Solar System Stroll

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Student Name:

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Background

It is a challenge to visualize the relative sizes of the planets, much less how far apart they are in space. This is in large part due to the inability of most people to accurately interpret numbers that are large – and let's face it, all of the numbers describing the solar system are HUGE!

So, what we need to do is to shrink the whole solar system down to a size we can understand. We want to be able to walk through our model and back in one hour or less. And we don't want to shrink the planets so small that we can't see them. You'll find that this can be quite a challenge!

This exercise will not only allow you to create an accurate scale model of our solar system, but will also expose you to the concept of scale. The concept of a scale model is pretty simple — how many times smaller must the model objects be compared to the real thing? In a scale model, all of the dimensions are "shrunk" by the same amount.

This scaling skill is obviously of tremendous value to people designing buildings, drawing maps, and developing new automobile, spacecraft or aircraft designs.

Your goal is to find a **scaling factor** (how much you have to shrink things down) that will allow us to see the smallest of the planets (including the dwarf planet Pluto) while keeping the distance to be walked no greater than about 1 kilometer in one direction.

Objective

The objective of this activity is to create an accurate **scale model** of the solar system.

Materials

- calculator
- all other materials will be provided by your teacher

SPECIAL NOTE: The model created will be very accurate in terms of sizes and distances; however, the planets NEVER line up in a straight line as demonstrated during the walk. The straight line of the model is due to the need to be able to see as much of the 1 km model at a time as possible, which requires the straight line.

Procedure

1. Answer the pre-activity questions posed in Questions and Conclusions, page 2.
2. Using the data provided in the data table (page 3), calculate the scaling factor for creating a model of the solar system that will allow us to see the smallest of the planets (including the dwarf planet Pluto) without magnification, while keeping the distance to be walked no greater than about 1 kilometer in one direction. Record the scaling factor on page 3. [See Special Note: The planets *never* really line up like this!]
3. Once you have the scaling factor, use it to calculate the distance to each of the planets in your model assuming that the Sun is placed at the beginning of the 1 kilometer model. This means that you have to either divide or multiply each of the solar system's actual dimensions by the calculated scaling factor. Would you multiply or divide to create this model? Circle the correct process…

   Multiply   Divide   (record your calculations in the data table)
4. Now use the scaling factor to calculate the scale diameter of the Sun and each of the planets in the model. Just as for the distances between the planets, multiply or divide the real measurements of a planet's diameter by the scaling factor in order to find the diameter of the planet in our 1 km model. (record your answers in the data table)
5. Your teacher will lead the class in a walking tour of our solar system using a scale that is very similar to the one that you just calculated. Pay careful attention during the tour to the size of each planet and the distances between them.

Questions and Conclusions

Pre-Activity Questions: **Student Name: ______________________________**

1. Before completing the model, indicate your current understanding of the structure of our solar system.
   Our solar system is… (circle a number)

   1 2 3 4 5 6 7 8 9 10

   Packed Fairly Full Somewhat Empty Mostly Empty

2. Even the smallest of the planets is thousands of kilometers in diameter, knowing this fact, which planets do you think can easily be seen from Earth? (circle any that apply)

   Mercury Venus Mars Jupiter Saturn Uranus Neptune Pluto (dwarf)

3. If your model is really built to scale, how large do you think the Sun will appear in your model when viewed from the Earth's position? (circle one)

   Smaller than the real Sun

   The same size as the real Sun

   Larger than the real Sun

4. Explain your answer to question number 3.

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Activity Questions:

5. When you are at the Earth's position…
   Look back at the Sun in the model and compare its size to the real Sun. The Sun in the model appears to be…?
   (circle one)

   Smaller than the real Sun

   Cloudy, can't tell

   The same size as the real Sun

   Larger than the real Sun

6. When you are at Jupiter's position…
   Jupiter is much larger than Venus, therefore it can reflect more sunlight toward the Earth. So why does Venus shine many times more brightly than Jupiter in our nighttime sky?

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7. After completing the model…
   Indicate your current understanding of the structure of our solar system. Our solar system is… (circle one)

   1 2 3 4 5 6 7 8 9 10

   Packed Fairly Full Somewhat Empty Mostly Empty

Data Table

Student Name: ______________________________

Scale Factor: Scale = 1 : ____________________

Planet/Sun	**Distance from Sun** (kilometers)	**Scale Distance from Sun** (meters)	**Diameter of Object** (kilometers)	**Scale Diameter of Object** (centimeters)
Sun	does not apply	does not apply	1,391,980	
Mercury	58,000,000		4,880	
Venus	108,000,000		12,100	
Earth	150,000,000		12,800	
Mars	228,000,000		6,800	
Asteroids (middle)	419,000,000		933 (largest: Ceres)	
Jupiter	778,000,000		142,000	
Saturn	1,430,000,000		120,000	
Uranus	2,870,000,000		51,800	
Neptune	4,500,000,000		49,500	
Pluto (dwarf planet)	5,900,000,000		2,300	

Challenge Questions:

1. The nearest star beyond the Sun is Alpha Centauri, and it's 40,396,400,000,000 km away. How far would this star be from the Sun in your model?

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2. Our star, the Sun, is a middle-sized star. Betelgeuse (in the constellation Orion) is a large star. Its size varies as it expands and contracts over time, but its average diameter is 521,962,500 km. What would the diameter be on your scale?

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3. If we placed Betelgeuse at the center of our solar system, half of its diameter (its radius) would extend out in all directions into the solar system. How much of the solar system would be filled by Betelgeuse?

Out past the planet ______________________________.

Background for Teachers

Students studying Astronomy concepts, whether participating in a high school Earth and Space Science course or in an elementary or middle school unit in Geology or Astronomy, routinely run up against the problems of scale and of large numbers that are often not encountered in other science lessons. Yet, the astounding sizes and vast distances involved just within "our own" galaxy, are crucial prerequisites for understanding these subjects.

"How big *is* space?," is not only a perfectly legitimate question in its own right, but discovering the answer will also help to prepare anyone for further investigations of the planets and the stars. In astronomy, part of the problem is, of course, the lack of context or experience into which this kind of problem can fit. Surprisingly, there is something else lacking as well: it is almost certainly true that none of our students has ever seen a true scale model of this solar system! Globes of the Earth and model railroads are carefully constructed and highly accurate scale models with which everyone is familiar, but students rarely encounter anything besides wildly distorted models of this solar system. Students just haven't ever seen a true solar system scale model - not in books, museums, or classrooms. How can this be? Isn't it just a problem of scale? Yes, as a matter of fact, a really BIG problem of scale.

The essence of the problem is this: if a scale is selected to correctly portray the relative sizes of the planets and the Sun, then that same scale can't be used to also convey the relative distances separating these objects from each other. The opposite situation is equally true: if a scale is selected to correctly establish relative distances within this solar system, then that same scale can't be used to also provide the relative sizes of the planets and the Sun. The choice has always been either to distort the relative sizes of the Sun and planets in order to develop an accurate distance model or to distort the relative distances in order to accurately describe the relative sizes of things. Basically, a true scale model of this solar system just can't fit onto the page of any book, or in any classroom, or in any gymnasium, or in any field house, but when the weather is fair, a truly great scale model of this solar system can be quite easily constructed outdoors.

At its simplest, any scale model involves just reducing all of the sizes involved by the same amount or factor. The actual diameters and distances for the planets in our solar system are listed on the student pages, and are accurate enough for the purposes of this activity.

Important Points for Students to Understand

- The planets of the solar system NEVER actually line up in outer space… their orbits are tilted relative to each other and their periods of revolution around the Sun vary by more than two magnitudes (a factor of 100!). The straight line is used in the model only to allow a student to see as much of the 1 km model at a time as is possible in an urban setting.
- The solar system is fundamentally empty. You could scrape every last bit of matter orbiting the Sun (planets, moons, comets, asteroids, etc.) into a single pile that would have approximately 1% of the mass of the Sun.
- The planets are teeny-tiny compared to the vast emptiness that exists between them. It is this fundamental truth that makes it so challenging for astronomers to study the planets of our solar system.
- A scale model is reduced equally in all dimensions from the original.

Materials: total for the class

- 9 inch ball (orange or yellow)
- 1 set of stainless steel planet plates with laser-cut holes representing the scale size of the planets, some moons, etc.
- 1 "planet plate post" for each planet (9)
- Trundle wheel for measuring distances (meter) [optional]
- calculators (one per student or group) [optional]
- Safe solar viewing glasses [optional]
- planet information cards (1 set)

***Note:** this entire set is available through the Science Materials Center.

Vocabulary

Scaling factor: the amount by which the real object has been reduced in order to create the model.

km: abbreviation for kilometer, which equals 1000 meters.

m: abbreviation for meter, which equals 100 centimeters.

cm: abbreviation for centimeter, which equals 10 millimeters.

Credit: special thanks to Art Camosy (Memorial High School) for his contributions to this activity.

Procedures

1. Discuss the Background Information and complete the students' procedure #1, answering the Pre-Activity Questions.
2. **Scaling Factor:** The scaling factor can be derived by students (an excellent small group activity) or provided by the teacher, depending on the students' level of sophistication in mathematics. This matches with students' procedures #2-4.

- Students in grades 5 - 8 can simply be told that the single scale they choose should provide the class with a large enough size for the smallest object (dwarf planet Pluto) so that it can be seen without magnification, while at the same time, the most distant object from the Sun (Pluto) can be reached after only a moderate walk. It is desirable for students to discover that it is in the extremes that the problem of scale must be solved. If the students are having trouble, they can be told to use Pluto's scaled distance as 1 kilometer.
- Younger students (grades 3-4) who have learned to use a calculator, can be given the scaling factor, and then they can do the math with your instruction.
- Even the youngest students (grades k-2) will still benefit by walking through the model—without doing the math at all.
- **Numbers:** Once the number crunching is done, teachers will usually find that students are proposing scale factors that cluster in the range of several billions to one. A scale factor of six billion to one works well, providing a very small but still visible Pluto at a distance from the Sun of about one kilometer. So there it is. Our scale model must extend for **about** one kilometer if we are to be able to just see the smallest "world" in this solar system. That's why neither books nor posters nor anything else offers such a scale model. Item one on your planning list, then, is to find a location which allows a one kilometer straight line walk. If you do use a scale factor of six billion to one, then the following sizes and distances result.
- **Option:** there is a wonderful web page designed to make these calculations. You could let the students use the site, or you could use it to check their math. Here's the web address: http://www.exploratorium.edu/ronh/solar_system/

Planet/Sun	**Scale Distance from Sun** (meters)	**Scale Diameter of Object** (centimeters)
Sun	does not apply	23.33
Mercury	9.7	0.08
Venus	18.0	0.20
Earth	25.0	0.21
Mars	38.0	0.11
Asteroids (middle)	75.0	0.02 (Ceres)
Jupiter	130.0	2.39
Saturn	238.0	2.00
Uranus	478.0	0.86
Neptune	750.0	0.82
Pluto (dwarf planet)	983.0	0.04

*Now may also be a time for students to complete the Challenge Questions. It would also be effective to have them complete the Challenge Questions after they have experienced the model.

Special Note: read through these procedures carefully, and remember to stop at the appropriate positions along the way as specified.

3. **Start at the Center:** Start your walk by placing the Sun -- a nine inch yellow ball or the stainless steel Sun plate as we begin our journey through the model.

4. **Strolling to Mercury:** Within a short distance, 9.7 meters or roughly thirty feet, we come to Mercury. This distance can be measured or paced out, or the usual five foot length of a typical sidewalk slab can be relied upon to provide the distance.

   While you're stopped: The stops are an excellent time to talk about the planet, discuss mission results, show photographs, and allow students to daydream a bit. Show the pre-cut hole in the plate which represents the size of the planet. These stops can be as elaborate or as simple as you care to make them. This would also be a good time to remind the students that having the planets in a straight line is only for ease of building the model, and that the planets never line up.

   Into the ground next to the sidewalk, push the planet plate post deep enough so that it will hold up the Mercury plate.

5. **Strolling to Venus:** Continue walking. At a distance of 18 meters or nearly sixty feet from our Sun, you come to Venus, and push another prepared planet post into the ground.

6. **Strolling to Earth:** Your walk now brings you to Earth at a distance of 25 meters or about eighty feet from our Sun. Plant the planet plate post.

   Important Point: It is right here that you need to emphasize that this project is not just an abstract mathematical exercise. Here's how. (Tips for observing the Sun follow.) Students should try to make the following observation: look at our model Sun (still being held back at the starting point by a student volunteer) at a distance of 25 meters, and compare the apparent size to how big the Sun appears in the sky. The apparent sizes of both the model Sun and the real Sun will match beautifully -- a stunning demonstration of our planet's place in space and an excellent confirmation of the accuracy of our scale! Remember that we are observing the Sun from the Earth! However, students should never look directly at the sun! You should buy at least one solar filter, or a class set of eclipse glasses (see Preparation section on p. 7).

   • Have the students fill in their answer to question #5 in their Questions and Conclusions section.

Special Safety Tip

Students should never look directly at the sun! The best method is to buy at least one solar filter. You can buy solar filter film and make multiple filters for students to use.
You can use a #14 welding glass, and hold it for the students to make their observation.

*See **Preparation** section on page 7.

7. **Strolling...Mars through Pluto:** Signal your Sun holder to rejoin the group (carrying the Sun along) and proceed with the rest of the tour. Each stop on the tour gets the planet post treatment with the proper sized laser-cut hole.

   While you are stopped at Mars: discuss Challenge Question #2-3.

   While you are in the asteroid belt: show the approximate beginning of the belt (50m), the middle (75m: where you might want to place the marker), and the end (100m).

   While you are stopped at Jupiter: discuss question #6 in the students' Questions and Conclusions section. Help them to look back toward the Earth, and to compare the scale distances and sizes of Jupiter and Venus.

   While you are stopped at Pluto: discuss Challenge Question #1.

8. **Coming Home:** At the end of the walk, turn around and retrace the route home, pulling up stakes as you go. The sense of the emptiness of space is

overwhelming. Who will be the first to spot Earth on the way back? (It's not visible even in binoculars from the model's outer planets.)

9. **Back in the classroom:** refer the students to #7 in their Questions and Conclusions section, and discuss their impressions of this experience. You might also want to discuss the graphics they've seen in books, magazines, or the Internet depicting the solar system (see Suggestions for Further Study below).

Time Management

The introduction to the activity and the number crunching can be done in one class period. The stroll through the model requires another class period.

Preparation

• **Find a location** near your school which 1 km in length, and hopefully in a straight line and level enough so that you can see from one end to the other.

• **Special Note:** you may choose to do this activity outside of Memorial High School when you visit the planetarium. You may also request to have a member of the planetarium staff lead you on your tour. Discuss this with the planetarium staff when you make your planetarium reservations.

• Request the Solar System Stroll kit from the Science Materials Center. This will include all materials except the calculators and eclipse shades (if you choose to use them).

• Assemble the planet plate holders (provided in the kit). Instructions located in the box.

• (optional) Purchase/prepare safe solar filters to keep at your school.

Eclipse Shades (a.k.a. Solar Viewing Glasses or Eclipse Glasses): you can purchase them for less than $1 each at the Rainbow Symphony Store (http://www.rainbowsymphonystore.com/)

• **Choose the date of your journey carefully**, and you can finish the tour in the best of all possible ways -- directing students to find real planets in tonight's night sky.

Variations

• Have the students create a computer spread sheet, or provide them with a spread sheet to calculate the scale sizes and distances. You could also direct the students to use the Exploratorium web site as mentioned on page 5.

Suggestions for Further Study

• Consider using the activities **Voyager to the Stars**, and **Driving the Planets** which also emphasize the scale and distance of our solar system. Contact the planetarium office or web site for these activities.

• Consider using the activity **Our View of the Solar System** which allows the students to explore the current positions of the visible planets in a model, and compare this to the planet positions in the current sky.

• Use the Internet to get up-to-date information about the planets from space probes which are currently exploring them. (see the planetarium's web site in the Astro List section for links to many of the current probes.)

• You might also consider (after the activity) asking the students to search for graphics depicting the solar system. Hopefully, you can generate some discussion about how empty the solar system really is, and how graphics can cause people to have misconceptions. Any graphic showing the planets orbiting the Sun grossly exaggerates the sizes of the planets.

Answers to Questions and Conclusions

Pre-Activity Questions

1. Answers will vary.
2. Mercury, Venus, Mars, Jupiter, Saturn
3. Answers will vary.
4. Answers will vary.

Activity Questions

5. The same size as the real Sun.
6. Distance. Venus is so much closer than Jupiter that it cancels out the difference in size.
7. Answers will vary, but hopefully they will be toward the “mostly empty” end of the scale.

Answers to Data Table

Scale Factor: Scale = 1 : 6 billion (or very close)

Planet/Sun	**Distance from Sun** (kilometers)	**Scale Distance from Sun** (meters)	**Diameter of Object** (kilometers)	**Scale Diameter of Object** (centimeters)
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Neptune	4,500,000,000	750.0	49,500	0.82
Pluto (dwarf planet)	5,900,000,000	983.0	2,300	0.04

Answers to Challenge Questions:

1. The nearest star beyond the Sun is Alpha Centauri, and it’s 40,396,400,000,000 km away. How far would this star be from the Sun in your model? **6733 km** (this is approximately the distance from Wisconsin to Hawaii)
2. Our star, the Sun, is a middle-sized star. Betelgeuse (in the constellation Orion) is a large star: ave. diameter = 521,962,500 km. What would the diameter be on your scale? **87 m**
3. If we placed Betelgeuse at the center of our Solar System, half of its diameter (its radius) would extend out in all directions into the Solar System. How much of the Solar System would be filled by Betelgeuse? Out past the planet **Mars**.