to a deep red color.

Teaching and Pedagogy

It won't take long for your students to figure out that a lunar eclipse happens when the full Moon passes through the Earth's shadow at the node of the orbit. There is however, more to learn here. Set the model up with the Moon on its orbital ring inside the Earth's shadow. Ask your students: "What is being eclipsed?" In other words, what is going dark? The Moon is obviously going dark here, but how? The Moon experiences darkness as its ***orbital motion*** carries it through the Earth's massive shadow! This shadow is large and it takes several hours for the Moon to pass completely through the Earth's shadow. Unlike a total solar eclipse which lasts just a few minutes, the total lunar eclipse can last ***more than two hours!***

Take another look at your model and ask your students: "Who can see this eclipse?" With the solar eclipse, only those people who were exactly underneath the point of the Moon's shadow could see the total event. But with the lunar eclipse, ***half the Earth*** is inside that giant shadow! And since the total eclipse event, from the Moon's first contact with the Earth's shadow until it finally passes out of the shadow completely can take 5-6 hours, ***even more people*** rotate into position to see the lunar eclipse as it wears on. Generally speaking, about 75% of the surface of the Earth can see at least some part of a lunar eclipse! A lunar eclipse is truly an eclipse for everyone! There is no need to travel to exotic locations or arrive at a precise time; the long lasting lunar eclipse is a show that is usually visible right in your back yard and lasts for many hours for you to enjoy.

We are not completely done with eclipses yet! Our last eclipse activity is a short one, and easy to make. This one will show us why eclipses are so rare, and so special

Student Outcomes

What will the student discover?

1. There is a substantial difference between a solar and lunar eclipse. Timing, appearance, ease of observing all differ – and most of the difference has to do with the Earth's atmosphere, and the size of the Earth's shadow in space.
2. Where the solar eclipse is a blackout of the Sun, the lunar eclipse never totally darkens the Moon's disk. The students will discover the role of the Earth's atmosphere in this phenomenon.

What will your students learn about science?

1. The power and flexibility of the scientific model to explain what we see in the night sky should be apparent to your students by this point in the course.
2. The student has learned that scientific models are flexible – not rigid. It is always possible to go back to our model, modify it, add new features, even change it as required by new data and observations. The science is ***never settled.***

Conducting the Activity

Materials

1. All materials from the solar eclipse model (Activity #34). You will probably want to start with a new marble, but you can keep the marble with the paper shadow cone on it for more realism if you wish.
2. Another sheet of black construction paper (any dark color works).

Exploring the Lunar Eclipse Model

1. Place your Earth model on the sunshine arrow as you did before in Activity #28. If you have marked the lunar orbit with lunar phases, make sure that the new moon phase is on the same side as the base of your solar arrow, and the full moon phase is on the pointed side of the solar arrow.

2. You will be using paper to make another shadow cone, but this time, the cone will be moving away from the Earth in the direction that the arrow is pointing. The Earth's shadow cone only needs to go out as far as the lunar orbit ring. This will be more of a paper tube than a paper cone, the Earth is much larger than the Moon, and the Earth's shadow does not taper very much in that distance.
3. Take your construction paper and cut it to the correct length to fit just inside the lunar orbit ring. Wrap the paper around the Earth to form a tapering tube and tape it to the Earth model with masking tape.

Discussion Questions

1. Why is the lunar eclipse visible to almost the entire Earth when it happens?

   Answer: The Earth's shadow is much larger than the Moon's. As the Moon moves through the shadow, it is visible from most of the Earth's surface. As the Earth rotates, almost 75% of the planet can see at least some of the eclipse.

2. Why are lunar eclipses less rare than solar eclipses?

   Answer: The large size of the Earth's shadow makes it much easier for the Moon to be eclipsed than the Earth.

   Answer: The eclipse is also visible to most of the Earth making it easy to see without traveling to a special location.

   Answer: The lunar eclipse lasts for hours, compared to just minutes for a total solar eclipse. This also makes it much easier to spot.

Supplemental Materials

Going Deeper

Unlike a solar eclipse, the lunar eclipse is relatively common and any given eclipse is visible over 70% of the Earth or more. Both of these factors make it much easier to see a lunar eclipse. Unlike a solar eclipse however, a lunar eclipse always occurs at night. Sometimes we are lucky and get an eclipse that occurs shortly after dark, other times we must stay up late (or get up very early!) to see a lunar eclipse.

The timing means that if you are to have students observe a lunar eclipse, you will have to get parents involved and make the event a 'Family Eclipse Night' at your school. The effort will be well worth it! There is also the safety factor to consider – unlike a solar eclipse, no one needs special equipment to look at and enjoy a lunar eclipse!

Being an Astronomer

Lunar eclipses are not that rare, chances are you will not have to wait more than 1-2 years to see the next one. Be sure you investigate and find out when your next lunar eclipse will be!

Work with your parent groups, PTA, and local astronomy club. Chances are that your local high school football field is an excellent place to hold an eclipse party! Parents and students can bring lawn chairs and blankets to sit on, and football stadiums generally have bathroom facilities and even snack shop areas for preparing food for the hungry observers!

Make your next lunar eclipse an exciting night for everyone in your community!

Being a Scientist

Photographing and recording an eclipse can be an exciting event. You can photograph an eclipse with a simple camera, even a cell phone camera will do.

Never the less, photographing the eclipse through a telescope will give you a much better photograph to enjoy and study later. Once again, working with your local astronomy club will be a terrific benefit.

Following Up

The color of the Moon during a lunar eclipse can vary from a bright orange to a deep red. In fact, when the Moon enters the Earth's shadow, the only light that falls on the Moon is ***sunset light***. The reds and oranges that we see at sunset happen because our atmosphere scatters and filters out blue, green, and yellow colors – only the red light bends easily around the curve of the Earth, this is why sunsets are red.

With the red color of sunset illuminating the Moon, it changes color to a lovely orange-red, and the exact color of the Moon during a lunar eclipse is always different; just like the exact color of tomorrow's sunset will be different from today's.

Activity 36:

Why are Eclipses so Rare?

With our two shadow models, we have seen the mechanics of the solar and lunar eclipse. Your students should now be able to explain to someone ***how eclipses work,*** and why both light and shadow are needed to create one. But why are eclipses so rare? Most people have never seen a lunar eclipse although they are fairly common and occur in bunches of three to four events spread out over 18-24 months. These eclipse clusters occur every few years, there are many on-line almanacs that can help you find the next lunar eclipse visible from your area.

Only relatively few people have ever seen a total solar eclipse. These fleeting events last only minutes, and one has to be in a very exact position to observe them. Adventurers, astronomers, and wealthy tourists take trips to exotic locations, people even charter cruise ships to travel to a particular point in the ocean and drift motionless while those on board observe the fleeting event! The model we created seems to suggest that an eclipse should be possible every full and new moon – so why are they so infrequent?

In order to understand this last piece of the eclipse puzzle, we will create yet another model using ping-pong balls again, and our ping-pong Sun model, too. We are going to make a new ping-pong Earth model, this time with the Moon's tilted orbit attached to it!

Academic Standards

Science and Engineering Practices

Developing and using models
Using mathematics
Constructing explanations
Argument from evidence

Crosscutting Concepts

Patterns in nature
Cause and effect
Systems and system models
Structure and function
Stability and change

Next Generation Science Standards

Space systems (K-5, 6-8, 9-12)
Structure and function (K-5, 6-8, 9-12)
Waves and electromagnetic radiation (6-8, 9-12)
The Earth-Moon system (6-8, 9-12)

For the Educator

Facts you need to know

1. The Moon's orbit is tilted 5.5 degrees with respect to the Earth's orbital plane around the Sun.
2. A five degree orbital tilt seems very small, but this small angle carried over 380,000 kilometers often places the Moon far above, or below, the plane of the Earth's orbit.
3. In order to have an eclipse of any kind, the Earth, Moon, and Sun must be precisely aligned in space. It is the tilt of the Moon's orbit which interferes with this alignment.

Teaching and Pedagogy

You will remember that in Activity #30, we used a toy gyroscope to show students that a spinning object's axis is stable in space, no matter how we move it around. The Moon in its orbit is not a solid ring like the metal ring of the gyroscope, or a solid ball of stone like the Earth, but as it spins it acts in much the same way. Spin the gyroscope up and balance it on your finger, push it over so it is tilted a bit just as the Earth's axis and the Moon's orbit are tilted. Students will be quick to notice that it stays upright, but it also wobbles a bit. As with our toy gyroscope, so goes both the Earth and the Moon – this 'toy' is an excellent scientific model!

The lunar orbit, like the Earth's axis, stays pointed in the same orientation as the Earth-Moon system orbits the Sun. In other words, if the highest point on your model's lunar orbit faces north, it must remain facing north as you move the model around the Sun. It may also help to have your model from Activity #34 handy to help illustrate what is happening on a larger scale!

Student Outcomes

What will the student discover?

1. Once again, the scale of distances in our solar system comes into play. Although the tilt of the Moon's orbit is relatively small, the great distances between Earth and Moon make this small angle very significant!
2. The interplay of light and shadow is a magnificent thing. The precise path of light through our solar system, and the shadows created by planets and moons create beautiful phenomena such as eclipses.
3. The design of the solar system is simple, but the many moving bodies and the differences in speed, distance, orbital tilt and position mean that the sky is always changing. As astronomers, we must look when phenomena are available – some of the things we see may never again be visible in our lifetimes!

What will your students learn about science?

This model is the capstone of our exploration of the Earth-Moon system (but not the end of our adventures!) You and your students have seen how models begin with patterns and time keeping, and advance by creatively playing with these models to see what predictions they make, and then testing these predictions with observations and experiments. Instead of reading about science in a book, you and your students have actually engaged in it; building the models, discovering the predictions, and putting them to the test for yourselves. Science is a verb! Science is an adventure! Science is the joy of discovery!

Along the way, we have seen how a single model of the Earth-Moon system could not creditably demonstrate everything we know about the size, scale, motions, and interactions of the Earth, Moon, and Sun. Like real scientists, we have used a variety of models to demonstrate, or rather highlight, different features of the Earth-Moon system that we have discovered. Your students have also seen how we sometimes exaggerate, or deemphasize features of our models by changing size, speed, and distance to suit our own program of investigation and discovery.

Your students have also discovered that science is neither perfect, nor unchanging. Sometimes scientific models and theories must be changed a bit, modified extensively, even tossed out completely. There is no such thing in science as an emotional attachment to a pet theory, or loyalty to an idea which has been demonstrated to be incorrect.

Scientists do not change their minds about a theory lightly, it takes data to drive these changes; but in the face of mounting evidence, any good scientist will go humbly wherever the evidence of nature leads. For all of our magnificent technology, gleaming electronics and massive telescopes, science is a very human activity. It is driven by our curiosity about the universe around us, and our desire to understand the world we live in. Scientists are all children at heart, creative explorers lured on by some interesting pattern that they have glimpsed while at play, delighted by the prospect of learning something new and sharing it with everyone else.

Conducting the Activity

Materials

1. One ping-pong ball
2. A manila file folder or similar stiff card stock
3. Four 3-5 mm beads (grey is preferred, but any color will do)
4. A golf tee
5. A piece of wood or ball of modeling clay for a stand
6. Ping-pong Sun model (See Activity #20)
7. A toy gyroscope (for a teacher demonstration)
8. Markers, glue, poster putty, etc.

Building the Rare Eclipse Model

1. Use markers to decorate a model Earth – your students should be getting good at this by now! You will see why we need a new Earth after we add the lunar orbit to our model!
2. Use silicone glue to attach the South Pole of your model to the golf tee and set it in a ball of clay to stand and dry. Remember that silicone glue needs 24 hours to cure properly. Hot glue can be used to speed up the process if you wish.
3. On the file folder, use a compass to draw and cut out a 5-inch circle. Then cut out a 4.0 cm wide circle from the center of this to create your lunar orbit. If you have done things properly, you should have a lunar orbit ring that will fit nicely over your ping-pong ball. You may use markers to color this black or dark grey if you wish, but do not use crayons, the waxy finish will interfere with attaching our little moon beads to our model later!

4. Place your lunar orbit on the ping-pong Earth model. Be sure the orbit it tilted enough so that the ends of the orbit are well above and below the level of the Earth itself. When you are satisfied that you have everything in the correct position, go ahead and secure your orbital ring with a couple of drops of white glue or super glue.

   With this large and tilted orbit attached, you can see why we needed to put our Earth model on a stand such as a golf tee! Remind your students that the real lunar orbit is 60x the size of the Earth, we have cheated a bit with a lunar orbit just 5x as wide as the Earth to keep the size of our model manageable.

5. Use some poster putty to attach your four moon beads. One each should go at the highest and lowest position on the orbit, and at the ***nodes*** where the orbit crosses the Earth's equator. Younger children might find four moons a bit confusing, in that case simply keep one bead on the orbital ring and move it about as you need to. You must be careful to treat the lunar orbit ring carefully lest you bend it up and damage the model! In any case, with your moon bead now attached, your model is ready to use.

Exploring the Rare Eclipse Model

1. Have your students begin with the moon bead at one of the node positions. Adjust your model so that the Earth is directly between the Moon and the Sun – this is the correct position for a lunar eclipse with the Moon on the node and the node pointed directly at the Sun.
2. Now advance the Earth 90-degrees anti-clockwise (keep the orbit ring oriented in the same direction!), and advance the Moon bead the same 90-degrees anti-clockwise around its orbit ring. Remind your students that this represents three months of time (¼ of a year!) The Moon is now between the Earth and Sun again, but it is either too high above or too far below the Earth for its shadow to create an eclipse!
3. Continue to advance the Earth and Moon 90-degrees at a time and observer the results. You will quickly see that there are only two times per year, six months apart, when an eclipse is possible. These are called ***eclipse seasons***. For an eclipse to occur, the Moon must be precisely on a node on exactly the correct day when the node is pointed at the Sun. No wonder the eclipses are so rare!

Discussion Questions

1. What factors make eclipses so rare?

   Answer: The large size of the lunar orbit.

Answer: The tilt of the lunar orbit that prevents the shadows from striking Earth or Moon most months.

Answer: The small size of the Moon compared to the Earth.

2. What compromises have we made with this model of the Earth-Moon system?

Answer: We have shown the Moon much closer to the Earth than it really is. The diameter of the Moon's orbit is 30x the Earth's diameter; and orbit this large would make our model difficulty to construct and operate.

Supplemental Materials

Being an Astronomer:

Did you know that you can see eclipses happening on other planets? The Galilean moons of Jupiter are large enough that it is possible to observe, and even photograph these moons and their shadows as they pass in front of their planet Jupiter.

Observing such events requires a relatively large telescope; either a refractor of 100 mm aperture or greater, or a reflector of at least 8-inch aperture, preferably 12-inches or even larger. Once again, your local astronomy club may come to your aid. Most clubs have at least one member with a large reflector telescope of the type required to see the shadow of a moon cross the face of Jupiter.

Observing such an event takes planning! These events can be predicted months in advance, just as eclipses on Earth can, but they do not always happen in the early evening when it would be convenient for students and parents to participate. Meet with your club at the beginning of the school year and see if you can plan an effective observation schedule!

Being a Scientist:

If you have a chance to observe an eclipse on Jupiter, you may be able to set up a live video feed for all of your students to look at. If the eclipse happens at an inconvenient time, you may find that your astronomy club may be able to provide you with a video of the event for your class to look at in the comfort of your classroom.

Scientists observe events making careful note of ***first contact, time of totality,*** and ***last contact.*** You can observe these events either live, or from a video. It can be interesting to compare eclipse events from the different Galilean moons (Io, Europa, Calisto, and Ganymede.) Because of their different distances from Jupiter, each of the Galilean moons travels at a different speed in orbit. This can greatly affect the time of totality as the moon’s shadow crosses the face of Jupiter.

Following Up

Predicting eclipses is a very difficult endeavor! Looking at modern calculations of past eclipses that were visible over the Mediterranean and Middle East from 100 BC to 1000 AD, we find that some solar eclipses were just 18 months apart, other times the next solar eclipse might be 400 months apart – that’s more than 33 years separating two solar eclipses.

To predict a solar eclipse, you must know the shape of the Moon’s orbit precisely, and determine how the Earth and Moon speed up and slow down in their orbits. The Greeks reached this level of sophistication in the first century BC, and the Chinese astronomers reached that level of knowledge about 300 AD. There are rumors that Maya or Inca astronomers may have reached that level of knowledge, but much of their mathematical literature was destroyed by their Spanish conquerors in the early 1500’s, so it is unlikely that we will ever know how far these new world astronomers had progressed.

Glossary:

This glossary undoubtedly contains terms that you already know. I have tried to be inclusive by making notes from my lectures, and the questions that students ask me. This glossary not only contains words that I am sure will be of value to many readers, but many terms that students have asked about during lecture over the years.

Acceleration – To increase steadily in speed. *See also: Gravity, and Velocity.*

Accretion – To increase in size by adding smaller pieces. Ex: Planets grow by accretion.

Altitude – The angle above the horizon. Ex: Measuring the Moon's altitude angle.

Analemma – A horizontal figure-8 shape. *See also: Solar Calendar.*

Angular Velocity – Rotational speed. Ex: degrees per hour or revolutions per minute (rpm). *See also: Rotation, Revolution.*

Antipodes – Any two points on exact opposite sides of a planet or moon. Ex: The poles of any planet are also antipodes.

Aperture – The diameter of a telescope's primary lens or mirror. The term is also used for binoculars and other optical equipment. *See also: Focal Length, Focal Ratio, and Magnification.*

Aphelion – The farthest point from the Sun in a planetary orbit. Ex: the Earth's farthest distance from Sun each year is called its aphelion. *See also: Apogee, Lunar Orbit, Perigee, and Perihelion.*

Apogee – The farthest point from the Earth in an orbit in space. Ex: the Moon's farthest distance from Earth each month is called its Apogee. *See also: Aphelion, Lunar Orbit, Perigee, and Perihelion.*

Apparent Motion – An illusion of motion caused by the rotation of our own planet. Ex: The daily motion of the Sun crossing the sky as it appears to circle the Earth.

Artificial Horizon – A line or boundary that represents the true horizon in a model.

Asteroid – Any object in space too small to be seen with the naked eye. Asteroids are different from planets in that they are irregularly shaped. Asteroids do not have enough gravity to crush themselves into a spherical shape.

Astronomical Unit – The distance from Earth to the Sun, approximately 150 million km. This is often used as a yardstick distance when discussing the dimensions of a solar system. Also referred to as an AU.

Axis – The imaginary line around which a planet spins. A planet's axis is also defined by a line connecting its north and south poles.

Azimuth – A compass bearing. Azimuth points the way from our own position to some distant place or object.

Barringer Crater – The best preserved impact crater in the world. Located near Winslow, AZ, Barringer Crater is almost one mile in diameter and ¼ mile deep.

Binary Planet – Two planets of similar size locked in a tight orbit around a common point in space between them. Ex: Pluto-Charon is a binary planet system located 40 AU from the Sun. *See also: Earth-Moon System.*

Celestial Equator – A line that divides the skies into a southern and northern hemisphere; essentially a projection of the Earth's equator onto the sky.

Celestial Pole – A projection of the Earth's polar axis onto the night sky. Viewed from Earth, all the stars appear to rotate around the celestial pole. *See also: Apparent Motion.*

Central Mount – A mountainous feature located in the center of a large crater. Central mounts require large craters – usually over 50 km wide – and are known to exist on Earth, Moon, and Mars.

Centrifugal / Centripetal – Centrifugal [Latin: Center fleeing] is the outward force or motion that we experience when rapidly spinning around a central point, such as on a carnival ride. Centripetal [Latin: Center seeking] is the inward force that holds any object in circular motion, such as Earth's gravity holding the Moon in orbit.

Chixulub Crater – The largest known impact crater on Earth. Located of the Yucatan coast of Mexico, Chixulub is a 180 km wide crater. It is also the site of the impact that caused the extinction of the dinosaurs.

Clockwise / Anti-clockwise – Clockwise rotates to the right, as the shadow on a sundial does. Anti-clockwise rotates to the left.

Competing Theories – It is frequently the case in science that there are competing theories trying to explain a poorly understood phenomenon. This is a strength of science – not a weakness. In any case, it is experiments which decide between competing theories – not people. *See also: Experiment.*

Constellation – A collection of bright stars that appear to form a pattern or shape. Constellations are cultural, different cultures see and name different patterns even though everyone sees the same stars in the sky. *See also: Zodiac.*

Constructivism – A method of teaching that relies on the student to explore and discover instead of relying upon the teacher to deliver facts and vocabulary.

Crater – Bowl-shaped excavations created in just seconds by the impact of an asteroid or meteoroid. Craters range from microscopic to thousands of kilometers in diameter and are found on all terrestrial planets and moons. *See also: Crater Rim, Ejecta, Maria, and Rays.*

Crater Rim – The raised outer ring of stone surrounding an impact crater. The rim is created in seconds from the pressure and heat of the asteroid impact. *See also: Craters, Ejecta, Maria, and Rays.*

Crescent Moon – One of the five different lunar phases, crescent moon is seen just before or after the new moon. The crescent is a curved shape, often described as looking like a fingernail. *See also: Full Moon, Gibbous Moon, New Moon, and Quarter Moon.*

Daylight Savings Time – Each fall the clocks are adjusted back one hour so that the Sun is still near the zenith at 12 'o clock noon. Without daylight savings time, sunrise would not occur until 9 or 10 'o clock in northern latitudes.

Diurnal Motion – The daily motion of the Sun, Moon, and stars across the skies. [Latin: Daily]

Dwarf Planet – The smallest category in a system that classifies planets by size. There are competing classification systems that order planets by the type of surface, interior composition, and location in space. *Note: Dwarf planets such as Pluto and Quaoar are <u>still indeed planets</u>.*

Earth-Moon System – The Earth and Moon affect each other in many ways, including gravitation, orbital motion, orbital stability, and others. Astronomers often study our planet and its satellite as a system of two bodies in orbit around each other. *See also: Binary Planet.*

Eclipse – An event when one body in space crosses into the shadow of another body. *See also: Eclipse Seasons, Lunar Eclipse, Nodes, Partial Eclipse, Path of Totality, and Solar Eclipse.*

Eclipse Seasons – Because of the nature of the orbit of the Earth-Moon system around the Sun, eclipses tend to happen during the same months for several years in a row. The eclipse season changes slowly on a 19-year cycle. *See also: Eclipse, Lunar Eclipse, Nodes, Partial Eclipse, Path of Totality, and Solar Eclipse.*

Ecliptic – The plane of the solar system projected across the skies as seen from Earth. Because our solar system is essentially flat (all the planets orbit in roughly the same plane), the *ecliptic* is the path across the sky taken by the Sun, Moon, and all the planets. *See also: Zodiac.*

Ejecta – Material blasted out of a crater by the blast energy of an impacting asteroid. Ejecta covers the area immediately surrounding the crater in an *Ejecta Blanket.* Some ejecta is sprayed out in long thin streams called *Rays* which can be hundreds of kilometers long. *See also: Craters, Crater Rim, Maria, and Rays.*

Ellipse – An oval-shaped geometrical figure, similar to the circle, except that instead of having a single center point, the ellipse has two focal points. Kepler proved that all planetary orbits are elliptical in shape with the Sun located at one focal point. *See also: Hooke's Pendulum, and Johannes Kepler.*

Equinox – The single day of the year when Earth has 12 hours of daylight and 12 hours of darkness. [Latin: Equal Night] The *Vernal Equinox* happens around March 21st, the *Autumnal Equinox* happens around September 21st. *See also: Solstice.*

Exoplanet – A planet that orbits a star other than the Sun. There are currently approximately 4000 confirmed exoplanets – most discovered by the Kepler satellite. Current estimates are that there may be over 1 trillion (1,000,000,000,000) exoplanets in our galaxy alone.

Experiment – A controlled scientific test that examines only one variable at a time. Experiments are used to support, or invalidate, theories and hypotheses. An experiment can *never prove an hypothesis true – it can only falsify it.* *See also: Hypothesis, Model, Proof, Theory, and Truth.*

Far Side – The side of the Moon that forever faces away from the Earth. We cannot see the far side of the Moon unless we send a spacecraft there. *See also: Near Side, and Synchronous Orbit.*

Fixed Earth – An ancient idea related to the Geocentric Theory. The term *fixed* literally means 'motionless'; in this theory, the Earth neither spins on its axis nor revolves in orbit around the Sun. See also: *Geocentric Theory, Heliocentric Theory, and Aristotle.*

Focal Length – The distance from the surface of a lens or mirror to the point where all light comes gathered to a point. *See also: Aperture, Focal Ratio, and Magnification.*

Focal Ratio – The ratio of focal length to aperture, dividing these two values gives an f-number or focal ratio. Ex: A telescope has a focal length of 900 mm and an aperture of 125 mm. This gives a focal ratio of 900/125 or *f/7.2*. *See also: Aperture, Focal Length, and Magnification.*

Full Moon – The brightest lunar phase when the entire disk of the Moon is visible. *See also: Crescent Moon, Gibbous Moon, New Moon, and Quarter Moon.*

Fundamental Forces – There are four fundamental forces that control everything in the Universe; the Strong Force (atomic nuclei), Weak Force (radioactivity), Electromagnetic Force (light), and Gravity. Only electromagnetic force (light) and gravity concern us in observational astronomy. *See also: Gravity, and Light.*

Galilean Moons – The four great moons of Jupiter discovered by Galileo in 1609. These moons were named for friends and lovers of Jupiter (Zeus), they are called: Io, Europa, Calisto, and Ganymede. *See also: Galileo.*

Geocentric Theory – An ancient theory which states that the Earth is fixed (motionless) and also the center of the cosmos. In this theory, the Sun and Moon, as well as all the planets and stars, revolve around the Earth. This theory was disproved by Copernicus and Galileo. *See also: Fixed Earth, Heliocentric Theory, Copernicus, and Galileo.*

Geologically Dead – A planet that has cooled and become solid all the way to its core (no magma or liquid mantle), no earthquakes, volcanoes, or tectonic plate movement is possible on a dead planet. Small planets generally cool and solidify faster than large planets. Ex: The Moon and Mercury are geologically dead, the larger planets Earth and Venus are not.

Gibbous Moon – The phase of the Moon seen just before or after the full moon, this phase is often described as 'almost full', but the entire lunar disk is ***not*** visible here. *See also: Crescent Moon, Full Moon, New Moon, and Quarter Moon.*

Gnomon – A vertical stick or rod, used in sundials to cast a shadow and tell time. *See also: Solar Clock.*

Gravitational Constant – The amount of gravity depends in part upon a planet's mass, the more massive the planet, the stronger its gravity. The acceleration or rate at which something falls on any particular planet or moon is called local gravity or the gravitational constant for that world. Ex: Earth's gravity is 9.8 m/s^2, while the Moon's gravitational constant is just 1.6 m/s^2. *See also: Fundamental Forces, and Gravity.*

Gravity – One of the four fundamental forces in Nature. Gravity is always attractive – objects are always pulled toward each other. Gravitational strength is related to mass – the larger an object is, the more gravitational pull it has. *See also: Fundamental Forces and Gravitational Constant.*

Gyroscope – A device with a rapidly spinning wheel or disk, used to keep rockets and small aircraft stable in flight. Small toy gyroscopes can be used to demonstrate the stability of the Earth's axis in space.

Heliocentric Theory – A theory first developed in ancient Greece and revived by Copernicus. In this theory, the Sun is the center of the solar system, and the Earth is just one of many planets. This theory was first proven true by Galileo in 1620. *See also: Fixed Earth, Geocentric Theory, Copernicus, and Galileo.*

Hooke's Pendulum – A specialized pendulum that moves in an elliptical path. Robert Hooke invented this pendulum and used it to prove that only gravity and momentum were necessary to create an elliptical orbit. *See also: Ellipse, Orbital Motion, Pendulum, Robert Hooke, and Isaac Newton.*

Hypothesis – An particular or limited idea or speculation based upon observation and data. An hypothesis must be falsifiable, able to be disproved by experiment, in order to be valid. *See also: Experiment, Model, Proof, Theory, and Truth.*

Ice Giant Planet – Some Jovian planets are large enough to compress their gaseous interiors first into liquids, then into solid ice forms deep in their interiors (think of dry ice here.) Neptune and Uranus are examples of this type. *See also: Jovian Planet, and Terrestrial Planet.*

Impact Energy – The amount of energy that an impactor delivers when it strikes the surface of a moon or planet. Impact energy depends on just two factors: the mass of the impactor and its speed. Impact energy of this type is usually expressed in megatons (MT), one megaton is sufficient to completely destroy a large city. *See also: Impactor.*

Impactor – Any object from space that strikes a planet or moon. Impactors may be man-made such as a falling satellite, or natural such as an asteroid.

Inertia – The property of matter that resists any change in motion. Ex: If you try to throw a bowling ball, you feel a resistance – this is due to the ball's inertia.

Inferior Planet – Any planet closer to the Sun than the Earth. Mercury and Venus are the only inferior planets in our solar system. Inferior planets show changing phases, like the Moon does, when they are seen in a telescope. Galileo used the phases of Venus to prove the heliocentric theory in 1620. *See also: Galileo, Heliocentric Theory, and Superior Planet.*

Infrared Light – A wavelength of light that is too long for the human eye to detect. Infrared light can be felt by the skin as heat. *See also: Ultraviolet Light, and Visible Light.*

Inner Solar System – All planets inside the orbit of Jupiter: Mercury, Venus, Earth, Mars, Vesta, Ceres, and the asteroid belt. ($R \leq 5$ AU) *See also: Outer Solar System.*

Interstellar Space – Vast empty spaces between the stars and their respective solar systems; the distance to our nearest star is 4.6 light years – almost all of this is empty interstellar space.

Jovian Planet – Any planet that is composed primarily of gaseous elements such as helium and hydrogen. Jupiter, Saturn, Uranus, and Neptune are all Jovian worlds. These used to be called *Gas Giant Planets*, but it has been learned that most of the interior of these worlds are under so much pressure that the gas becomes liquid, and even solid deep in the interior. *See also: Ice Giant Planet, and Terrestrial Planet.*

Kilo / Mega / Giga / Tera – These are metric prefixes. Kilo = thousands; Mega = millions, Giga = Billions, and Tera = trillions.

Kuiper Belt – large belt of comets in the outer solar system. This belt is thought to extend from 50 – 100 AU out from the Sun, far beyond the orbit of Pluto. *See also: Oört Cloud.*

Latitude – Lines that divide the Earth in a north-south direction, starting with the equator (0 degrees) and extending to the poles ($^+/_-$ 90 degrees). *See also: Longitude.*

Leap Year / Leap Second – Because the does not take exactly 365 days to orbit the Sun, we add an extra day to February every four years to keep the calendar correctly aligned with our seasons. The leap second is similar and used because Earth's rotation on its axis does not take exactly 24 hours.

Libration – The wobbling motion of the Moon as it orbits the Earth. Libration turns the Moon so that we may occasionally see a small portion of the lunar far side. *See also: Far Side, Near Side, and Orbital Motion.*

Light – Light is also called *electromagnetic radiation*. The electromagnetic spectrum includes radio waves, infrared (heat), visible light, ultra violet, x-rays, and gamma rays. We have telescopes that can 'see' in all these types of light – each kind of light brings us unique kinds of information about distant stars and galaxies. *See also: Fundamental Forces.*

Light Year – The distance that a beam of light in space will travel in one year; approximately six trillion kilometers.

Longitude – Lines that divide the Earth in an east-west direction, starting with the Prime Meridian (0 degrees) and extending to the International Date Line (180 degrees). *See also: Latitude.*

Lunar Atlas – A high resolution map of the Moon which names craters, mountains, maria and other features.

Lunar Eclipse – An event where the Moon crosses into the Earth's shadow for a period of a few hours. This darkens the Moon from silvery-white to a red-brown-orange color, similar to the effect of the light of a sunset on hills or buildings. *See also: Eclipse, Eclipse Seasons, Nodes, Partial Eclipse, Path of Totality, and Solar Eclipse.*

Lunar Orbit – The elliptical path of the Moon around the Earth; the nearest point to the Earth is called perigee while the most distant point of the Moon's orbit is called Apogee. The Moon is held in orbit by the Earth gravitational pull. *See also: Apogee, Gravity, and Perigee.*

Lunar Phases – The changing appearance of the Moon as it orbits the Earth is called lunar phases. *See also: Crescent Moon, Full Moon, Gibbous Moon, New Moon, and Quarter Moon.*

Lunation – One complete cycle of lunar phases from new moon to full moon and back to new moon again, this cycle takes about 29.5 days. *See also: Lunar Orbit, and Lunar Phases.*

Magnification – Magnification is a measure of how much closer an object appears when looking through a binocular or telescope. If an object appears ten times closer in the telescope than in the naked eye, this is referred to as 10x, or 10-power magnification. Magnification is a *very poor* way to judge the quality of a telescope or binocular; it is a complex subject worthy of much study.

In binoculars, 10x is generally the highest power that is practical. With a telescope, our atmosphere limits the highest practical magnification in any telescope to 350x under most conditions. A telescope's magnification is calculated by dividing the telescope's focal length by the eyepiece's focal length. Ex: An eyepiece with a focal length of 12 mm is attached to a telescope with a 900 mm focal length. Magnification = 900/12 or 75x. *See also: Aperture, Focal Length, and Focal Ratio.*

Maria – A lake or ocean of lava that fills a very large crater. The most famous maria is the *Sea of Tranquility* where men first set foot on the Moon in 1969. *See also, Crater, Crater Rim, Ejecta, and Rays.*

Meteor / Meteoroid / Meteorite – A *meteoroid* is a small object in space, usually less than a few meters across. While a meteoroid falls through the atmosphere and burns up due to air friction, it is called a *meteor*, this phase lasts only a few seconds. Once a meteor lands on a planet's surface and comes to rest, it is called a *meteorite. See also: Impactor, and Impact Energy.*

Model – A model is a physical or mathematical hypothesis. A model allows the scientist to explore and gather data and predictions that can be tested by experiment or observation. If a model is sufficiently broad in scope, it may be referred to as a theory rather than an hypothesis. *See also: Experiment, Hypothesis, Proof, Theory, and Truth.*

Moonrise / Moonset – Like sunrise and sunset, moonrise is the time when the Moon rises above the horizon and becomes visible in the sky; moonset is the time when the Moon falls below the horizon and is no longer visible.

NASA / ESA / JAXA – These are the space exploration agencies of the United States, European Union, and Japan respectively.

Near Side – The side of the Moon that forever faces the Earth. *See also, Far Side, Synchronous Orbit.*

Nodes – A point in space where the orbit of the Moon crosses the plane of the Earth's orbit. If the Earth or Moon cross over a node, an eclipse is possible. *See also: Eclipse, Eclipse Seasons, Lunar Eclipse, Partial Eclipse, Path of Totality, and Solar Eclipse.*

Oört Cloud – A spherical shell of comets extending from 100 – 150 AU from the Sun. No object this far from the Sun has ever been directly observed with a telescope. *See also: Kuiper Belt.*

Orbital Motion – The motion of a smaller body (the satellite) in an elliptical path around a larger body. *See also: Gravity, Lunar Orbit, and Orbital Period.*

Orbital Period – The time it takes for an object to complete one orbit around another body. For planet Earth, this is called a *year*. *See also: Gravity, Lunar Orbit, and Orbital Motion.*

Outer Solar System – The portion of the solar system that resides at or beyond the orbit of Jupiter (R = 5 AU to 150 AU). This includes the Jupiter, Saturn, Uranus, and Neptune, many dwarf planets, and two comet belts. *See also: Inner Solar System.*

Pantograph – 1) A device for copying a drawing or shape from one surface to another. 2) A specialized device for copying the shape and size of a constellation in the sky accurately onto paper.

Parabolic Curve – Any object freely falling under the influence of gravity moves in a parabolic curve. This includes falling bodies such as a ball in flight to orbiting bodies such as moons and planets. *See also: Gravity.*

Partial Eclipse – A condition where only part of a body such as the Sun or Moon is darkened during the eclipse event. *See also: Eclipse, Eclipse Seasons, Lunar Eclipse, Nodes, Path of Totality, and Solar Eclipse.*

Path of Totality – The shadow of the Moon upon the Earth is relatively small, often less than 50 km wide. This circular shadow traces a path across the Earth during a solar eclipse called the *path of totality,* only if one stands inside this narrow pathway can one see a total eclipse of the Sun. *See also: Eclipse, Eclipse Seasons, Lunar Eclipse, Nodes, Path of Totality, and Solar Eclipse.*

Pendulum – A device comprised of a weight or bob suspended by a line. The pendulum bob swings back and forth in a regular motion; the period or time of the swing is controlled only by the length of the line – not the weight of the pendulum bob. *See also: Hooke's Pendulum.*

Perigee – The closest point to Earth in an orbit in space. Ex: the Moon's closest approach to Earth each month is called its Perigee. *See also: Aphelion, Apogee, Lunar Orbit, and Perihelion.*

Perihelion – The closest point to the Sun in an orbit in space. Ex: the Earth's closest approach to Sun each year is called perihelion. *See also: Aphelion, Apogee, Lunar Orbit, and Perigee.*

Period – *See: Orbital Period.*

Pinhole Camera – A primitive camera that projects an image onto a screen or film through a small pinhole – very useful for viewing a solar eclipse safely. Also called a *camera obscura.*

Proof – Proof is a mathematical concept, it has no place in science at all. A scientific hypothesis or theory can be *supported* by data, but ***never proven.*** Experimental data and observations increase our confidence in a theory, but a good scientist always acknowledges room for error. Ex: Newton's theory of gravitation was considered absolutely sound (but not proven!) for over 250 years until Einstein's theory of relativity reformed and updated it. *See also: Experiment, Hypothesis, Model, Theory, and Truth.*

Punctuated Equilibrium – A theory that says geological change on a planet is very gradual over millions of years, but occasionally interrupted by massive sudden change such as from a large asteroid impact. *See also: Impact Energy, Impactor, and Meteor.*

Quarter Moon – The phase of the Moon where exactly half of the lunar disk is visible. This phase occurs when the Moon is one quarter of the way around its orbit, half-way between the full and new moon phases. *See also: Crescent Moon, Full Moon, Gibbous Moon, and New Moon.*

Rays – Thin streams of powdered rock ejecta that are blasted out of a crater during impact. Rays are usually only a thin layer of powder on the ground and difficult to see unless the lighting is exactly right. *See also: Crater, Crater Rim, Ejecta, and Maria.*

Relativity Theory – Developed by Albert Einstein in 1915, this is the first significant correction to Newton's theory of gravitation in 250 years. Einstein envisioned space and time as a unified fabric – not separate things. Spacetime fabric could be bent or warped – and this curvature is the cause of gravity. *See also: Albert Einstein, Gravity, and Spacetime.*

Revolution – The motion of one body around another. Ex: The Earth revolves around the Sun. *See also: Orbital Motion, Rotation, and Satellite.*

Rotation – The motion of a body spinning on an internal axis. Ex: The Earth rotating on its axis creates the daily cycle of night and day. *See also: Revolution.*

Satellite – Any object that orbits another larger body. Satellites may be natural (such as the Moon) or artificial (such as a weather satellite.) *See also: Orbital Motion, and Revolution.*

Scale – The size of one thing relative to another. Ex: If the Sun is the size of a basketball, then Neptune is the size of a small marble almost 1 kilometer away – this shows the *scale* of the solar system.

Seasonal Cycle – The annual change from spring, to summer, fall, and winter. This seasonal change in the weather is caused by the tilt of Earth's axis. *See also: Tilted Axis.*

Solar Clock – Also called a sundial, this is a device that uses a gnomon (vertical stick) to cast a shadow in order to tell time. *See also: Gnomon.*

Solar Eclipse – An event when the Moon temporarily blocks the light of the Sun. When seen from Earth, the Sun appears to go completely dark for a period of minutes. *See also:*

Eclipse, Eclipse Seasons, Lunar Eclipse, Nodes, Partial Eclipse, and Path of Totality.

Solstice – The day where the Sun reaches is greatest northern (or southern) position in the sky; this is also the date when we experience either the longest night (winter solstice – Dec 21) or the longest day (summer solstice – June 21.) [Latin: Sun Stands Still] *See also: Equinox.*

Spacetime – A concept from Einstein's theory of relativity, Einstein saw space and time as one unified thing instead of separate entities. The curvature of spacetime is what causes gravitational force. *See also: Albert Einstein, Gravity, and Relatively Theory.*

Star Party – A public event where students, parents, and members of the public are invited to come and enjoy observing through telescopes; often hosted by members of an astronomy club.

Sun Spot -- A cool spot on the surface of the Sun that appears darker than surrounding areas. Sunspots average 4500° K – almost 1500 degrees cooler than the rest of the solar surface. Sunspots are caused by *magnetic storms*, anomalies in the Sun's powerful magnetic field.

Sundial – *See: Solar Clock.*

Superior Planet – Any planet that lies further out from the Sun than the Earth. Mars, Jupiter, and Saturn are all superior planets. Superior planets always appear as full disks (never phases) when you see them in a telescope. *See also: Inferior planets.*

Synchronous Orbit – A large planet may lock a small satellite in position so that one side forever faces the planet, and one side always faces away; this process is also called Tidal Locking. When a moon is locked in synchronous orbit, it has only one rotation on its axis for each revolution around the planet. This 1:1 ratio gives a synchronous orbit its name. *See also: Near Side, and Far Side.*

Terminator – The line that separates daylight from darkness on the lunar surface. *See also: Lunar Phases.*

Terrestrial Planet – A planet with a rocky crust (silicate composition.) Ex: Mercury, Venus, Earth, and Mars are all terrestrial planets. [Latin: Earthlike] *See also: Ice Giant Planet, and Jovian Planet.*

Theory – A mathematical or physical model that explains *everything we know* about a particular subject. A theory not only explains what we know, it points our way to new investigations and ideas by acknowledging what we do not know. A theory is always far greater in scope than a mere hypothesis, and often represents many years of effort and study by many scientists. *See also: Experiment, Hypothesis, Model, Proof, and Truth.*

Tilted Axis – Any planet that has an axis which is not aligned with the axis of the Sun is said to have a tilted axis. Ex: Earth's axis is tilted by 23.5 degrees – this causes the seasonal cycle on our planet. *See also: Seasonal Cycle.*

Tonne / Ton – a unit of weight. 2,000 pounds is an *Imperial Ton.* In metric units, 1,000 kilograms is a *Metric Tonne.* Because of the difference in metric and Imperial units, the metric tonne is approximately 20% heavier.

Truth – Truth is a philosophical concept, not a scientific one. Scientists performing experiments never learn the Truth – they collect data which may support an hypothesis or theory, but a good scientist always acknowledges room for error. *See also: Experiment, Hypothesis, Model, Proof, and Theory.*

Ultraviolet Light – A wavelength of light that is too short to be detected by the human eye. Ultraviolet light causes tanning, sunburn, and can cause skin cancer. *See also: Infrared Light, and Visible Light.*

Velocity – Rate of travel, usually expressed in meters per second (m/s), kilometers per hour (kph), miles per hour (mph), etc. *See also: Acceleration.*

Visible Light – The narrow range of the electromagnetic spectrum that the human eye can detect. There are seven color bands in the visible spectrum: red, orange, yellow, green, blue, indigo, and violet, but the human eye can detect millions of distinct colors. *See also: Infrared Light, and Ultraviolet Light.*

Waning – 1) Decreasing or growing smaller. 2) The portion of the lunar cycle from the full moon to the new moon when the lighted portion of the Moon gets smaller each day. *See also: Waxing.*

Water Clock – A primitive clock that uses water dripping from a small hole in a jar to tell the time.

Waxing – 1) Increasing or growing larger. 2) The portion of the lunar cycle from the new moon to the full moon when the lighted portion of the Moon gets larger each day. *See also: Waning.*

Zodiac – A group of 13 constellations that lie along the *ecliptic*. The 13th constellation, *Ophiuchus – The Healer*, is less well-known than the other 12 constellations which are known from fiction and fantasy such as horoscopes, etc. *See also: Ecliptic.*

Famous Names in Astronomy:

Albert Einstein – German-American physicist. Einstein is primarily remembered for his *Theory of Relativity*, developed from 1905-1915. This theory was the first significant correction to Isaac Newton's *Theory of Gravitation* in 250 years. 100 years after the theory was first developed, scientists are still doing experiments to confirm Einstein's predictions.

Aristarchus of Samos – c. 250 BC. Greek astronomer and mathematician who presented the first known model of the solar system with the Sun in the center of the cosmos.

Aristotle – c. 350 BC. Greek philosopher and scientist known for championing the Earth-centered model of the solar system.

Carl Sagan – American astronomer and scientist. Known for championing space exploration, particularly probes to the outer planets. Creator and host of the original *Cosmos* TV series in the 1980's.

Copernicus – c. 1525. Polish astronomer and mathematician. Known for the redevelopment of the heliocentric (Sun-centered) theory of the solar system. Published his theory posthumously without proving it. Theory was later shown to be true by Galileo.

Eratosthenes – c. 225 BC. Greek mathematician and astronomer. Known for measuring the circumference of the Earth, distance to the Moon, etc.

Galileo Galilei – c. 1610. Italian astronomer, inventor, and mathematician. Known for inventing the first practical astronomical telescope, mapping the Moon, and proving that the geocentric (Earth-centered) model of the solar system was wrong.

Gerard Kuiper – Dutch-American astronomer. Along with Kenneth Edgeworth, Kuiper is known for predicting a belt of icy comets located beyond the orbit of Pluto.

Isaac Newton – c. 1665. English physicist and mathematician. Inventor of the reflector telescope, theory of gravitation, particle theory of light, and along with Gottfried Leibnitz the inventor of calculus.

Johannes Kepler – c. 1600. Kepler was the assistant of the Dutch astronomer Tycho Brahe. Kepler inherited all of Kepler's scientific work and used Tycho's data to prove that all planets orbited the Sun in elliptical orbits. Known for the three laws of planetary motion.

John Packard – c. 1900. American physics teacher. Known for the invention of the *Packard Apparatus*, a slanted table which allowed students to track the path of a rolling marble and calculate the gravitational constant of the Earth.

Pythagoras – c. 520 BC. Greek mathematician. Known for the Pythagorean Theorem and the study of geometry and numbers.

Robert Hooke – c. 1665. English scientist and inventor. A rival of Isaac Newton and inventor of *Hooke's Pendulum* used to prove that only gravity and inertia are necessary to create an elliptical orbit.

Tycho Brahe – c. 1575. Danish nobleman and astronomer. Known as the most accurate astronomer in the pre-telescope era. Tycho built his own observatory and designed and built his own instruments which enabled him to make more accurate observations than anyone before him. Tycho's many years of observational data made it possible for Kepler to develop his *Laws of Planetary Motion* after Tycho's death.

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