# Planetary properties: A systems perspective

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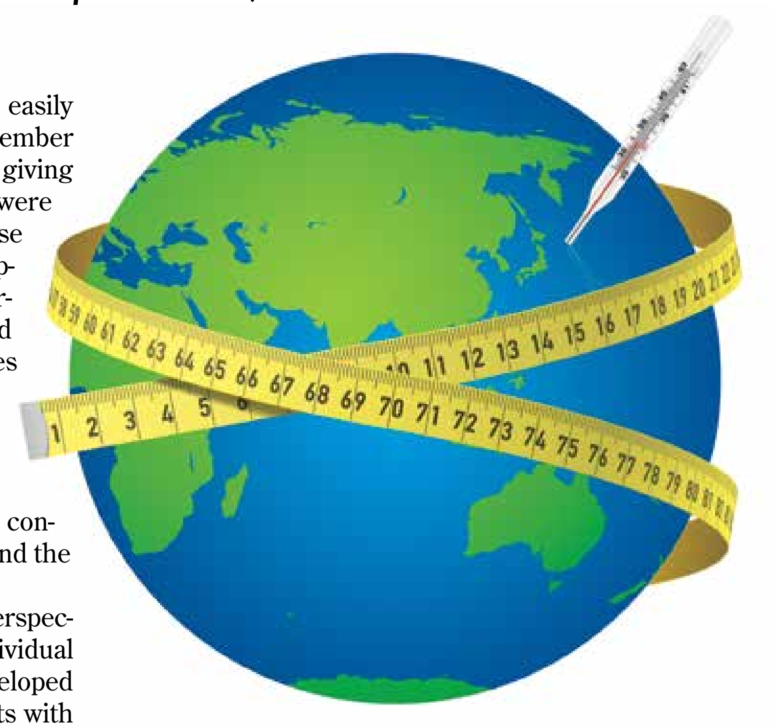



What was your planet? Many people can easily answer this question because they remember creating a diorama, writing a report, or giving a presentation on a specific planet when they were in elementary or middle school. Although these types of projects provide students with an opportunity to learn information about the properties of individual planets, they do so in a limited and disconnected way. When instruction focuses on individual planet projects, students rarely have the opportunity to learn about how the individual planets fit into the larger structure of the solar system. In order to make planetary properties meaningful, students need to make connections between each planet's characteristics and the solar system as a whole.

The first step in moving toward a systems perspective is to recognize the patterns across the individual objects in the solar system. Therefore, we developed and implemented a lesson that provides students with an opportunity to learn about the properties of each planet as well as properties that the planets share. The lesson described in this article addresses Earth's place in the universe (MS-ESS1-3) by focusing on the Earth and the Solar System (ESS1.B) disciplinary core idea from the *Next Generation Science Standards* (NGSS Lead States 2013). Students will engage in the scientific practices of Analyzing and Interpreting Data and Engaging in Argument From Evidence using astronomical data (NGSS Lead States 2013). By completing this lesson, students will also have the opportunity to apply several crosscutting concepts, such as Scale, Proportion, and Quantity; Systems and System Models; and Patterns (NGSS Lead States 2013).

## The partnership

With support from the National Science Foundation, the Earth and Space Science Partnership (ESSP) was established to develop a collaborative relationship among scientists, education researchers, middle school teachers, and high school teachers. One set of goals of ESSP is to improve teacher content knowledge, quality of teacher instruction, and student academic achievement around the big idea of the solar system and its formation. Because research through ESSP revealed that many students have a limited understanding of planetary properties and how the planets can be grouped by these properties, a lesson was developed to help support teachers in teaching this material to their students. This lesson was designed using a claims, evidence, and reasoning (CER) framework (McNeill and Krajcik 2012). According to this framework, a claim is "a statement or conclusion that answers the original question/problem," evidence is "scientific data that support the claim," and reasoning is "a justification that connects the evidence to the claim using scientific principles" (McNeill and Krajcik 2012, p. 35). In this lesson, the teacher and students use a CER framework to develop a scientific argument about how to group the planets in the solar system (McNeill and Krajcik 2012).

In our discussion of the lesson below, we draw on the experiences of one of the authors, a middle school science teacher, who adapted the lesson to meet the needs of her sixth-grade students. However, this lesson could be used in any middle school grade.

### Teacher background knowledge

The solar system formed approximately five billion years ago from a slowly rotating cloud of dust and gas. Over time, the force of gravity caused this cloud to collapse into a disk. At the center of this disk, intense pressure caused the Sun to form. The remaining material within the disk then combined to form the individual planets. The entire solar system formed from the same initial cloud of dust and gas; therefore, many of the planets share common properties, such as their mass, density, and size. If this model is unfamiliar, we recommend that teachers refer to *Origins: Fourteen Billion Years of Cosmic Evolution* (Tyson and Goldsmith 2005) for more information about how the formation and evolution of the solar system resulted in the current planetary properties.

### The lesson

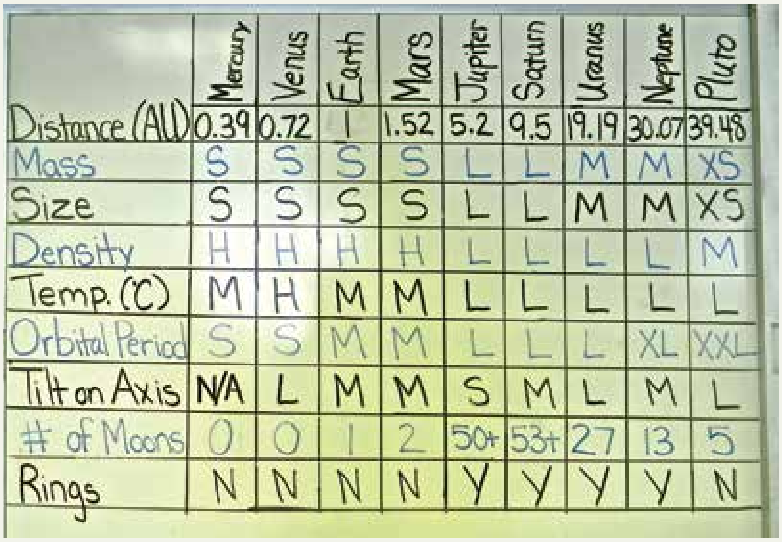
Because this lesson draws on a variety of astronomical concepts, it should be implemented after students have received instruction on the size and scale of the solar system, planetary composition, and planetary movement. Due to the complexity of developing a scientific argument, the lesson is designed to occur over the course of four to five instructional days. The purpose of this lesson is for students to develop an understanding of the individual planetary properties and the properties that the planets have in common, such as their mass, density, and size. To accomplish this, students identify patterns within a data set of planetary properties to determine how the planets can be grouped based on the characteristics they have in common. By identifying patterns in planet groupings, students learn that the planets are parts within a system that share commonalities.

The teacher can introduce this lesson to students by presenting them with a problem that astronomers once faced and that is similar to the problem they will address by completing this lesson. Because astronomers lacked a classification system for what constitutes a planet, when new objects in the solar system were discovered, scientists faced a dilemma as to whether or not these new objects should be classified as planets. The teacher could present the problem to students by having them read *When Is a Planet Not a Planet? The Story of Pluto* (Scott 2007), a short nonfiction text that includes a description of the problem astronomers faced when new objects were discovered in the solar system. The teacher could then point out that, like the astronomers who proposed a classification system for planetary objects, students must develop an evidence-based classification system for determining how the planets can be grouped according to their properties. This framing of the problem allows students to engage with the nature of science by considering how scientific knowledge is open to revision. To help students develop this knowledge, the teacher could ask, "What prompted the astronomers to develop a new classification system?" Student responses should indicate that astronomers found evidence of new objects in the solar system, which led them to revise their thinking about planetary objects.

### *Phase 1: Data collection*

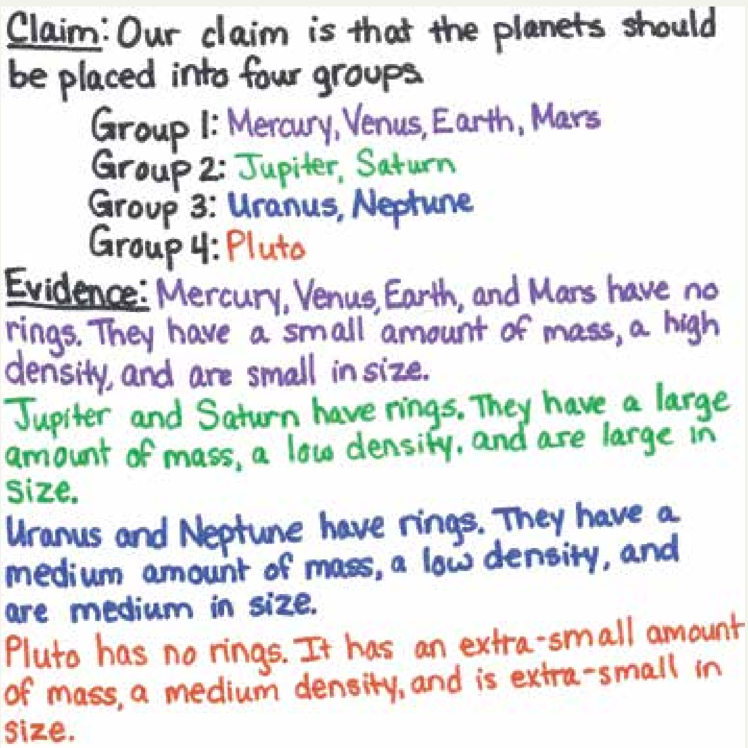
This lesson begins with the teacher providing students with the following investigation question: How can the planets be grouped according to their properties? In a class discussion, the teacher asks students to suggest what data they think are needed, how they would organize the data, and how they would use that information to answer the investigation question. This will improve student engagement by providing them with a sense of ownership. Next students are placed into mixed-ability groups (two to four students per group) to provide them with an equal opportunity to collaboratively analyze the data. To answer this question, students collect data for each of the planets and the dwarf planet Pluto (data could be gathered for additional dwarf planets, if time allows). Each student group can be assigned a specific property, such as mass (see additional properties, below). With this assignment in place, students collect the relevant data for the specific property that they were assigned for all of the planets. Students can use resources such as the Nine Planets and Solar System Exploration websites (see Resources) to collect data on (1) the planets' distance from the Sun, (2) the mass of the planets, (3) the planets' size (diameter), (4) the density of the planets, (5) the temperature of the planets, (6) the planets' orbital period, (7) the planets' tilt, (8) the planets' number of moons, and (9) whether or not the planets have rings. Density of the planets can be used as a proxy for their composition, because rocky planets have higher densities than gaseous planets. Alternatively, students could collect data on the composition of each of the planets.

**FIGURE 1** Example of a planetary properties data chart



| | Mercury | Venus | Earth | Mars | Jupiter | Saturn | Uranus | Neptune | Pluto |
|---|---|---|---|---|---|---|---|---|---|
| Distance (AU) | 0.39 | 0.72 | 1 | 1.52 | 5.2 | 9.5 | 19.19 | 30.07 | 39.48 |
| Mass | S | S | S | S | L | L | M | M | XS |
| Size | S | S | S | S | L | L | M | M | XS |
| Density | H | H | H | H | L | L | L | L | M |
| Temp. (C) | M | H | M | M | L | L | L | L | L |
| Orbital Period | S | S | M | M | L | L | L | XL | XXL |
| Tilt on Axis | N/A | L | M | M | S | M | L | M | L |
| # of Moons | 0 | 0 | 1 | 2 | 50+ | 53+ | 27 | 13 | 5 |
| Rings | N | N | N | N | Y | Y | Y | Y | N |

**FIGURE 2** Example of student claims and evidence



Claim: Our claim is that the planets should be placed into four groups.

Group 1: Mercury, Venus, Earth, Mars
Group 2: Jupiter, Saturn
Group 3: Uranus, Neptune
Group 4: Pluto

Evidence: Mercury, Venus, Earth, and Mars have no rings. They have a small amount of mass, a high density, and are small in size.

Jupiter and Saturn have rings. They have a large amount of mass, a low density, and are large in size.

Uranus and Neptune have rings. They have a medium amount of mass, a low density, and are medium in size.

Pluto has no rings. It has an extra-small amount of mass, a medium density, and is extra-small in size.

The data can all be collected numerically; however, this may be difficult for students if they have not had much experience with large amounts of data. If this is the case, we suggest collecting the planets' distance from the Sun and the number of moons that the planets have numerically while using a low/medium/high scale, a small/medium/large scale, or a yes/no scale for the remaining data. For example, the density of the planets would be recorded using a low/medium/high scale, the size of the planets would be recorded using a small/medium/large scale, and a yes/no scale would be used for whether or not the planets have rings. In order to use this data-collection method, the class would need to develop a common understanding of low/medium/high or small/medium/large for each of the planetary properties. The teacher could provide students with a predetermined scale that they would use while collecting their data. Alternatively, if the teacher wants to give students additional practice in more complex mathematical reasoning, students could collect all of their data numerically, and then the class would develop a scale for each planetary property based on the data that were collected.

Once the data have been collected, each group of students shares its data with the rest of the class. As the data are being shared aloud, the teacher or students write it in a chart on the classroom whiteboard. This chart should be organized so that students can easily determine the individual properties of each planet and how the properties of each planet compare to one another (Figure 1). This will allow students to identify patterns within the data. However, if students have difficulty identifying patterns across the data, the teacher could focus their attention on density, because it is the most easily recognized pattern. There are four planets with similarly high densities (Mercury, Venus, Earth, and Mars), and four planets with similarly low densities (Jupiter, Saturn, Uranus, and Neptune). From there, the teacher could ask students whether or not this pattern is consistent across other planetary properties.

**FIGURE 3** Claims and evidence scoring rubric

| | 0 | 1 | 2 |
|---|---|---|---|
| **Claim** | The claim does not answer the investigation question. | The claim partially answers the investigation question. | The claim sufficiently answers the investigation question. |
| **Evidence** | The evidence does not include specific/accurate data that support the claim. | The evidence includes some specific/accurate data that support the claim. | The evidence includes sufficient specific/accurate data that support the claim. |

### *Phase 2: Data analysis*

During this phase of the lesson, students work within their small groups to develop a claim that is supported by evidence to answer the investigation question (How can the planets be grouped according to their properties?). In order for students to develop proper claims and evidence, they must be provided with sufficient time to explore the data. If students are not familiar with the claims, evidence, and reasoning framework, the teacher will need to provide them with additional support (see McNeill and Krajcik 2012). For this lesson, students' claims should identify which planets should be grouped together. For example, a claim may state that Mercury, Venus, Earth, and Mars should be grouped together; Jupiter and Saturn should be grouped together; Uranus and Neptune should be grouped together; and Pluto should be in its own group (Figure 2). Evidence to support the claims that students make should include multiple attributes; however, they do not have to include information about each of the nine properties that were collected. For example, evidence for grouping Mercury, Venus, Earth, and Mars together may be that they are at a similar distance from the Sun, they are similar in size, they have a similar mass, and they have a similar number of moons. During this time, the teacher should pay attention to the number of properties that students are using to determine their planetary groupings. If students are only using one or two properties, the teacher should encourage them to find more evidence to support their claim. Notice how students who created the claims and evidence in Figure 2 were able to use the properties as evidence for patterns they observed in the solar system, rather than focusing on individual properties of the planets.

### *Phase 3: Scientific argumentation*

Next the teacher provides groups of students with a medium to simultaneously share their claims and evidence, such as individual whiteboards. To allow students the opportunity to engage in argumentation and learn from their peers, the teacher can have students participate in a "board meeting" (Desbien 2002), in which they display their whiteboards and take turns justifying their claims with the evidence that they have provided. To encourage discussion, the teacher could use the following prompts after each group has shared its claim and evidence:

- How do your claims and evidence compare to the claims and evidence that this group developed?
- Does the evidence that this group used support its claim?
- Is there any additional evidence that this group could use to support its claim?

It is more than likely that students will produce multiple ways of grouping the planets, which may lead students to ask about which grouping is "correct." Rather than telling students the scientific groupings that astronomers typically use, the teacher should engage the class in a discussion of the different grouping methods that students developed in order to determine whether or not the class could come to a consensus. However, it is important to note that a consensus is not necessary as long as students understand that they must support their claims with evidence. Following this discussion, students write their final claims and evidence for summative assessment, which would address the *Common Core State Standard* CCSS.ELA-Literacy.WHST.6-8.1: Write arguments focused on discipline-specific content

(NGAC and CCSSO 2010). A scoring rubric is provided in Figure 3.

## Extension

The lesson above provides the first steps for understanding the solar system from a systems perspective. The next step requires answering the following question: Why do the planets have so many common properties? The answer involves understanding the formation model as a dynamic system. This connects the individual objects through their formation. Answering this question would allow students to complete the reasoning component of the CER framework (McNeill and Krajcik 2012). The teacher can have students begin this process by working in groups to think about why the planets have so many common properties. During this time, students may suggest the formation process or the planets' distance from the Sun as possible explanations for the similarities among the planets. In order for these ideas to develop into reasoning based on scientific principles, the formation model will need to be addressed.

To help students learn this model, the teacher could engage them in a lesson on the solar system formation process that relates to the properties of the planets. We suggest using the NASA lesson Active Accretion (see Resources). During this lesson, students use their bodies to represent how materials within the disk of dust and gas came together to form the planets. Although this lesson specifically addresses the composition of the planets, it can also be used to determine how the solar system formation process affected many of the planets' characteristics, such as their mass, density, and size. Students can then use this information to complete the reasoning for the claims and evidence that they developed when determining how to group the planets according to their properties. For example, the reasoning may state that because the planets formed from the same initial cloud of dust and gas, they share similar properties and can be grouped by these properties.

## Conclusion

By working with planetary data over several days, students have the opportunity to engage in the scientific practices of analysis, interpretation, and argumentation to make connections between the individual planets and the solar system as a whole. In implementing this lesson, we found that students not only learned that each planet has specific properties but that the planets have many properties in common. In addition to this, students learned that the planets can be grouped by these properties in many different ways. ■

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## Resources

Active accretion (NASA)—*https://solarsystem.nasa.gov/docs/ActiveAccretion.pdf*

Nine planets—*http://nineplanets.org*

Solar system exploration (NASA)—*http://solarsystem.nasa.gov*

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