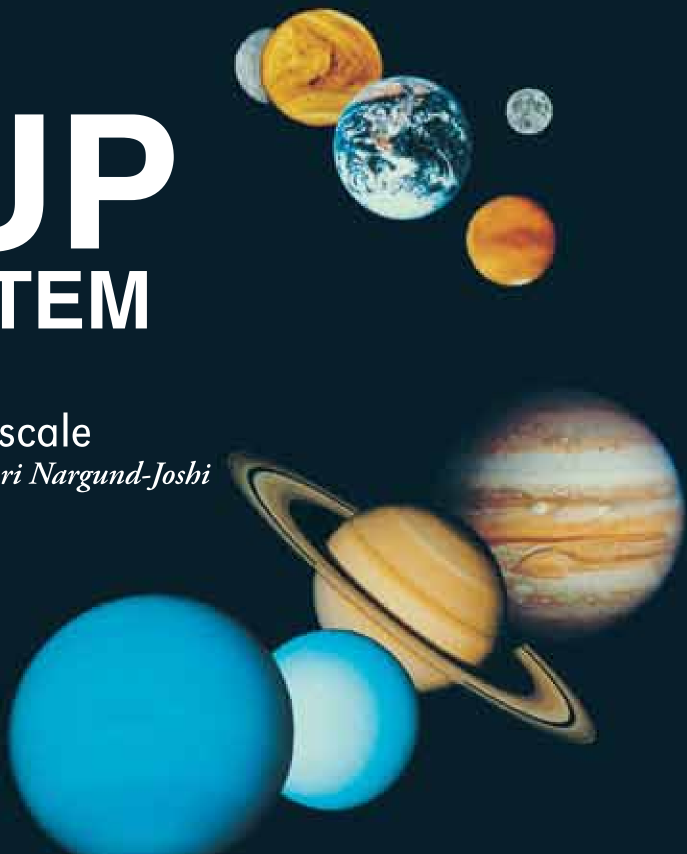
SIZING UP THE SOLAR SYSTEM



Students learn about the notion of scale

By Heidi Wiebke, Meredith Park Rogers, and Vanashri Nargund-Joshi

When you ask "What is a model?" and your student responds "A very attractive woman," you can't help but laugh. However, this was not quite the response I was hoping for. As I probed a little further, I realized that most of my elementary students have little knowledge about what models are, and even fewer know how they are used in science. What could I do?

The American Association for the Advancement of Science (AAAS 1993) states that by the end of fifth grade, students should understand that a model, such as those we often see depicting the solar system, is a smaller version of the real product, making it easier to physically work with and therefore learn from. However, for students and even adults, understanding the size and distance of the solar system is hard to grasp (Hanuscin and Park Rogers 2008). Thus, learning about the solar system in the classroom becomes a challenging task and helping students understand the notion of "scale" with models needs to be addressed. We describe one approach teachers can use to elicit students' misconceptions about the distance between planets in our solar system. Using this information, they can then address the importance of scale in scientific models.

Problems With Current Models

Numerous solar system models are created online and in kits to help students understand the position of the planets and their size in the solar system. However, rarely do these models depict the distances between planets and the Sun accurately, often leading to misconceptions (Larson 2009). Jonassen, Strobel, and Gottdenker (2005) explained that presenting students with scale-appropriate models can help them mentally formulate their own visual representations for comparing and extrapolating ideas from the system. Therefore, having students construct their own scaled scientific models has the potential of providing students with the experience necessary to meet the goals of conceptual understanding described by AAAS (Jonassen, Strobel, and Gottdenker 2005).

Addressing the Problem

The following activity is designed for upper elementary students and could take two to three days to complete. The purpose of the lesson is to help students understand that models are scaled representations, often revised as more evidence is gained, and are used to explain scientific phenomenon that cannot be directly observed (Hanuscin and Park Rogers 2008). The lesson begins with a preassessment of students' understanding of models in the form of an entrance slip. An entrance slip helps students access their prior knowledge concerning the daily lesson topic and allows teachers to understand what the students already know about the topic. A common misconception found through this preassessment is the placement of planets in relation to each other and the Sun. The activity that follows the preassessment addresses this problem.

The activity was adapted from the Utah Core Academy (2008) curriculum and modified to fit a 5E Instructional Model (Bybee 1997). The use of a 5E Model approach takes into account students' prior experiences and how those may affect their learning of the content. It also encourages the use of assessment throughout the learning experience while approaching learning from a conceptual level in which students are asked to explore then explain (Abell and Volkmann 2006).

Engage: Preassessment

To first learn what students understand about scientific models, provide each an entrance slip and ask him or her to answer the following questions: (1) What do you think makes something a model in science? (2) Why do you think scientists use models in their work? (3) How do you think scientists developed models of the solar system? (4) Draw a sketch and describe what you think a model of the solar system looks like. For students needing a little more guidance in writing responses to these questions, their entrance slip could be formatted with prompts to fill in, such as "A model is ______________. Scientists use models to ______________ and scientists develop models by ______________. I think a model of the solar system looks like: (leave drawing space)."

One particular student stated that, "Something is a model in science if it represents a real object. Scientists use models to understand things they cannot easily see. Scientists develop models of the solar system using telescopes." The sketch the student drew of the solar system looked very similar to Figure 1. Some students may know that models are used in science as representations of something that is too big or too small for the human eye to see, but the majority will most likely not know how scientists create models of the solar system as this process is rarely discussed in the development of models. Also, their initial drawings and descriptions of the solar system may show the distance between planets as equal. This is another common misconception because many online images, text images, and kits of the solar system show the planets in order but evenly spaced apart. It is this latter issue, equal distance between planets, which the remainder of this lesson addresses.

Engage: Introducing the Lesson

Provide groups of three to four students two pictures modeling the solar system (Figure 1 and Figure 2) and criteria for what a solar system model should include (Figure 3, p. 38). Figure 1 is an inaccurate model of the solar system because it shows the planets evenly spaced from the Sun. Figure 2 is a more accurate model of the solar system because it shows the inner planets (Mercury, Venus, Earth, and Mars) as closer to the Sun than the outer planets (Jupiter, Saturn, Uranus, and Neptune).

Ask the students to look at the pictures and discuss—using the criteria provided (Figure 3)—the similarities and differences between the pictorial models of the solar

Figure 1.

Inaccurate solar system model.

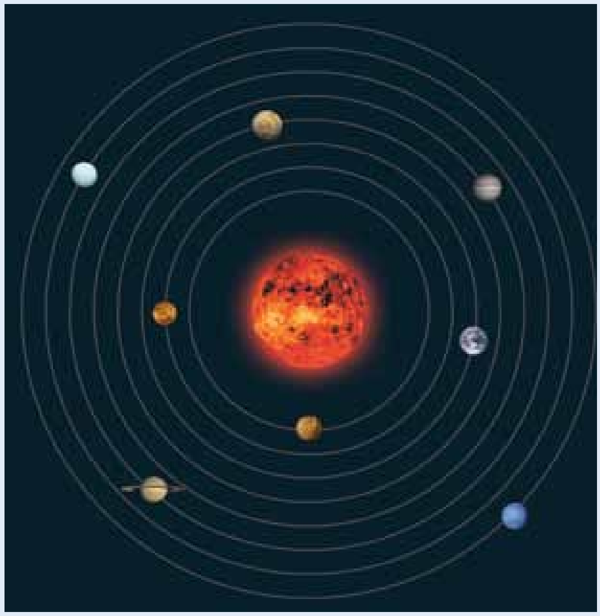


Figure 2.

The solar system depicting the planets' distance almost accurately, but not drawn to scale.

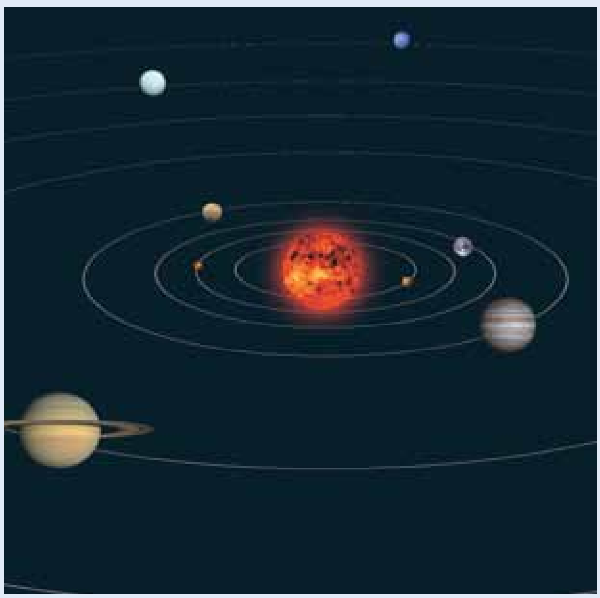


Figure 3.

Criteria for observing solar system models.

Number of Planets	There should be eight planets visible
Order of Planets	Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune
Planets' Distances	Mercury, Venus, Earth, and Mars' distance from the Sun and each other should be close together. Jupiter, Saturn, Uranus, and Neptune's distance from the Sun and each other should be far apart.
Planets' Size	Mercury, Venus, Earth, and Mars should be smaller than Jupiter, Saturn, Uranus, and Neptune.
Planets' Orbital Path	The orbital paths of all the plants should be elliptical (circular) and should go around the Sun in the center.

system (Figures 1 and 2). Also, focus the students' attention to how their drawing of the solar system from the entrance slip is similar to and different from the two pictures. To support students in doing this comparison, have the students construct a T-chart or Venn diagram and provide them with the following questions: (1) What do you notice about these different models of the solar system? (2) How does your solar system model compare to the models presented in these pictures?

Students may instantly notice similarities and differences between the pictorial models and their original drawing models, but they might not come to a consensus as to which picture or drawing is more accurate even with the criteria presented. One student in the class stated, "My solar system model looks almost exactly like the first picture (Figure 1)". Another student said, "The planets in this picture (Figure 1) are spaced out differently than they are in this picture (Figure 2)." "I wonder why?" Most students may state that their drawing model looks similar to Figure 1 because they have seen other models like it before. This kind of statement suggests the need for a discrepant event where the students' previous ideas are contradicted. The remainder of the lesson explains such an event.

Exploring a "New" Model

Next, provide each student with a sentence strip (available at most teacher stores) along with the directions (Figure 4) to create the next model of the solar system. While handing out the sentence strips and directions to the students, explain that the strip represents the amount of space in our solar system from the Sun to the farthest recognized planet (Neptune). Have them follow directions exactly to construct the next model. As they work, students should think about how the planets are positioned from the Sun and how this looks in comparison to the pictorial models (Figures 1 and 2) and their own original drawing.

At this point the teachers can decide whether they want to hold a discussion with students as to why Neptune is now the furthest planet out from the Sun and not Pluto (see Internet Resources). For the purpose of this activity, we decided to use only the eight planets currently listed in our solar system.

Explaining the "New" Model

When the students are finished, they should recognize how this new model has the inner planets extremely close to each other and the Sun, whereas the outer planets' distance is much farther from the Sun and perhaps look to be evenly spaced (Figure 5). As a class, discuss the following questions: (1) What do you notice about the planets in this solar system model? (2) How does this model of the solar system compare to the pictorial models presented earlier? (3) Is this solar system model different from the one you originally drew and if so, how? (4) Do you see any problems with this new model? Students may struggle to answer this last question, which leads to the next phase of explanation. Examples of student comments during this discussion may include: "The first four planets are really close together and the last four planets are so much farther apart" or "This model looks similar to the second picture we looked at (Figure 2)." When comparing their original drawing to the new one, a student may recognize that, "The spacing of planets in my new model is much different from what I originally thought, I just never thought about that before. "

The conversation needs to direct students' attention to the folding process they went through in creating this new model. In particular, how many of the folds required them to fold toward the center or from the end with the

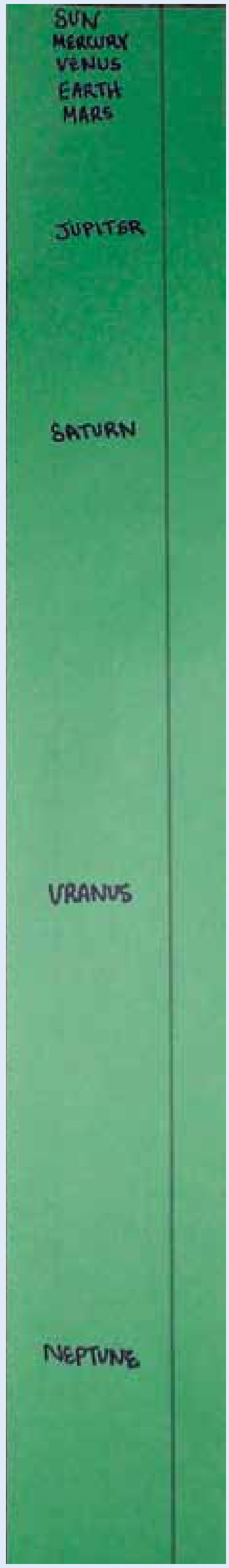
Figure 4.

Steps for sentence strip model.

Steps	Directions
1	Hold the sentence strip vertically and write “Sun” horizontally in small letters (height of 1 cm) at one end of the sentence strip.
2	Hold the sentence strip vertically and then fold the sentence strip in half horizontally and make a crease. Unfold the sentence strip and write “Uranus” horizontally on the fold.
3	Hold the sentence strip vertically and then fold the bottom of the sentence strip (no label) horizontally up to the Uranus fold and make another crease. Unfold the sentence strip and on the new fold write “Neptune” horizontally.
4	Hold the sentence strip vertically and then fold the strip horizontally from the Sun down to the Uranus fold and make another crease. Unfold the sentence strip and on the new fold write “Saturn” horizontally.
5	Hold the sentence strip vertically and then fold the strip horizontally from the Sun down to the Saturn fold and make another crease. Unfold the sentence strip and on the new fold write “Jupiter” horizontally.
6	Hold the sentence strip vertically and then fold the strip horizontally from the Sun down to the Jupiter fold and make another crease. Unfold the sentence strip and on the new fold write “Mars” horizontally.
7	Hold the sentence strip vertically and then fold the strip horizontally from the Sun down to the Mars fold and make another crease. Unfold the sentence strip and on the new fold write “Venus” horizontally.
8	Halfway between Venus and Mars write the “Earth” horizontally.
9	Hold the sentence strip vertically and then fold the strip horizontally from the Sun down to the Venus fold and make another crease. Unfold the sentence strip and on the new fold write “Mercury” horizontally.

Figure 5.

Folded sentence strip model example.



word “Sun.” In doing this, it appears to evenly space all the inner planets from one another and the outer planets from one another. Ask students whether it could be possible for the planets to be so evenly spaced? If many agree, provide them with the actual distance each planet is from the Sun (Figure 6, p. 40) and ask them again, “looking at these numbers do you think this is plausible?” Provide students with an opportunity to talk in their groups about this last question; especially using measurements in Figure 6. The students should notice that the distance of the inner plants from one another does not double in number as they look at the measurements from the Sun to Mercury, Mercury to Venus, Venus to Earth, and Earth to Mars. Similarly, the measured distances do not evenly double with the outer planets either. Therefore, this is yet a third model that looks like it could be right but has inaccuracies.

At this point take a moment to discuss the following questions: (1) In what ways do you think this process of redesigning our model is similar to what scientists do with models? (2) What could we do with these measurements to make a more accurate model of the solar system? The purpose of this discussion is to have the students realize that scientists use data, develop a scale, and use the scale to calculate large measurements (e.g., space between planets) into a unit of measurement more manageable. An audio clip can help students understand how scientists have de-

Figure 6.

Conversion chart for scale model of the solar system.

Planet	Distance from the Sun (km)	Scaled Distance 80,000,000 km = 1 cm
Sun	————	
Mercury	57,909,227	0.72
Venus	108,209,475	
Earth	149,598,262	
Mars	227,943,824	
Jupiter	778,340,821	
Saturn	1,426,666,422	
Uranus	2,870,658,186	
Neptune	4,498,396,441	

Planet distances from the Sun taken from *http://sse.jpl.nasa.gov/planets/index.cfm.*

termined each planet's distance from the Sun (see Internet Resources).

Elaborating on What We've Learned

Depending on how much experience students have with the metric system and making unit conversions within this system, it may be possible to go onto this next phase in which students develop a model similar to Figure 5 but to scale. Begin with asking students whether they think we can make a model using the same sentence strip as before using kilometers as the unit of measurement. They should recognize that a kilometer is much larger than the sentence strip and that the distances in Figure 6 are much larger than one kilometer, so a 1:1 scale will not work.

Next provide students with a 30 cm ruler and ask them what metric unit of measurement could likely fit onto the strip using the simple rulers that they have. Most students will probably say centimeters or millimeters because that is what they can easily read on their rulers. Select as a class to use centimeters because it is easier to work with and then walk the students through a sample calculation. For example, the distance Mercury is from the Sun is 57,909,227 km, so using the scale 80,000,000 km = 1 cm, which is based on NASA's recommendations, the scaled distance Mercury is from the Sun is equal to 0.72 cm. Show this to the students as a simple algebraic problem in which they need to solve for X:

57,909,227 km = X cm
80,000,000 km = 1 cm

You may choose to work through one or two more together as a class but then have the students work in their previous model, creating groups to calculate the remaining measurements to complete Figure 6. (See NSTA Connection for a teacher's version of this chart with all calculations.) With all calculations completed, the groups create another sentence strip model, this time using the calculated measurements in centimeters and measuring from the Sun for each planet's distance.

To conclude this lesson, hold a discussion with the students based on the following questions: (1) How does this last model compare to the previous solar system models you have created and observed? (2) In what ways is this last model more helpful than the other models? (3) Like our other attempts at constructing a model of the solar system, do you think this model will ever change? If so, why? If not, why not? The goal of this conversation is to help students realize that this model is a more accurate representation of each planet's distance from the Sun. Tell them that observing each planet's distance from the Sun can help solve other questions concerning the solar system (e.g., understanding similar features between inner planets versus outer planets).

Evaluating Student Learning

Formative assessment of students' thinking and reasoning is captured throughout the lesson through the use of specific questions (see NSTA Connection). After a short discussion about the scaled model, have students complete an exit slip as a form of summative assessment of what they have learned the past few days about creating scientific models. See NSTA Connection for a rubric with a list of potential questions for the students to respond to and a scale for evaluating their responses.

For students needing modifications, similar to the entrance slip, the questions can be asked in the form of a prompt in which they fill in the blanks. For example, "From this lesson I learned that scientific models are __________ and are used by scientists to _________. I have also learned that models are developed by __________ and that sometimes they can change. For example, ________. When I started this lesson I thought the solar system model looked like ___________, but now I know it looks like ____________.

Where to Go?

In recent iterations of this lesson, students have often asked why Pluto is not included. We explain to the students that in 2006 the criteria for what makes something a planet in our solar system was redefined by some scientists and as a result Pluto no longer fits the criteria. It is therefore labeled a dwarf planet. A future lesson about the "criteria" for a planet in our solar system could be studied. Also, some students have wondered why the first four planets (Mercury, Venus, Earth, and Mars) are so close to the Sun and each other but the other four plants (Jupiter, Saturn, Uranus, and Neptune) are farther away from the Sun and each other. This type of question could lead to a lesson about properties of inner planets versus outer planets. Internet Resources are provided for each of these possible future lessons.

Conclusion

This lesson has a powerful impact on children's understanding of science and how scientific knowledge is created. It gives students the opportunity to work like scientists while learning how models of the solar system are created. Cooperatively with classmates, students learn that scientists construct models to resemble scientific phenomena not visible to the unaided eye in order to learn more. This lesson also allows students to explore how models can change as new evidence is gained. As a result, students develop an understanding of scientific models as suggested by the American Association for the Advancement of Science (AAAS 1993). ■

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Internet Resources

Audio Clip: How do scientist know distance between planets?
http://spaceplace.nasa.gov/en/kids/phonedrmarc/2002_november.shtml

Differences Between Inner and Outer Planets
www.bobthealien.co.uk/innerouter.htm

Is Pluto No Longer a Planet?
http://kids.nationalgeographic.com/kids/stories/spacescience/pluto-planet

King of the Ice Dwarfs
http://spaceplace.nasa.gov/en/kids/pluto/

The Planets and Dwarf Planets
http://starchild.gsfc.nasa.gov/docs/StarChild/solar_system_level2/planets.html

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NSTA Connection

For a rubric, formative assessment questions, and teacher's conversion chart, visit *www.nsta.org/SC1109.* Find related articles by searching "solar system" in the S&C archives at *www.nsta.org/elementaryschool.*

Connecting to the Standards

This article relates to the following *National Science Education Standards* (NRC 1996):

Content Standards Grades K–12

Unifying Concepts and Processes

- Evidence, models, and explanation

Grades 5–8

Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

Standard D: Earth and Space Science

- Earth in the solar system

National Research Council (NRC). 1996. *National science education standards.* Washington, DC: National Academies Press.