8.2: 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

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.

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!)

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.

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.
