What is a Planet?

Overview: Students learn about the characteristics of planets, comets, asteroids, and trans-Neptunian objects through a classification activity. Students can then apply what they have learned by participating in a formal debate about a solar system object discovered by the New Horizons spacecraft and by defining the term 'planet.'

Target Grade Level: 9-12

Estimated Duration: 3 class periods or about 135 minutes

Learning Goals: Students will be able to…

- Compare and contrast the characteristics of planets, comets, asteroids, and trans-Neptunian objects.
- Create a definition for the term *planet*.
- Formulate an argument for or against the planet status of a hypothetical solar system object discovered via telescope and then observed in a fly-by of the New Horizons spacecraft.

Standards Addressed:

Benchmarks (AAAS, 1993)

The Nature of Science, 1A: The Scientific World View

National Science Education Standards (NRC, 1996)

History and Nature of Science, Standard G: Nature of science

Table of Contents:

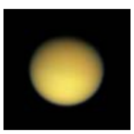
Background:

Why classify? Classification arises from the human desire to catalog objects, compare and contrast them, look for patterns among them, and communicate about them. We create classification schemes based on characteristics that are observable or measurable, and we organize the objects being classified according to this scheme. Classification can help clarify relationships between objects or perhaps reveal something about their histories or origins. Sometimes our understanding of objects and their relationships changes, and our classification schemes must be modified to incorporate new information.

For a moment, let's pretend we live in a simple solar system. Objects in this simple solar system (a classification in itself!) can be classified as planets, satellites, comets, asteroids, and trans-Neptunian objects (TNOs). Note that, in this system, Kuiper Belt Objects (KBOs) are a subset of TNOs, and are also referred to as Edgeworth-Kuiper Belt Objects.

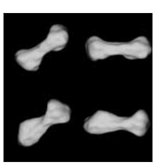
In our simple solar system, the following definitions might apply (all but TNO taken from *The American Heritage Dictionary, Fourth Edition, 2000*):

- **Planet:** A non-luminous celestial body larger than an asteroid or comet, illuminated by light from a star, such as the sun, around which it revolves. (Image: Jupiter, courtesy of NASA)

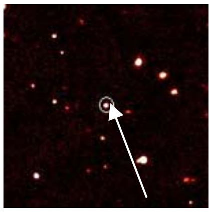


- **Satellite:** A celestial body that orbits a planet; **a moon**. (Image: Saturn's moon Titan, courtesy of NASA)

- **Comet:** A celestial body, observed only in that part of its orbit that is relatively close to the sun, having a head consisting of a solid nucleus surrounded by a nebulous coma up to 2.4 million kilometers (1.5 million miles) in diameter and an elongated curved vapor tail arising from the coma when sufficiently close to the sun. (Image: Comet Halley, courtesy of NASA)



- **Asteroid:** Any of numerous small celestial bodies that revolve around the sun, with orbits lying chiefly between Mars and Jupiter and characteristic diameters between a few and several hundred kilometers. Also called minor planet, planetoid. (Image: Asteroid Kleopatra, courtesy of NASA)



- **Trans-Neptunian Objects:** A trans-Neptunian object (TNO) is any object in the solar system with all or most of its orbit beyond that of Neptune. The Kuiper Belt and Oort cloud are names for some subdivisions of that volume of space. (Image: The 10th Planet? Courtesy of NASA/JPL)

In our real solar system, such neatly defined classes don't always apply. For example, some asteroids could just be the nuclei of comets that have lost all their volatile materials. Some satellites are so large compared with the planet they orbit that perhaps they would be better classified as binary planets. And a very recently discovered trans-Neptunian object is known to be larger than Pluto.

Some objects invariably defy neat and tidy classification. If the classification scheme is modified to include one such "defiant" object, other objects will likely defy the new scheme, until there are either too many classes or too many exceptions. As you probably already know, Pluto is one object that challenges a simple classification scheme for the planets!

But what is a planet? The term *planet*—which is used so frequently—has been actively debated in the scientific community for generations, and will likely continue to be debated for many years to come.

The *American Heritage Dictionary* actually lists two definitions:
Planet (noun):

1. A nonluminous celestial body larger than an asteroid or comet, illuminated by light from a star, such as the sun, around which it revolves. In the solar system there are nine known planets: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto.
2. One of the seven celestial bodies, Mercury, Venus, the moon, the sun, Mars, Jupiter, and Saturn, visible to the naked eye and thought by ancient astronomers to revolve in the heavens about a fixed Earth and among fixed stars.

Certainly the relative measure "larger than", in the first definition, lacks the quantitative means for comparison that is most useful in science. And of course the definitions for "asteroid" and "comet" are themselves potentially unclear. The second definition for *planet*, in the paragraph above, is from the perspective of ancient astronomers, and refers to naked eye visibility. This brings up an interesting point: definitions change as our measuring devices, technology, and/or perspectives change. After all, the Earth was once thought to be the center of the universe!

During the annual meeting of the International Astronomical Union (IAU) in the summer of 2006, members in attendance approved a newer definition for *planet* and other bodies. Here is a summary of the IAU resolution:

> The IAU therefore resolves that planets and other bodies in our solar system, except satellites, be defined into three distinct categories in the following way:
>
> (1) A "planet" is a celestial body that

(a) is in orbit around the Sun,
(b) has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium (nearly round) shape, and
(c) has cleared the neighbourhood around its orbit.

(2) A "dwarf planet" is a celestial body that
(a) is in orbit around the Sun,
(b) has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium (nearly round) shape,
(c) has not cleared the neighbourhood around its orbit, and
(d) is not a satellite.

(3) All other objects, except satellites, orbiting the Sun shall be referred to collectively as "Small Solar-System Bodies".

With the potential discovery of hundreds or thousands of objects similar to Pluto in the region known as the Kuiper Belt, our view of the solar system has changed. That change in perspective may necessitate a change in how we define the term 'planet.' Ultimately, an important point to keep in mind (and in the minds of your students) is that calling Pluto a planet, a dwarf planet, a Kuiper Belt object, or the King of the Ice Dwarfs doesn't change Pluto at all! The physical characteristics of Pluto, the other planets, and bodies that are yet to be discovered will remain the same regardless of how they are classified.

With that said, here are some of the arguments you may hear in the debate for and against the planet status of the **hypothetical** solar system object discovered via telescope and observed in a fly-by of the New Horizons spacecraft, temporarily called Pandora:

PROs (Pandora should be considered a planet)

- It is large enough that it is spherical due to its own gravity, unlike most asteroids.
- It orbits the Sun.
- It has a moon, Hope.
- It is not large enough to sustain fusion reactions and is therefore not a star.
- If its physical characteristics are similar to those of the other known planets in our Solar System then it, too, should be considered a planet, as should all other similar objects.

CONs (Pandora should not be considered a planet)

- It is really very small compared to most of the other planets.
- Its moon is large relative to its size.
- Its composition (rocky/ice) is out of sequence. The terrestrial planets are close to the Sun, and it isn't a gas giant like its planetary neighbors toward the Sun: Neptune, Uranus, Saturn, and Jupiter.
- Its orbit is highly inclined with respect to the ecliptic plane.
- It crosses another planet's orbit (Pluto's).
- It is among many other bodies in a 'belt' instead of being 'the largest body around' like the other planets.
- If Pandora is a planet, and we find more bodies of similar size as we are predicted to do, then we will have too many planets to memorize all of their names!

Materials:

- Access to reference materials for researching pro and con arguments for the debate: Is Pandora a Planet? (several online references are provided below)

Day 1

- Copies of Characteristic Cards (1 set per group)
- Copies of Blank Characteristic Card, if desired
- Copies of Classifying Solar System Objects (1 per group)
- Blank overhead projector pages on which to record classification schemes (1-2 pages per group) (or blank paper to record results, and then allow them to transfer information onto the chalk board/dry erase board)
- Overhead projector pens (1 for each group)

Day 2

- Copies of Pandora's Characteristics (classroom set)
- Copies of International Astronomical Union Member Analysis sheet (1 per member of panel)
- Copies of Debate Role and Stance sheets (number of copies follows list item)
    - Role: Opening/Closing statement presenter (4)
    - Role: Topic Presenter (12)
    - Role: Rebuttal Presenter (8)

Day 3

- Copies of Debate Rubric (for teacher's use, also may want to distribute to class or post so students understand the grading criteria) (at least 2 copies for teacher)
- Copy of the Debate Format sheet (for teacher's use)
- Copy of the 'Gravity Rules' article by Alan Stern (classroom set)

Procedure:

Generally speaking…

What the teacher will do: The teacher will begin by leading a discussion about classification. He or she will assign students to "Solar System Objects groups" (4-6 such groups), and provide each group with a set of Characteristic Cards, a Classifying Solar System Objects group data sheet, and blank overhead projector pages. The teacher can walk from group to group and help students classify solar system objects by different characteristics and then facilitate a discussion of results. In preparation for the debate, the teacher will assign students to read "Gravity Rules" by Alan Stern and provide access to other reference materials for student research on the current definitions for the word *planet*. Finally, the teacher will be the moderator in the formal debate of "Is Pandora a Planet?"

What the students will do: Students will use the Characteristic Cards to complete the Classifying Solar System Objects sheet as a group. This exercise asks them to classify the solar system objects by various characteristics and to look for patterns, recording their results on overhead projector pages to present to the class. Students will then be assigned to one of three groups: 1. International Astronomical Union (IAU) panel; 2. Yes, Pandora is a Planet; or 3. No, Pandora is not a Planet. Students must research their assigned perspective using the Pandora's Characteristics sheet, the current definitions of the word *planet*, and their knowledge of classification. They will then participate in a formal debate, either as a presenter (in Group 2 or 3) or as an IAU panel member. After both sides of the argument have been presented, the IAU panel (Group 1) will discuss the presentations and make a judgment as to the status of Pandora's planethood. Finally, students will be asked to write a definition for the word *planet*.

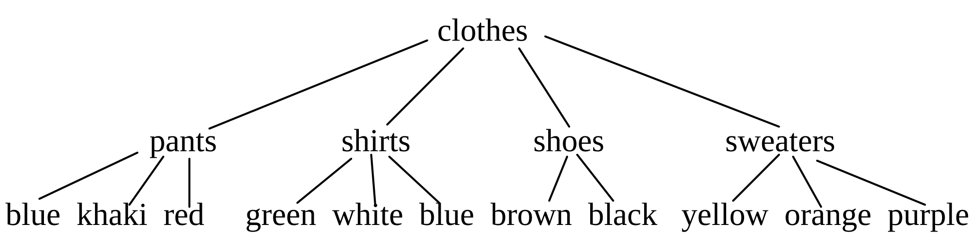
Advance Preparation

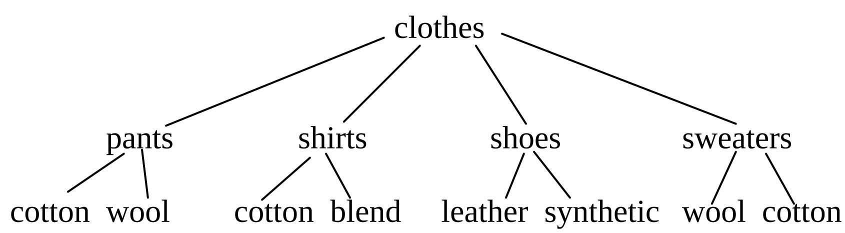
1. Make copies as indicated in the Materials section, above.
2. Cut out Characteristic Cards (1 set per group, 4 – 6 groups). Laminate if desired. Cut out one or more Blank Characteristic Cards per group if desired.
3. Review the Debate Format sheet provided.

In-class Procedure

Day 1

1. Begin with a discussion of classification. First introduce the concept of classification using a simple example, such as clothing in students' closets. Using the board or an overhead, solicit possible broad categories from the class (pants, shirts, sweaters, shoes). Ask how these objects could be further classified (color; materials such as cotton, wool, or blend, etc.). Draw each as its own scheme on the board/overhead as follows:





As another example, you may wish to discuss biology. Simple examples include plants, which can be further classified into deciduous trees, coniferous trees, perennials, annuals, etc. Likewise, animals can be classified as invertebrates (e.g. arachnids, insects, mollusks, etc.) or vertebrates (e.g. fish, mammals, birds, primates, etc.). Inform the class that they will be classifying solar system objects. Solar system objects are classified by **physical characteristics**.

2. Divide the class into about 4 – 6 groups (4 or 5 students per group). Distribute a set of **Characteristic Cards**, a **Classifying Solar System Objects** group data sheet, and blank overhead projector pages with pens to each group. Encourage them to use meaningful classification schemes based on the **physical characteristics** of the solar system objects (NOT 'these objects all have 5 letters in their name, these have 6, and these have more…'). Provide each group with a **Blank Characteristic Card** if you would like them to research and classify an object for which data is not provided.

3. Explain to students that they will now classify the different solar system objects according to characteristics of their choosing. For example, first they might separate cards into two groups: objects with a density of less than 2 g/cm^3 and objects with a density of 2 or greater g/cm^3. They will record their observations in the **Classifying Solar System Objects** group data sheet. Ask students near the end of the period to stop classifying and look at their data. Do they see any patterns? Are some objects often grouped together? Are some objects often misfits? Have them record at least one scheme on the overhead page and present it to the class. Ask the group to justify their decisions and further encourage discussions.

<u>Day 2</u>

4. Introduce students to the debate format and topic: A hypothetical solar system object has been discovered via telescope and observed in a fly-by of the New Horizons spacecraft. This object has temporarily been named Pandora. The students are to debate whether Pandora should be considered a planet, or not, based on its physical characteristics presented in the Pandora's Characteristics sheet. As part of their preparation, they should research the current definitions for the word *planet* in addition to reading the assigned article, "Gravity Rules" by Alan Stern.

5. Explain that the class will be broken into three main groups for the debate:
   - **Yes, Pandora is a planet—"Affirmative"** (10 - 12 students)
   - **No, Pandora is not a planet—"Negative"** (10 - 12 students)
   - **The International Astronomical Union (IAU)** panel (the remaining students)

   The 'Yes, Pandora…' and 'No, Pandora…' groups should be further subdivided into 6 groups of 2 students as follows:
   1. Opening and Closing Statement Presenters
   2. Topic Presenters, A
   3. Topic Presenters, B
   4. Topic Presenters, C (optional: if there are 12 students in the 'Yes…' and 'No,…' groups)
   5. Rebuttal Presenters, A
   6. Rebuttal Presenters, B

***NOTE**: this can be confusing, so you may want to assign groups and roles before class and record them on an overhead sheet or the board before class to save in-class time.

6. Provide each student with an appropriate **Debate Role and Stance** sheet and a copy of **Pandora's Characteristics** sheet. For example, all of the Topic Presenters are to receive a copy of the '**Role: Topic Presenter**' sheet. Likewise, all of the Rebuttal Presenters are to receive a copy of the '**Role: Rebuttal Presenter**' sheet. Provide each IAU panel member with a copy of the **IAU Member Analysis** sheet. You may also wish to show students the **Debate Rubric** that will be used for grading their performances.

7. Provide access to resources so that groups can research their stance. The International Astronomical Union members should become educated on the broad ideas surrounding the question of "Is Pandora a Planet"? They should resist forming an opinion, but learn about the many issues associated with this question. Further details regarding specific roles and how they are to operate are provided in the respective group data sheets. Allow enough time for groups to begin researching for their role and stance. Further research should be assigned as homework.

8. During about the last 10 minutes of class, allow the groups with similar roles to join together and plan their debate strategy. For example…
   - 'Yes,…' Topic Presenter groups A, B, and C should join together and decide which topic each group will present, and 'No, …' Topic Presenter groups A, B, and C should join together. The 'topics' are the main arguments for their assigned stance, and each side must come up with three main arguments, hence the A, B, and C. The topic presenters may also wish to send a liaison to the Rebuttal Presenters and the Opening/Closing Statement Presenters so that they all agree upon the team's approach.
   - Similarly, the Rebuttal Presenters are to answer or rebut arguments from the other stance. Rebuttal Presenter groups A and B can meet to discuss some possible responses to the opponents' main arguments.
   - The Opening and Closing Statement Presenters (a group of 2) will decide who will give the opening and closing statement. They may wish also to incorporate the three main arguments that will be presented by their team into their opening and closing statements.
   - The IAU panel members should discuss the broader issues surrounding Pandora's status as a planet.

<u>Day 3</u>

9. In the first 10 minutes of class allow the two teams ('Yes, …' and 'No, …') to organize their approach. Remind them that they will be graded on their ability to work as a team.

10. Let the debate begin! Review the rules and process for the students, as provided in the **Debate Format** sheet. Keep time or assign a time-keeper throughout the debate. Use the **Debate Rubric** to assess students as they present. Remind IAU members to take notes on their **Analysis** sheet during the debate!

11. After the debate is complete, allow the IAU to convene and discuss the arguments and rebuttals presented. They should decide by a vote whether Pandora should be considered a planet and present their conclusion to the class. (Vote is decided by 'majority rules').

12. As homework, assign students to create their own definition for the term *planet*. They should provide a written justification for their definition. Also, they should list all (or as many as possible) of the **Solar System Objects** (used in the classification activity) that would be considered a planet according to their definition.

Mercury		Venus		Earth		Mars	
Mean Radius: (km):	**2440**	Mean Radius: (km):	**6052**	Mean Radius: (km):	**6371**	Mean Radius: (km):	**3390**
Density (g/cm^3):	**5.4**	Density (g/cm^3):	**5.2**	Density (g/cm^3):	**5.5**	Density (g/cm^3):	**3.9**
Mass (kg):	**3.3×10^{23}**	Mass (kg):	**48.7×10^{23}**	Mass (kg):	**59.7×10^{23}**	Mass (kg):	**6.4×10^{23}**
Atmosphere? If yes, composition:	**He, Na, O_2**	Atmosphere? If yes, composition:	**CO_2, N_2**	Atmosphere? If yes, composition:	**N_2, O_2**	Atmosphere? If yes, composition:	**CO_2, N_2, Ar**
Orbits…	**The Sun**	Orbits…	**The Sun**	Orbits…	**The Sun**	Orbits…	**The Sun**
Average distance from body it orbits (km):	**57 million**	Average distance from body it orbits (km):	**108 million**	Average distance from body it orbits (km):	**149 million**	Average distance from body it orbits (km):	**227 million**
Period of orbit (yrs):	**0.24**	Period of orbit (yrs):	**0.62**	Period of orbit (yrs):	**1**	Period of orbit (yrs):	**1.88**
Period of spin (hrs):	**1407.5**	Period of spin (hrs):	**-5823.4**	Period of spin (hrs):	**23.9**	Period of spin (hrs):	**24.6**
Known satellites (moons):	**none**	Known satellites (moons):	**none**	Known satellites (moons):	**1; The Moon**	Known satellites (moons):	**2; Phobos, Deimos**

Jupiter		Saturn		Uranus		Neptune	
Mean Radius: (km):	**69,911**	Mean Radius: (km):	**58,232**	Mean Radius: (km):	**25,362**	Mean Radius: (km):	**24,624**
Density (g/cm^3):	**1.3**	Density (g/cm^3):	**0.7**	Density (g/cm^3):	**1.3**	Density (g/cm^3):	**1.6**
Mass (kg):	**18990×10^{23}**	Mass (kg):	**5684×10^{23}**	Mass (kg):	**868×10^{23}**	Mass (kg):	**1024×10^{23}**
Atmosphere? If yes, composition:	**H_2, He**	Atmosphere? If yes, composition:	**H_2, He**	Atmosphere? If yes, composition:	**H_2, He, CH_4**	Atmosphere? If yes, composition:	**H_2, He, CH_4**
Orbits…	**The Sun**	Orbits…	**The Sun**	Orbits…	**The Sun**	Orbits…	**The Sun**
Average distance from body it orbits (km):	**778 million**	Average distance from body it orbits (km):	**1,429 million**	Average distance from body it orbits (km):	**2,871 million**	Average distance from body it orbits (km):	**4,504 million**
Period of orbit (yrs):	**11.9**	Period of orbit (yrs):	**29.5**	Period of orbit (yrs):	**84.02**	Period of orbit (yrs):	**164.8**
Period of spin (hrs):	**9.9**	Period of spin (hrs):	**10.7**	Period of spin (hrs):	**17.2**	Period of spin (hrs):	**16.1**
Known satellites (moons):	**63!**	Known satellites (moons):	**46**	Known satellites (moons):	**27**	Known satellites (moons):	**13**

Pluto		Eris		Ceres		Tempel 1	
Mean Radius: (km):	**1150**	Mean Radius: (km):	**~1200**	Mean Radius: (km):	**467**	Mean Radius: (km):	**Nucleus: 3 km**
Density (g/cm^3):	**About 2**	Density (g/cm^3):	**2.3**	Density (g/cm^3):	**~2.1**	Density (g/cm^3):	**?**
Mass (kg):	**0.13×10^{23}**	Mass (kg):	**0.166×10^{23}**	Mass (kg):	**$.008 \times 10^{23}$**	Mass (kg):	**?**
Atmosphere? If yes, composition:	**N_2, CH_4, CO**	Atmosphere? If yes, composition:	**?**	Atmosphere? If yes, composition:	**Maybe!**	Atmosphere? If yes, composition:	**Dust and gas around nucleus**
Orbits…	**The Sun**	Orbits…	**The Sun**	Orbits…	**The Sun**	Orbits…	**The Sun**
Average distance from body it orbits (km):	**5,914 million**	Average distance from body it orbits (km):	**8,826 million**	Average distance from body it orbits (km):	**413 million**	Average distance from body it orbits (km):	**230 million *(will change!) (very elliptical orbit)**
Period of orbit (yrs):	**247.9**	Period of orbit (yrs):	**560**	Period of orbit (yrs):	**4.6**	Period of orbit (yrs):	**5.5 *(will change!)**
Period of spin (hrs):	**153.3 (or 6.39 days!)**	Period of spin (hrs):	**?**	Period of spin (hrs):	**9.1**	Period of spin (hrs):	**1.7 *(will change!)**
Known satellites (moons):	**3;Charon, Nix, Hydra**	Known satellites (moons):	**1; Dysnomia**	Known satellites (moons):	**none**	***will change as it passes by Jupiter due to Jupiter's gravity**	

The Moon		Europa		Enceladus		Charon	
Mean Radius: (km):	**1738**	Mean Radius: (km):	**1569**	Mean Radius: (km):	**249**	Mean Radius: (km):	**593**
Density (g/cm^3):	**3.3**	Density (g/cm^3):	**3.0**	Density (g/cm^3):	**1.2**	Density (g/cm^3):	**1.2**
Mass (kg):	**0.74×10^{23}**	Mass (kg):	**0.48×10^{23}**	Mass (kg):	**0.00073×10^{23}**	Mass (kg):	**0.016×10^{23}**
Atmosphere? If yes, composition:	**Basically none**	Atmosphere? If yes, composition:	**Tenuous: O_2, H_2**	Atmosphere? If yes, composition:	**Localized water vapor**	Atmosphere? If yes, composition:	**None?**
Orbits…	**Earth**	Orbits…	**Jupiter**	Orbits…	**Saturn**	Orbits…	**Pluto**
Average distance from body it orbits (km):	**384,000**	Average distance from body it orbits (km):	**671,000**	Average distance from body it orbits (km):	**238,000**	Average distance from body it orbits (km):	**19,600**
Period of orbit (days):	**27.3**	Period of orbit (days):	**3.6**	Period of orbit (days):	**1.37**	Period of orbit (days):	**6.39**
Period of spin (hrs):	**655 (or 27.3 days!)**	Period of spin (hrs):	**86.4 (or 3.6 days)**	Period of spin (hrs):	**32.9 (1.37 days!)**	Period of spin (hrs):	**153.3 (or 6.39 days!)**
Known satellites (moons):	**It is a moon**	Known satellites (moons):	**It is a moon**	Known satellites (moons):	**It is a moon**	Known satellites (moons):	**It is a moon**

Eros		Borrelly		Sedna	
Approx. size (km):	**33x13x13**	Approx. size (km):	**Nucleus: 8x4**	Approx. radius (km):	**At most: 900**
Density (g/cm^3):	**2.4**	Density (g/cm^3):	**varies**	Density (g/cm^3):	**?**
Mass (kg):	**7.2×10^{15}**	Mass (kg):	**varies**	Mass (kg):	**?**
Atmosphere? If yes, composition:	**None**	Atmosphere? If yes, composition:	**Dust and gas cloud around nucleus**	Atmosphere? If yes, composition:	**?**
Orbits…	**The Sun**	Orbits…	**The Sun**	Orbits…	**The Sun**
Average distance from body it orbits (km):	**172 million**	Average distance from body it orbits (km):	**Perihelion: 200 million**	Average distance from body it orbits (km):	**75,300 million**
Period of orbit (yrs):	**1.76**	Period of orbit (yrs):	**6.9**	Period of orbit (yrs):	**10,500**
Period of spin (hrs):	**5.27**	Period of spin (hrs):	**NA**	Period of spin (hrs):	**240**
Known satellites (moons):	**none**	Known satellites (moons):	**none**	Known satellites (moons):	**none**

Approx. radius (km):	
Density (g/cm^3):	
Mass (kg):	
Atmosphere? If yes, composition:	
Orbits…	
Average distance from body it orbits (km):	
Period of orbit:	
Period of spin:	
Known satellites (moons):	

Classifying Solar System Objects

Names of group members:

Your objective is to classify solar system objects by various characteristics. Use your set of Solar System Characteristic Cards to help you!

1. Begin by choosing a characteristic and as a team think about how you will group your cards according to that characteristic. Will you initially choose three different possible groups (e.g. density less than 1, density between 1.1 and 2, and density greater than 2 g/cm^3), or 4 groups, or 2 groups?
2. Use the information on the cards to determine in which group each Solar System Object fits. Record your classification scheme using a ‘tree’ similar to the clothing example presented.
3. Further classify your objects by other characteristics and add on to or modify your ‘tree.’

Here is an example to help you begin.

1. Let’s start with the characteristic ‘density’ and three different possible groups or classes.
2. Move your cards around so they are sorted by these classes, and draw a tree to represent this scheme. Here is what your tree might look like.

Solar System Objects

Density < 1	Density = 1.1 to 2	Density > 2
-Saturn	-Jupiter	-Mercury
-Borrelly	-Uranus	-Venus
	-Neptune	-Earth
	-Pluto?	-Mars
	-Enceladus	-the Moon
	-Charon	-Europa

At this point you need to make sure all of your cards have been used, since a classification scheme must provide an appropriate class to include all potential objects. Looking at the cards, there are four solar system objects that have unknown densities. So to the above scheme you must add another class, ‘unknown’ for it to be complete.

3. Assuming you have gone back and added another class so that all solar system objects are included, let’s see if we can further sort these objects. It will be easiest to look at the cards in each class and find a characteristic that might further divide them. For example, let’s further classify these objects according to the bodies they orbit. Here is one of them done for you (but in general you should do this for all classes, including density <1, density = 1.1 to 2, and density unknown!):

Density > 2

Orbits Sun
-Mercury
-Venus
-Earth
-Mars

Orbits Earth
-The Moon

Orbits Jupiter
-Europa

Your goal will be to create a *meaningful* classification scheme based on the physical properties of the solar system objects. In order to achieve this you may have to try several different schemes… Good luck!

Pandora's Characteristics

Pandora		Hope	
Mean Radius (km):	**950**	Mean Radius (km):	**500**
Density (g/cm^3):	**About 2**	Density (g/cm^3):	**About 1.5**
Mass (kg):	**0.07×10^{23}**	Mass (kg):	**0.01×10^{23}**
Composition:	**Mixture of rock and ice**	Composition:	**Mixture of rock and ice**
Atmosphere? If yes, composition:	**?**	Atmosphere? If yes, composition:	**?**
Orbits…	**The Sun**	Orbits…	**Pandora**
Perihelion (km): (closest point to Sun in orbit)	**6,550 million**	Average distance from body it orbits (km):	**18,000**
Aphelion (km): (furthest point from Sun in orbit)	**6,950 million**	Period of orbit (Earth days):	**7.6**
Eccentricity:	**0.03**	Period of spin (Earth days):	**7.6**
Period of orbit (yrs):	**300**		
Period of spin (Earth days):	**7.6**		
Inclination with respect to ecliptic plane:	**52°**		
Known satellites (moons):	**1, Hope**		

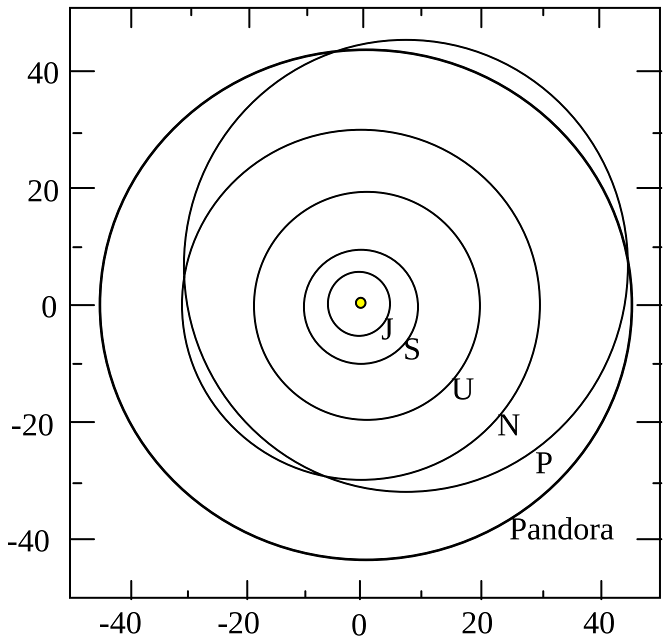


Figure 1. This diagram shows the orbits of the outer planets as well as Pandora's orbit as if you were a bird looking down from above the Sun. The Sun is in the center, at 0 astronomical units (AU). An AU is the average distance between the Earth and the Sun, although the Earth is not shown in this diagram. As you can see, Pluto crosses Neptune's orbital path and Pandora crosses Pluto's orbital path. Also notice that Pandora's is the outermost orbit or it is furthest from the Sun.

Other interesting information about Pandora:

- This is a cold object with ices such as methane, carbon monoxide, and possibly water ice!
- Pandora and Hope are both spherical.
- Most planets orbit the Sun in roughly the same plane as the orbital plane of the Earth, which is called the *ecliptic*. That is, if we imagine the plane of the Earth's orbit to be a tabletop, the orbits of all the other planets are nearly on the tabletop as well. But Pandora's orbit is far from the ecliptic; the plane of its orbit is tilted by 52 degrees with respect to our imaginary tabletop! For an idea of what this looks like, see Figure 2, below.

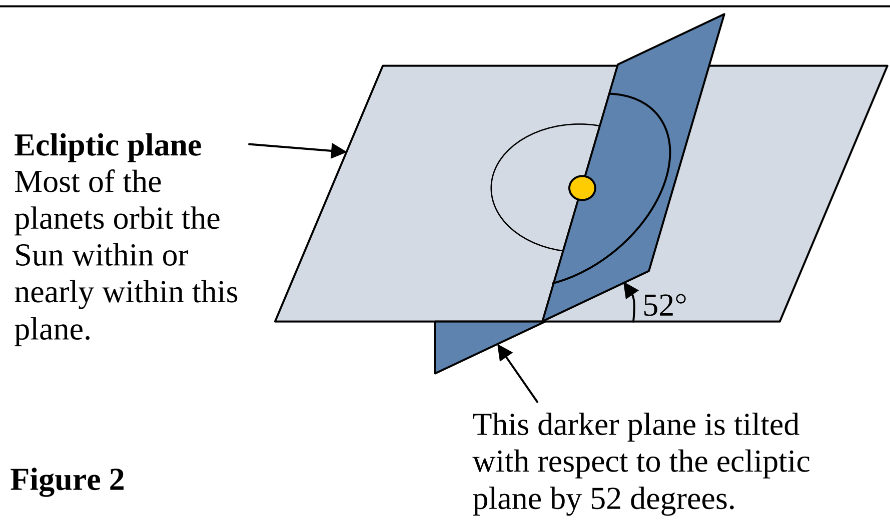


Figure 2

International Astronomical Union
Panel Member Analysis

You are representing the International Astronomical Union, which is the body that formally announces the discovery of new planets, decides on the official names of solar system objects, as well as many other roles in the international astronomical community.

As a member, your job will be to research the many arguments for and against Pandora's status as a planet. It is very important that you not form an opinion; you are to remain unbiased but well educated on the topic. Thoroughly review Pandora's Characteristics, the "Gravity Rules" article, and the current definitions for the word *planet*.

After you have heard the arguments presented for and against Pandora's status, you will then convene as a group and discuss the presentations. You will vote based on the quality of the arguments presented on the status of Pandora ('Yes, Pandora is a planet' or 'No, Pandora is not a planet') as a group, with a simple majority determining the status. You must select one member to present your findings to the class. You will have 5 minutes for discussion and voting.

Record compelling information from your research here:

Record detailed notes from each of the presentations here:

'Yes' Opening Statement:

'Yes' Topic Presenters
Group A:

Group B:

Group C:

'No' Opening Statement:

'No' Topic Presenters
Group A:

Group B:

Group C:

'Yes' Rebuttal Presenters
Group A:

Group B:

'No' Rebuttal Presenters
Group A:

Group B:

'Yes' Closing Statement:

'No' Closing Statement:

Debate Role: Opening/Closing Statement Presenters

Stance (circle yours!): Yes, Pandora is a Planet
No, Pandora is not a Planet

Let's begin with a look at how the debate will proceed in class. As you know, there are two sides to the debate: 'Yes, Pandora is a Planet' and 'No, Pandora is not a Planet.' We'll abbreviate these to 'Yes' and 'No' from now on. Here is how the roles will present in class during the debate:

- The moderator will begin with a reminder of the rules and format.
- 'Yes' Opening Statement (2 minutes)
- 'Yes' Topic Presenters
  - Group A (2 minutes)
  - Group B (2 minutes)
  - Group C (2 minutes)
- 'No' Opening Statement (2 minutes)
- 'No' Topic Presenters
  - Group A (2 minutes)
  - Group B (2 minutes)
  - Group C (2 minutes)
- 'Yes' Rebuttal Presenters
  - Group A (2 minutes)
  - Group B (2 minutes)
- 'No' Rebuttal Presenters
  - Group A (2 minutes)
  - Group B (2 minutes)
- 'Yes' Closing Statement (2 minutes)
- 'No' Closing Statement (2 minutes)

Opening Statement/Closing Statement Presenters: Your job is to provide a brief introduction (opening) or summary (closing) of your stance ('Yes' or 'No'). Use Pandora's Characteristics, "Gravity Rules" and the current definitions for *planet* for reference. You want to present the three main arguments supporting your stance. These are the same three arguments that the Topic Presenters will use, however they will cover these arguments in greater depth. Remember you will have 2 minutes for opening and 2 minutes for closing to present the three main arguments supporting your stance. (NOTE: you should not introduce material that will not be/was not presented during the main debate). You will be evaluated on your ability to form a succinct and coherent introduction and summary of your arguments as well as your ability to work as a team.
Three main arguments of your stance:

1.

2.

3.

Plan for presenting opening statement:

Plan for presenting closing statement:

Debate Role: Topic Presenter

Group: A B C (circle one)

Stance (circle yours!): Yes, Pandora is a Planet
No, Pandora is not a Planet

Let's begin with a look at how the debate will proceed in class. As you know, there are two sides to the debate: 'Yes, Pandora is a Planet' and 'No, Pandora is not a Planet'. We'll abbreviate these to 'Yes' and 'No' from now on. Here is how the roles will present in class during the debate:

- The moderator will begin with a reminder of the rules and format.
- 'Yes' Opening Statement (2 minutes)
- 'Yes' Topic Presenters
  - Group A (2 minutes)
  - Group B (2 minutes)
  - Group C (2 minutes)
- 'No' Opening Statement (2 minutes)
- 'No' Topic Presenters
  - Group A (2 minutes)
  - Group B (2 minutes)
  - Group C (2 minutes)
- 'Yes' Rebuttal Presenters
  - Group A (2 minutes)
  - Group B (2 minutes)
- 'No' Rebuttal Presenters
  - Group A (2 minutes)
  - Group B (2 minutes)
- 'Yes' Closing Statement (2 minutes)
- 'No' Closing Statement (2 minutes)

Topic Presenters: Your job is to present one of the main arguments that your team has decided is important. Use Pandora's Characteristics, "Gravity Rules" and the current definitions for *planet* for reference. You want to provide specific evidence supporting your stance ('Yes' or 'No') and your argument. Remember you will have 2 minutes per group (A, B, and C) to support your argument. You will be evaluated on your ability to form a coherent argument with ample supporting evidence as well as your ability to work as a team.

Group A main argument:

Group B main argument:

Group C main argument:

Your plan for presenting your argument:

Debate Role: Rebuttal Presenters

Group: A B (circle one)

Stance (circle yours!): Yes, Pandora is a Planet
No, Pandora is not a Planet

Let's begin with a look at how the debate will proceed in class. As you know, there are two sides to the debate: 'Yes, Pandora is a Planet' and 'No, Pandora is not a Planet'. We'll abbreviate these to 'Yes' and 'No' from now on. Here is how the roles will present in class during the debate:

- The moderator will begin with a reminder of the rules and format.
- 'Yes' Opening Statement (2 minutes)
- 'Yes' Topic Presenters
  - Group A (2 minutes)
  - Group B (2 minutes)
  - Group C (2 minutes)
- 'No' Opening Statement (2 minutes)
- 'No' Topic Presenters
  - Group A (2 minutes)
  - Group B (2 minutes)
  - Group C (2 minutes)
- 'Yes' Rebuttal Presenters
  - Group A (2 minutes)
  - Group B (2 minutes)
- 'No' Rebuttal Presenters
  - Group A (2 minutes)
  - Group B (2 minutes)
- 'Yes' Closing Statement (2 minutes)
- 'No' Closing Statement (2 minutes)

Rebuttal Presenters: Your job is to provide evidence opposing the arguments presented by the other stance. For example, if you are on the 'Yes' team, you want to provide evidence that illustrates why the arguments presented by the 'No' team are inadequate (and vice versa). Therefore you will have to research all of the potential arguments for the opposing stance and find weakness in their possible arguments. Since you don't know exactly which arguments the team representing the other stance will present, you want to prepare as many different points of opposition as possible. Use Pandora's Characteristics, "Gravity Rules" and the current definitions for *planet* for reference. Remember you will have 2 minutes for each of the two rebuttals. You will be evaluated on your ability to provide relevant counter-evidence to the arguments presented by the Topic Presenters from the other stance as well as your ability to work as a team.

Potential arguments presented by the opposing stance:

1.

2.

3.

4.

5.

Your rebuttals and counter-evidence to those arguments:

1.

2.

3.

4.

5.

<u>Debate Scoring Rubric</u>
Group score for: 'Yes, Pandora is a Planet' or 'No, Pandora is not a Planet'

	Overall Performance Level				
	1	**2**	**3**	**4**	**5**
Opening/Closing Statement Presenters: **Statements were…**	unclear, rambling, incoherent	wordy or long and somewhat disorganized	fairly succinct and coherent	succinct and coherent	succinct, coherent, and eloquent
Topic Presenters: **Arguments were…**	not coherent and lacked ample evidence	marginally coherent and supported with some evidence	coherent with adequate supporting evidence	complex and coherent with relevant supporting evidence	complex, coherent, and eloquent with ample relevant supporting evidence
Rebuttal Presenters: **Rebuttals…**	did not address the opponents' arguments	marginally addressed some of the opponents' arguments	addressed most or all of the opponents' arguments adequately	addressed each of the opponents' arguments with relevant counter-evidence	directly addressed each of the opponents' arguments with effective and relevant counter-evidence
Teamwork: **It was clear the team was…**	disorganized; presented material was contradictory; presentation was highly disjointed	marginally organized; presented material did not overlap; presentation was disjointed	organized; members presented material that did not overlap with previously presented material	well organized; members presented different but complementary material; overall presentation was clear	highly organized; each member built on previously presented material; overall presentation was clear and concise

(Teacher Page) Debate Format: This format is based on the Lincoln-Douglas Debates of 1858, but has been modified for classroom use. You will serve as the moderator in the debate. In this role, you are to begin the formal debate with a reminder of the rules and format (see below). After establishing the rules, announce the role and stance that will present, and continue this throughout the debate. For example, first announce "Opening statement, 'Yes, Pandora is a Planet'". After the opening statement presenter is finished, announce "Topic presenters, group A, 'Yes, Pandora is a Planet'", etc. If you don't want to keep time you should select a time-keeper.

Topic: A solar system object was discovered via telescope and observed in a fly-by of the New Horizons spacecraft. This object has temporarily been named Pandora. The students are to debate whether Pandora should be considered a planet, or not, based on its physical characteristics.

Rules:

- Speak only when recognized by the moderator. (You may wish to take away a point from a team if a member speaks out of turn).
- Use respectful and appropriate language throughout (no put-downs, no inappropriate language, be polite).
- Speak clearly, slowly, and loud enough for everyone to hear you.

Format:

- 'Yes' Opening Statement (2 minutes)
- 'Yes' Topic Presenters
  - Group A (2 minutes)
  - Group B (2 minutes)
  - Group C (2 minutes)
- 'No' Opening Statement (2 minutes)
- 'No' Topic Presenters
  - Group A (2 minutes)
  - Group B (2 minutes)
  - Group C (2 minutes)
- 'Yes' Rebuttal Presenters
  - Group A (2 minutes)
  - Group B (2 minutes)
- 'No' Rebuttal Presenters
  - Group A (2 minutes)
  - Group B (2 minutes)
- 'Yes' Closing Statement (2 minutes)
- 'No' Closing Statement (2 minutes)
  - IAU panel convenes for a 5 minute discussion of the debate.
  - IAU Chairperson presents conclusion of IAU panel as to status of Pandora's planethood.

Gravity Rules: The Nature and Meaning of Planethood

by S. Alan Stern
Boulder - Mar 22, 2004

I am a planetary scientist, so you won't find it surprising that this past Monday evening, March 15th, the dinner table conversation at our home eventually turned to the discovery of the largest ever Kuiper Belt Object, Sedna (2003 VB12). When I remarked that I was amused by the fact that some astronomers don't consider Sedna a planet, our teenage daughter Kate joined in-agreeing that Sedna shouldn't be classified a planet.

Surprised, I asked why. "Dad, if Sedna is a planet, then Ceres is too, and there are probably lots and lots more things this big that we haven't discovered. You all should leave it to just the normal nine we learned about in school. We can't have so many planets that you can't name them all!"

Flawed, as it was, Kate's logic about exactly what should and should not qualify as a planet is about as good what I have heard lately from some professional astronomers. I explained to Kate that no one knows the names of all the stars, or all the galaxies, but that doesn't mean we limit the number of stars and galaxies to just the first few handfuls that were named. For that matter, I remarked, if your brain was so completely full of names of people that it just couldn't take any more, would anyone new who you met after that, therefore not be a person? Of course not! We decide whether a person is a person based on their genetics, just as we do when classifying any given living thing into its species. Likewise, astronomers decide whether a star is a star or not, and whether a galaxy is a galaxy or not, based on its *physical properties*. It might be a dwarf star or a giant star, a dwarf galaxy or a giant galaxy, but the basic qualification is based on some physical characteristic of the object.

Stars, for example, are objects that generate the bulk of their energy as a result of sustained nuclear fusion in their interiors. If an object is too small to generate the bulk of its energy as a result of sustained nuclear fusion in its interior, then it isn't termed a star - period. Astronomers do not exclude tiny stars - called dwarf stars - as stars because they are too small; if they have the salient characteristic of a star, i.e., energy generation by fusion, they are termed a star. Despite that, however, some of my brethren think that dwarf planetary bodies like Sedna shouldn't be termed planets.

I'm amused by this. One doesn't deny a Chihuahua a place among dogs because it is too small. And we don't deny a gnat a place among insects, or a Japanese bonsai a place among trees for similar reasons to the reason we don't exclude dwarf stars from the list of stars - because something deeply characteristic - "genetic" if you will-binds the classification across a wide range of sizes.

Owing to the recent discoveries of objects as mind-bending as Sedna, pulsar planets, and super-Jupiters, planetary astronomers are now facing the question of determining formal planet classification criteria. What is needed is a clear, unambiguous criterion (or a set of criteria) that can be applied to test any given astronomical object to determine whether it is a planet.

Why hadn't we astronomers faced this issue long ago? It's because until recently, technological limits kept us from seeing very many examples, and therefore much real variety, among planets.

This situation astronomers are facing now is rather as if Kate had grown up entirely in our house, having never left it or seen any of the outside world, except through our windows (there are days mind you that I think this might have been a good thing). With her range of view, and therefore her range of experience, limited this make believe way, Kate would only know of a handful or so of other homes that one can see from ours. Several are one story homes, several are two story, and there isn't much real variation in the range of compositions. If Kate were then one day able to ascend to our roof - or better - to roam the streets of our town, seeing neighborhood after neighborhood, she'd suddenly be confronted with a much greater population of houses. Moreover, in this larger population, she'd see much greater variations in the sizes, styles, compositions, and settings that houses can take on.

This is *exactly analogous* to what has happened in astronomy over the past dozen years or so with regard to our knowledge of the range of bodies that one might classify as a planet. Simply put, the growing capabilities of telescopes and detector systems available since the early 1990s have enabled the discovery of bodies with masses about that of the Earth that orbit pulsars ("pulsar planets"), objects many times the mass of Jupiter that orbit far away stars ("super Jupiters"), and a growing bevy of tiny worlds in the icy Kuiper Belt beyond Neptune ("ice dwarfs"). These findings dramatically broadened our knowledge horizon and forced us to confront what is and isn't a planet.

Oddly, there isn't much controversy to the upper boundary line above which an object is no longer called a planet. If there is enough mass that the object ignites in fusion, such an object is simply termed a star. I have yet to hear anyone call for a separate category for those objects that generate most of their energy by gravitational contraction, as objects like Saturn and Jupiter, and the giant "super Jupiters" do.

Where the controversy comes in is at the small end - i.e., in deciding what the lower size boundary should be for planet classification. In that regard, I have heard a lot of suggestions as to how we might go about deciding whether any given object is too small to be a planet, or not. The ones I don't like fall into three categories.

Idea 1: Formation Mechanism Rules. "If an object forms like a planet then it is a planet; if it forms like a star, then it is a star."

A nice try, I say, but this is fatally flawed in at least two different ways. First, we do not know how to determine how any given object formed without ambiguity. Just how did those pulsar planets form? No one knows. How about those super Jupiters? There are least five separate proposed formation mechanisms for these bodies in the technical literature. How about our own Jupiter for that matter? We can't even agree yet on this - because we don't have sufficient data to distinguish between two well-developed, plausible models. Another problem with the Formation Mechanism idea is that both stars and planets can each occasionally form by mergers and also by the fission of a rapidly rotating parent body - so in those cases the formation criterion can't distinguish whether such objects are stars, or planets, or some kind of astrophysical hermaphrodite. We simply have to find a better criterion than this.

Idea 2: Just legislate it. "Adopt some minimum size or mass-say the size or mass of Mercury (diameter=4800 km), or maybe even Pluto (diameter=2400 km), as the minimum size for a planet."

Using this criterion, anything above the legislated line (that isn't so massive as to turn itself into a star) would qualify. This idea is nicer than the first one because you can actually hope to measure an object's size or mass. It also allows one to keep from jarring the public who were taught for so long that Pluto is a planet. However, legislation like this certainly isn't a very scientific way to proceed. In fact, I'd say it's at best a lazy person's way out because it's completely arbitrary, and has no connection to the physical attributes of planetary bodies. If biologists had adopted this kind of size rule for species classification, babies would be excluded from their own species, despite the fact that we know they are genetically related to adults by their DNA! Ridiculous; search on.

Idea 3: Location Rules. "Let's use an object's location as the criterion to establish or reject it from planethood."

I like this one least of all because it is nothing but quicksand. The most common form of this idea is to classify an object as a planet if it is the largest thing in its region. By this criterion, objects like Ceres and Sedna *are* planets, for they are the largest known things in their regions of the solar system. But what happens when we later discover something out there past Sedna in the Oort Cloud that is larger still. Will we declassify Sedna and replace it with Mr. New Planet? And what if we then find still larger and bigger bodies there? And what do we do about the extra-solar planetary systems where we have no idea what else lurks out there beyond the one or two or three bodies we have spotted so far in each system? Just like the Formation Mechanism criterion, the Location Rules criterion either leaves us paralyzed, unable to render classifications, or living with the threat of *endless* reclassification. Moreover, we know that planets can migrate around their planetary systems, changing orbits and therefore location for various reasons. By the Location Rules criterion, which objects in a given system are planets becomes a function of when you look, which is nuts. The root of the problem with the Location Rules criterion is that it, like the Formation Mechanism and Legislative criteria, fails because it doesn't recognize any physical attribute of about the nature of a given object, simply its size *relative* to its cohort population. ("Pluto can't be a planet because it is in the Kuiper Belt.") If biologists adopted this kind of criterion for species classification, a cowboy would become a cow when he herds his cattle! Location is an important factor for realtors, but I don't think it serves anybody satisfactorily for planet classification.

Well, if none of these three ideas work, what are we to do?

The idea that I do like is very simple. It identifies a physical characteristic for setting a lower boundary to planet classification, akin to the "fusion energy generation" criterion for stars. Any kid knows that when you draw a picture of a planet, you have to draw something round. So the idea I like is this: If an object is large enough for gravity to round its shape, then it is no longer just a structure ruled by mechanical strength, like a rock, a building, or a mountain - instead, it is a wholly different kind of structure that we call a planet. I like to call this criterion, **"Gravity Rules."**

One can calculate the minimum size body that will become rounded by its own gravity starting from very basic principles of physics. Doing so, you find the boundary is a diameter of a few hundred kilometers.

A great number of scientists like this idea. I like it for a number of reasons. For one thing, it's based on physics. In fact, it is ultimately the same kind of physics (the effects of gravitational forces) that stars are classified by - for the thing that turns a large enough body to fusion is its self gravity - which heats an object's interior sufficiently to ignite nuclei in a chain reaction. As a result, this criterion provides a satisfying connection across major classification schemes in astronomy. For another thing, Gravity Rules is comparatively easy to apply - by simply measuring an object's mass or radius (some of the easiest things to determine from afar), we can perform the test to decide if an object should be classified as a planet, or not. Furthermore, the Gravity Rules criterion provides welcome stability - objects don't change classification as they evolve or change location.

Adopting Gravity Rules, all of the planets cited in textbooks, all of the pulsar planets, the super Jupiters, and Pluto, Sedna, Ceres, along with a handful of other asteroids and numerous large Kuiper Belt Objects, fall into the broad category of planets because gravity has rounded them. Some are giants, some are dwarfs, but all are planets, in the same way that some people are giants and some are dwarfs, but all are *homo sapiens* that share a deeper connection than just a size criterion.

Interestingly, the Gravity Rules criterion just happens to put the Earth about mid-way in size, in a logarithmic sense, between the tiniest dwarf planets and the largest giant planets.

The Gravity Rules criterion of course means that planetary systems (including our own) have very many planets - and most of them dwarfs. I tell school kids that the old view of the solar system that I was taught had nine planets; but things are changing and *their* kids are likely to hear a number closer to nine hundred than nine. This seems to be a problem for some of my colleagues, but frankly, I don't see why. It simply involves a situation for planetary systems that is analogous to the established fact that galaxies have very many stars, and most stars are dwarf stars (by the way, it is also known that most galaxies are dwarf galaxies). Frankly, this is the first time I can ever remember large numbers scaring any astronomers.

Fewer and fewer astronomers find they can compellingly argue against the Gravity Rules criterion. Alas, not so my teen, who is sticking to her guns. "Dad," Kate told me yesterday over coffee, "I can deal with too many stars to name. I can deal with Pluto, which is obviously a planet because, duh, it is round and it is in my textbook - but there are only nine planets and there should never be any more. Otherwise it's like I told you, we will just have a mess on our hands when it comes time to name them all on tests."

Planetary scientist Alan Stern is an Executive Director of the Space Science and Engineering Division of the Southwest Research Institute, and the Principal Investigator of NASA's Pluto-Kuiper Belt mission, New Horizons (http://pluto.jhuapl.edu/).

Extensions and Adaptations:

- If a student is unable to present in the debate for any reason, they could be the official time-keeper for the debate.
- To adapt this activity to younger students, cut the time for the debate to 1 minute per role/speaker instead of 2 minutes.
- Some of the characteristics in the Solar System Characteristic Cards were unknown at the time of writing. Students could research the Solar System Objects for which characteristics were unknown to see if new information is yet available.

References and Resources:

- Rules of debate and adaptations for classroom use from Education World: http://www.educationworld.com/a_lesson/lesson/lesson304b.shtml
- *The Kuiper Belt*, from the NASA New Horizons mission to Pluto and the Kuiper Belt: http://pluto.jhuapl.edu/science/everything_pluto/12_kuiper_belt.html
- *Is Pluto a Planet*, from the NASA New Horizons mission to Pluto and the Kuiper Belt: http://pluto.jhuapl.edu/science/everything_pluto/11_pluto_planet.html
- *Gravity Rules: The Nature and Meaning of Planethood*, by Alan Stern of the Southwest Research Institute: http://www.spacedaily.com/news/outerplanets-04b.html
- *Pluto is a Planet*, by John Stansberry: http://rincon.as.arizona.edu/~stansber/PlutoPlanet.html
- *Is Pluto a giant comet?* From the Harvard-Smithsonian Center for Astrophysics: http://cfa-www.harvard.edu/icq/ICQPluto.html
- *Having Pups Over Pluto and the Planetary Misfits of the Kuipers*, by Robert Sanders for SPACEDAILY: http://www.spacedaily.com/news/outerplanets-03e.html
- *Definition of a Planet*, by Marc Buie, Lowell Observatory: http://www.lowell.edu/users/buie/pluto/planetdefn.html
- *Yes, Pluto Really is a Planet*, by Marc Buie, Lowell Observatory: http://www.lowell.edu/users/buie/pluto/planet.html
- *Much ado about Pluto*, from NASA Space Science News: http://science.msfc.nasa.gov/newhome/headlines/ast17feb99_1.htm
- *It May Be Small, But It's Still A Planet*, from Space Today Online: http://www.spacetoday.org/SolSys/Pluto/PlutoPlanet.html
- *A Good Definition of the Word "Planet": Mission Impossible*, by Gibor Basri, for the Universe in the Classroom, the Astronomical Society of the Pacific: http://www.astrosociety.org/education/publications/tnl/59/planetdefine.html
- The International Astronomical Union: http://www.iau.org/
- *'New planet' forces rethink*, by Helen Briggs, BBC News Online: http://news.bbc.co.uk/2/hi/science/nature/3516952.stm
- 2004 NASA News Release: *Most Distant Object in Solar System Discovered*, http://www.jpl.nasa.gov/releases/2004/85.cfm
- *Distant Object Could be 'Tenth Planet'*, by Maggie McKee for the New Scientist: http://www.newscientist.com/article.ns?id=dn4776
- http://www.gps.caltech.edu/~mbrown/sedna/index.html#planets
- http://www.gps.caltech.edu/~mbrown/planetlila/

Standards:

National Science Education Standards (NRC, 1996)

Content Standards: 9-12
History and Nature of Science, CONTENT STANDARD G:

- Science as a human endeavor
- Nature of scientific knowledge
- Historical perspectives

Benchmarks (AAAS, 1993)

Chapter 1. The Nature of Science

1A: The Scientific World View

Grades 9 through 12

- Scientists assume that the universe is a vast single system in which the basic rules are the same everywhere. The rules may range from very simple to extremely complex, but scientists operate on the belief that the rules can be discovered by careful, systematic study.
- From time to time, major shifts occur in the scientific view of how the world works. More often, however, the changes that take place in the body of scientific knowledge are small modifications of prior knowledge. Change and continuity are persistent features of science.
- No matter how well one theory fits observations, a new theory might fit them just as well or better, or might fit a wider range of observations. In science, the testing, revising, and occasional discarding of theories, new and old, never ends. This ongoing process leads to an increasingly better understanding of how things work in the world but not to absolute truth. Evidence for the value of this approach is given by the improving ability of scientists to offer reliable explanations and make accurate predictions.