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Teaching What a Planet Is: A Roundtable on the Educational Implications of the New Definition of a Planet

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Abstract

A quick review of the August 24, 2006, decision by the International Astronomical Union about how to define a planet in our Solar System is followed by commentary from planetary scientists and educators from various settings. A table of relevant dates and a list of useful resources are appended, and readers are invited to participate in the discussion.

Preface

Readers of the *Astronomy Education Review* are often the ones on the front lines of our educational system, teaching students, meeting with planetarium and museum audiences, and responding to media requests for information. Given all the hoopla about the new definition of a planet in our Solar System by the International Astronomical Union (IAU) at its meeting in Prague in August 2006, we thought it might be interesting to gather a cross-section of reactions from noted astronomy educators and then invite our readers to voice their opinions.

We begin with a personal report by David Morrison, who was in Prague and served on one of the committees that considered the issue of defining a planet. This is followed by comments from Owen Gingerich, the chair of the IAU Planet Definition Committee, and a statement from Richard French, the chair of the main organization of planetary astronomers in the United States. We then continue with commentary from a number of planet experts and several formal and informal educators, including three textbook authors. (The authors of each comment wrote independently, and there is thus a small amount of overlap in their comments that we have left in when needed for clarity.)

At the end, we invite readers to join in the discussion. A table with the history of the number of planets being taught and a resource guide of relevant readings and Web sites are included as appendixes.

—Andrew Fraknoi

My Very Educated Mother Just Said, "Uh-oh, No Pluto!"

"What's in a name? that which we call a rose by any other name would smell as sweet."
Shakespeare, *Romeo and Juliet*

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A. INTRODUCTION

1. David Morrison
NASA Ames Research Center

As a participant in the recent International Astronomical Union (IAU) meetings and votes on the definition of a planet, as well as previous debates on the same subject, let me note some of my thoughts on both the process and the result.

First, let's look at the actual new IAU definition of a planet in our Solar System. Note that the upper limit in size for a planet (distinguishing it from a brown dwarf star) had earlier been set by requiring that it must not have sufficient mass to derive energy from fusion reactions at any point in its evolution. To this upper limit we now add,

> The IAU . . . resolves that planets and other bodies in our Solar System 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 neighborhood 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 neighborhood around its orbit, and (d) is not a satellite [of a planet].
>
> (3) All other objects orbiting the Sun shall be referred to collectively as *Small Solar System Bodies*.
>
> The IAU further resolves that Pluto is a *dwarf planet* by the above definition and is recognized as the prototype of a new category of *trans-Neptunian objects*.

This new definition is controversial, and not just among scientists. Such public interest is appropriate, because the definition is not primarily a science issue. No scientific study or mission has been waiting for this decision, and scientists can (and often do) use all sorts of jargon without official approval. The whole issue is of interest primarily because nonscientists, including school textbook writers, want a definition. Now they have one. It remains to be seen whether planetary scientists will adjust their terminology because of the IAU votes.

The process was highly convoluted. I was a member of the IAU committee of 19 elected planetary scientists who debated for months and finally adopted a definition by a vote of 11–8, in which Pluto remained a planet, along with any new objects discovered with a radius greater than 1000 km.

This proposed definition, which would eventually have led to several new trans-Neptunian planets, was not even on the table at the IAU. Instead, several versions were debated that were formulated by a committee (which I was not on) chaired by historian of science Owen Gingerich. Rightly or wrongly, many astronomers considered this process to be lacking in transparency, and they seemed to be unwilling to trust their representatives on either committee. During the IAU meeting, the Gingerich committee reported and alternate suggestions were made, so that the issue was in a constant state of flux. This process ultimately led to a public vote on a series of issues, with no amendments allowed. The vote was taken on the last day of the IAU meeting and involved fewer than 500 astronomers, which is only about 5% of all IAU members.

One of the major rifts evident in discussions at the IAU was between astronomers who study physical properties of objects and those who study orbits (dynamics). The dynamicists dominated at the IAU, and many of them would not accept any definition that was based solely on physical properties such as size. They rejected the analogy with stars, which are classified based on what they are, not where they are located (e.g., in a star cluster).

Some of the dynamicists noted the historical distinction of planets as "wanderers," as well as the established distinction between moons (satellites) and planets, even though some moons (such as Ganymede and Titan) are larger than the planet Mercury. In contrast, many planetary scientists who study these objects as individual worlds prefer a definition based on the intrinsic properties of the object itself. The final compromise definition contains elements meant to satisfy both camps.

Is Pluto, then, still a planet? Yes and no. The answer is semantic, based on whether dwarf planets are planets, just as dwarf pines are pines and dwarf galaxies are galaxies. I would say that Pluto is a planet, but it is a dwarf planet, and the first example of the class of trans-Neptunian dwarf planets. Less defensible (to me) is the use of the term *dwarf planet* for Ceres, the largest asteroid. There is some precedent, because Ceres was considered a planet for the first decades after its discovery in 1800, and it fits nicely into Bode's law tables. But I suspect that Ceres will continue to be thought of by most scientists as the largest asteroid, not as a dwarf planet.

There remain many uncertainties in applying the new definitions. The lower limit in size for a dwarf planet is defined by its roundness, something that cannot be measured for trans-Neptunian objects when they are discovered. In practice, astronomers will probably need to adopt brightness as a proxy for the unmeasurable size, just as size is itself a proxy for roundness. (Large objects become round from the pull of their own gravity.) The meaning of "clearing its orbit" is also undefined, but in practice, it must permit both stable populations of companions, such as Jupiter's Trojan asteroids, and transient populations, such as the near-Earth objects (NEOs) that cross the orbit of Earth. The usefulness of the new definitions will depend on the decisions to be made in their implementation.

It has been apparent for at least a couple of decades that Pluto is much different from the eight "classical" planets. In particular, its mass is much smaller than that of other planets and also much smaller than had been estimated when it was discovered in 1930. Further, Pluto's orbit crosses the orbit of Neptune. If it were found today, Pluto would probably not be classified as a major planet. In addition, we now recognize Pluto as the prototype of a new category of trans-Neptunian objects of great interest to scientists. There are thus good arguments for distinguishing Pluto from the eight larger planets. Calling Pluto a dwarf planet is a reasonable choice of nomenclature, and it also makes sense to extend this same terminology to similar objects found in the outer Solar System, such as Eris.

We now have a reasonable definition of a planet, including the new category of dwarf planet. Why, then, does the public find this decision so controversial, especially in America? I suggest the following three reasons:

1. Bad connotations of the word *dwarf*. Although astronomers have a long tradition of using this word (e.g., dwarf star, dwarf galaxy), this is not a common word in general usage. To many people, apparently, *dwarf* has a negative connotation, which was not intended by the IAU. (There may also be some problems with translating this word into other languages.)

2. Affection for Clyde Tombaugh and the "poor boy makes good" story of his discovery of Pluto. This seems to be primarily an American reaction. Some of my non-U.S. colleagues suggest that much of the support for Pluto could be a form of U.S. nationalism.

3. Concern about teaching the new definitions or about asking students to "unlearn" the nine planets they memorized in grade school. This seems to me to be a minor concern. This is only nomenclature, and classifying it as a dwarf planet in no way diminishes the scientific importance of Pluto. I see this as a teaching opportunity. At the simplest level, it is a story of new discoveries: (1) that Pluto is a lot smaller (less massive) than it was thought to be when it was discovered and classified as a planet, and (2) that we have found other large trans-Neptunian objects (of which Pluto is the prototype) that reveal a fascinating part of the Solar System that was undreamed of when Pluto was discovered. An even more important lesson about the nature of science is that (3) scientists change their ideas when new data become available.

One of the problems of the new IAU definitions is that they exclude extrasolar planets. If the new definitions are to be applied beyond the Solar System, considerable interpretation is required because neither "roundness" nor "clearing its orbit" are properties that can be observed at stellar distances. This is a question to be resolved in the future, and it ensures that this issue of defining *planet* and *dwarf planet* will continue to generate controversy among astronomers.

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2. Owen Gingerich
Harvard-Smithsonian Center for Astrophysics

I have been silently following the conversation about the definition of a planet with great interest, and I wanted to add a few comments. I am indifferent as to whether Pluto was demoted. Our committee's proposed resolution effectively demoted Pluto from the ranks of "classical planets" by making it another kind of planet. I was, however, unhappy with the resolution as passed, because it was clumsy and not well worded. For example, defining *dwarf planet* as not a planet is linguistically preposterous.

If the IAU voters had recognized that there can be different kinds of planets and had simply agreed that by their dynamicists' definition, they were defining only "classical planets," things would have been much better. The wording of the resolution that passed is not clear to the public and to many astronomers, though its scientific intent is a reasonable alternative to the definition proposed by our committee: namely, that a planet needs to be round. Although it is scientific, the new definition is not sensitive to the cultural and historical context, which our committee was explicitly charged with considering. I think that the social context is hugely important for the kids (who are our future astronomers) and for the taxpayers who support our very expensive enterprise.

Ultimately, usage will win the day, and that may be difficult to control. There is a lot of rebellion out there now. Pluto will, I believe, never make it back into the ranks of being a major planet because it is so small and very characteristic of the Kuiper Belt objects, but it may well be considered a planet of a different kind. I hope that the community adopts *plutonians* for that class of bodies and *cereans* for the round rocky asteroids, because a few more large asteroids besides Ceres will prove to be round, and hence dwarf planets. Given these two very useful educational categories, we can then drop the confusing term *dwarf planets*.

At the IAU meeting, there were certainly some vociferous voices not interested in compromise, which made the process particularly unpleasant but interesting. It reminded me of trying to do diplomacy in the Middle East!

B. THE SCIENTIFIC ISSUES

3. Richard French
Wellesley College

On August 24, 2006, the IAU passed two resolutions that defined three categories of bodies in the Solar System: planets, dwarf planets, and small Solar System bodies. (For the full text of the resolutions, see "News item from the IAU" in the Appendix 2.)

Some controversy has arisen over the merit of the definition itself and the fairness of the process by which the resolutions were passed. This discord is not surprising, given the long history of foundered efforts to reach agreement on just what a planet is and the unwillingness of nature to be categorized into neat compartments.

Could the IAU have been more open and inclusive? Probably. Would it have resulted in a different result? That is far less certain. Nearly every possible planet definition has been proposed and rejected many times, and there is no single right answer. What is definitely true is that the IAU has the authority to make such working astronomical definitions for its own purposes, that it established a procedure to define a planet in that context, and that it followed its own rules.

All possible definitions have a degree of fuzziness that requires intelligent application: what does "round" really mean? What does it mean to "control a zone"? These are technical issues to be addressed by Division III of the IAU, currently chaired by Ted Bowell of the Lowell Observatory. There is still work to be done, too, in constructing a definition that is generally applicable to extrasolar planetary systems. These and other changes, radical or moderate, may well be addressed at the next IAU General Assembly in Rio de Janeiro in 2009.

What is a planet? Ultimately, the true test will come in time through common and scientific usage. In the meantime, let’s continue the scientific study of Pluto and all the other beasts in our celestial menagerie: planet, dwarf planet, satellite, asteroid, comet, or mote of dust. We’ll surely then be in a better position to decide what it really takes to be a planet.

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4. Steven Soter
American Museum of Natural History

A planet, according to the new definition by the International Astronomical Union (IAU), is an object orbiting the Sun that "has cleared the neighborhood around its orbit." This definition, although imperfect, reflects our understanding of how the planets formed by accumulation from a flattened disk of gas and dust (the solar nebula) in orbit around the primordial Sun. A planet is a body that has swept up or gravitationally scattered away most of the mass from its orbital zone in the original accretion disk. The result of this process is a small number of planets in nonintersecting orbits, and a large number of smaller asteroids and comets. The small bodies are leftover debris from the accretion process and differ from planets in that they can collide with each other and with planets.

While the IAU had the right idea, its unqualified use of the word *cleared* has caused some confusion. The clearing is never perfect because asteroids and comets continue to stray into the neighborhood of planets. A more precise definition would say that a planet "dominates" its orbital zone. In any case, the degree of clearing is quantifiable, both in theory and by observation. All the planets in our Solar System are sufficiently massive to scatter the leftover debris from their orbital zones in a time much less than the age of the Solar System. Today, each planet contains at least 5,000 times more mass than all the debris found in its orbital zone, in striking contrast to the asteroids, comets, and Kuiper Belt objects (KBOs), including Pluto, which live amid swarms of comparable bodies. Our Solar System contains no objects intermediate between planets and nonplanets, defined in this way. Planets are few in number because the Solar System has insufficient dynamical room for many. Gravitational perturbations by the massive planets rapidly destabilize the orbits of neighboring small bodies.

A prominent objection to the IAU definition of a planet is the contention that we must define natural objects only by their intrinsic properties--such as mass, shape, and composition--and not by their dynamical context. But why is context any less important? After all, we distinguish meteoroids orbiting the Sun from meteorites lying on the ground. And we define all natural objects that orbit planets as "moons" even though two of them are larger than the planet Mercury, and most of them (called irregular satellites) are captured asteroids and comets. The IAU definition similarly distinguishes planets, which dominate a well-defined volume of orbital space, from asteroids, comets, KBOs, and ejected planetary embryos, which do not.

The historical definition of "nine planets" no doubt retains a strong sentimental attraction. However, definitions contrived to retain Pluto as a planet are not only clumsy but also conceal the recent paradigm shift in our understanding of the architecture of the Solar System in relation to its origin in a solar nebula. We can use the debate on the definition of a planet as a fine example to teach students that scientific knowledge is not engraved in stone, but continues to evolve. Scientists sometimes need to revise their definitions to reflect the improved understanding that arises from new discoveries.

Astronomers have excellent historical precedents for this. The ancient Greeks recognized seven lights in the sky that moved against the background pattern of stars--the Sun, the Moon, Mercury, Venus, Mars, Jupiter, and Saturn--and called them *planetes*, their word for wanderers. After Copernicus (1543), we redefined planets as objects orbiting the Sun, adding Earth to the list and deleting the Sun and Moon. Discoveries with the telescope added the planets Uranus and Neptune. In 1801, we began to discover asteroids, small rocky objects in orbits between Mars and Jupiter. For several decades, astronomers counted the asteroids as planets, but by 1851, the total number of "planets" had reached 23 and was growing rapidly. Something had to be done. We then decided to relegate the asteroids to a separate category, minor planets. In 1930, Pluto was discovered and hailed as the ninth planet. The recent recognition that Pluto is actually one of the KBOs, and not even the largest one, led to its change of status, and Pluto joined the ranks of the other "former planets"—the Sun, the Moon, and the asteroids.

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5. Mark Sykes
Planetary Science Institute

There is a tendency to teach science as a collection of incontrovertible facts: the Earth has a solid iron core; gravity causes things to fall down; a planet moves in an elliptical orbit about the Sun. These are inferences from observations. Now, such inferences can be so robust and consistent with repeated observations that they are referred to as a "law." However, science promotes no absolute truths. Even many of these "laws" need a little updating around the edges, such as Einsteinian modifications to Newtonian "laws" of motion. In fact, science to me is at its best when we take a law or model or definition and see where it breaks down. That is where the new discoveries, ideas, and perspectives lie, and that is where, in my opinion, science is most fun.

Change is a predictable aspect of science, and so is argument. Scientists are just like other people in that they do not like to have their way of looking at things challenged, particularly if they have an emotional attachment to that perspective. The debate about Pluto and the definition of a planet is a good case in point. Few scientists today remember a time when Pluto was not a planet (it was discovered in 1930). Pluto being a planet is something that is part of the assumed set of "facts" that scientists have walked around with since childhood.

Many scientists knew Clyde Tombaugh and have positive feelings about him. The thought of Pluto's arbitrary demotion by the International Astronomical Union (IAU) to something not a planet has stirred a lot of passion against it. On the other side, there are those who feel that only big, gravitationally important bodies deserve the title of *planet*, and those who feel that the number of planets should not exceed a number around the number of fingers on their hands.

The IAU defines a planet as "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." Because all objects that could clear their orbits would be so massive that they would have to be round, removing item b has no impact on the application of the definition; its presence was purely political. Thus, for an object to be a planet under the IAU definition, it must orbit the Sun and have "cleared the neighbourhood around its orbit." The meaning of this latter phrase is not at all clear. The presence of large clouds of asteroids (Trojans) straddling Jupiter's orbits and asteroid impacts on Earth have raised the issue of whether Jupiter and Earth are planets under a plain reading of the definition. This is the kind of an issue that a high school or college teacher might have to deal with. One can imagine the growth of explanatory supplementary material that would have to accompany every textbook that embraces the IAU's work.

There are more serious problems for people who study these objects. One is that the minimum mass for an object to be considered a planet increases with increasing distance from the Sun. So, according to calculations by some dynamicists, a newly discovered object the size of Earth beyond, say, 150 AU would not be a planet because it could not have scattered sufficient material out of the "neighborhood" (whatever that means) of its orbit over the age of the Solar System. If Mars were shifted just a little farther out into the asteroid belt, it would not be a planet either, for the same reason.

This is only a problem, of course, if one assumes that a definition should group together objects sharing similar intrinsic characteristics. The IAU definition groups together objects sharing a characteristic that is a complex function of mass, but it is a characteristic that depends on its effect on other objects nearby over some span of time. An imaginary alien ship visiting the Earth with the IAU definition in hand could not determine whether the Earth was a planet just by studying it.

Consequently, more than 300 planetary scientists and astronomers have signed a petition protesting the adoption of the IAU definition and do not plan to make use of the definition in their work or in their teaching. What they will teach, however, will probably reflect their own view of what makes sense to be grouped under the label of *planet*.

The IAU has authority only to the extent that astronomers follow it. In its process of defining the common term *planet*, the IAU has undermined its authority. Unfortunately, under its own rules, the IAU will not be considering this issue again for three years. In the meantime, the Internet allows scientists to have a wider, more open discussion and construct a better definition. If a new grassroots definition results in a different list of planets (could the gas giants be redefined as "stellar embryos"?), it may end up with the broader usage because of the greater participation in its formulation.

In the end, a definition based on intrinsic properties is likely to develop and gain a following. Perhaps a competing system of nomenclature will be established. What ends up prevailing will be driven by usefulness; the most useful system will, in the end, be the one in common use. Whether this occurs over the next year or the next several decades is unknown.

Textbook writers do a disservice to students when they reduce science to a string of immutable facts. The "great planet debate" will be with us for a little while at least, and students will learn more if they are taught to the issues rather than to a particular outcome.

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6. Gibor Basri
University of California, Berkeley

Actually, the astronomers at the 2006 IAU General Assembly did not attempt to define the word *planet*. They contented themselves with establishing nomenclature for objects in our Solar System. Even so, they adopted a basic definition of the smallest mass that could qualify as a planet. This requires that it take on a nearly spherical shape because of its self-gravity. I have advocated this limit for some years and so was pleased with that part of the proceedings. The upper limit mass for planets had been addressed by the IAU Working Group on Extrasolar Planets, which said that planets should be incapable of core fusion. This is also what I have been advocating, and it completes a definition of the planetary mass range. From an astrophysical point of view, that is all one needs to do, although it is obvious that all objects in that mass range are not planets (our Moon being the nearest such example). I have suggested coining a new term, *planemos* (which stands for "planetary mass objects"), to cover all astrophysical objects in the planetary mass range. The fun begins when one tries to narrow down which planemos should be called planets.

We should teach that the Solar System has eight major planets (actually, four gas giant planets and four terrestrial planets) and many dwarf planets. Not until middle school should much attention be paid to the dwarf planets. One could say that the first examples discovered of rocky and icy dwarf planets are Ceres and Pluto. The fact that there are more and larger icy dwarf planets in the Kuiper Belt leads to a discussion of the formation of planetary systems and the composition of the Universe (in high school). Nobody need be burdened with learning the names of all the dwarf planets. This scheme promotes discussion of the scientific fact of how the Solar System is laid out, while only violating the least number of important cultural expectations (exclusivity of planets, which would soon no longer be an expectation at all). This is essentially what was initially proposed to the IAU--although with a number of dubious additions--but it did not survive.

The next possibility, which was chosen, is to reject the dwarf planets altogether as planets, based on the circumstances that they find themselves in. The dynamicists who held a majority at the end of the meeting--albeit a tiny minority of all IAU members--insisted that objects in belts are not dynamically important enough to deserve the label *planet*, but then used it anyway in *dwarf planet*. They did not think very carefully about how hard this definition is to actually apply, nor how much it depends on special circumstances, nor what difficulties it might run into in other planetary systems. Just a few of the problems, beyond defining *cleared* and *neighborhood* precisely enough, are (1) that whether a body clears its neighborhood depends in part on whether there is a large planet nearby to help out, and how far from the star the body is; (2) the Earth has 10,000 asteroids crossing its orbit, so has it cleared its neighborhood? (3) Eris orbits at 45 degrees to the ecliptic and so is unlikely to have many neighbors in its orbit; is it therefore a "real" rather than "dwarf" planet? and (4) if you put Mars into the Kuiper Belt, it would not clear its neighborhood. Is this any way to define a fundamental class of objects? All these circumstantial issues should be dealt with by adjectives, and then the IAU action would have been fine.

A substantial number of astronomers are rejecting the IAU action, so if I were a teacher or textbook writer, I wouldn't presume that we have heard the final word. Rather, teaching about the controversy itself allows a lot of fun science to be introduced, along with the idea that science is not "given truth," but is worked out by people who make observations and theories but keep their human foibles as well. It is good to also keep in mind throughout the discussion that nature does not care what labels we use.

C. THE EDUCATIONAL IMPLICATIONS

7. Debra Fischer
San Francisco State University

I'm going to try to stay away from my personal feelings about this issue and address the question that the editor has asked: How do we make this a teachable moment? Scientists categorize objects in order to better understand them. Studying how one group of objects (such as fossils or planets) is similar or different from another is one way that people have cracked some of the big mysteries in science. This process is iterative, and we must allow for refinements in categorization if science is to advance. If we collect objects on the beach and classify them as stones, and then later learn that some of the objects are really shells, it is silly to continue calling the shells stones. We need to reclassify the stones in order to refine our understanding.

On the other hand, what happens if the objects we collect on the beach are compositionally the same but have different sizes--for example, pebbles, stones, rocks, and boulders? How is our understanding of geology advanced by a clear division between what we call a rock versus a boulder? Does the word *rock* conjure up a different image from the word *boulder* that makes it more efficient to communicate what that object is? What happens if, based on our small sample, we think that the division between rocks and boulders is clear, and then we accumulate more specimens that sit on the border or fit both categories?

Teachable Issues

1) The most obvious point is that science is a dynamic process, not a collection of stagnant facts.

2) A range of objects orbit the Sun, from dust-sized particles up to Jupiter.

3) Our Solar System extends beyond the Sun and eight planets. We are just beginning to discover an amazing reservoir of objects from the outer reaches of our Solar System; some of these objects may be as big as the familiar inner Solar System planets.

4) Our Solar System is just one possible configuration of objects that orbit a star. Everything we are learning about other solar systems suggests that the process of forming planets is stochastic. In other solar systems, we can currently only see the biggest planets, like Jupiter, Saturn, and Neptune. Perhaps surprisingly, we are also beginning to see the smallest particles around other stars--dust--with infrared and sub-mm observations. Objects from centimeter-sized debris to planets that are several times the size of the Earth are currently not observable; they are invisible to us. This is an area of very active research, and space missions such as Kepler and the Space Interferometry Mission will help us to learn more.

5) One current definition of a planet, roundness, is going to be impossible to directly observe for objects in the outer Solar System and for objects orbiting other stars. If we can estimate the size or mass of an object, we can infer the roundness indirectly. But observations that estimate the size from brightness are tied to the (unknown) albedo of the object. What do students think about using unobservable characteristics as definitions classes of objects? What happens when the object is ambiguous?

An Exercise for the Student

In the case of our Solar System, there are objects that range from dust-sized particles, asteroids, comets, dwarf planets, and planets up to Jupiter. An interesting exercise is to plot the mass or size distribution of these objects. Before drawing any conclusions, think about which mass/size bins have the largest uncertainty; that is, which objects are we most likely missing, and why? Is there a clear break in this distribution that indicates that one set of objects is different from another? Are there other ways, besides mass/size, that you might distinguish one set of objects from another? Check the distribution of those parameters to see if the distribution is continuous or if one set of objects seems distinct from all others.

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8. Eric Chaisson
Tufts University

1. The IAU did some considerable damage to science education in making it seem that science is done by vote. Over the course of the past week, about a dozen nonscientists noted to me their surprise that "scientists decide facts by voting." It doesn't matter if we know otherwise, and it didn't help that the media hyped the vote--not to mention continuing the charade when, among several media inquiries I received, NBC asked me how I would henceforth explain Pluto's demotion to tearful third graders, and the *LA Times* wanted a comment about the economic impact of the decision.

2. That said, I personally think that the IAU made the correct decision. For years, we were inclined to claim in our textbooks only eight planets, but largely owing to publisher's conservatism had to settle for statements like "Kuiper Belt Objects are not major planets, and Pluto is no longer sufficiently different from them to warrant inclusion in a separate category." Now, I think it is incumbent upon textbook authors to collectively abide by the IAU decision, to reduce the Pluto episode to the minor issue that it really is, and to get on with addressing the more fascinating, nonsemantic aspects of astronomy today--even if that does reduce some of our colleagues to tears.

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9. Larry Lebofsky
University of Arizona

Having read David Morrison's introduction to the present piece, I must say that although I strongly agree with most of what he says, I disagree with his statement that the definition of a planet is not primarily a scientific issue. One way that we teach science to students is by telling them to look for patterns. In this way, we can classify objects and try to understand how these objects got there (e.g., the HR diagram). There are exceptions, and these exceptions are as important as the objects that "fit" our classification (e.g., why Io is relatively small and yet so active). Although some of my nonscience friends were OK with eight planets, most were fine with the idea of 12 or even more planets. However, all of them were strongly against the idea, mentioned by a few of my colleagues, of having separate scientific and popular definitions of a planet. If scientists cannot come up with a definition that can be easily explained to the

average person, it is not a good definition.

Unfortunately, nature does not necessarily care how we classify things. As a friend of mine, Bill Schmitt, a science educator, recently pointed out, "It is also important to know that classifying things can be done in many ways and the test of a system of classification is not if it is right or wrong, but rather if it is helpful for understanding nature. There can be many ways of classifying the same things and each way can help our understanding."

The demotion of Pluto and the promotion of Ceres to "dwarf planet" was a long time in coming and not due to a single major new discovery. The process by which scientists have gotten to the final vote on August 24 and the continuing debate on the definition of a planet are indeed teachable moments for teachers and their students. Personally, the idea of the classical planets, dwarf planets (a new class of planets), and small Solar System bodies does not seem all that bad. I had some minor concerns with the original resolution, but I have even more concerns with the resolutions that passed on August 24. Definitions are too vague and are only applicable to our Solar System as we know it--not good for distant objects and not good for other stellar systems. That is why I see this as a work in progress, and this is how I will teach it to my college students and to K–12 teachers and their students.

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10. Jay Pasachoff
Williams College

In the eyes of the International Astronomical Union, Pluto is newly a dwarf planet, the prototype of a new class of Solar System object. But is a dwarf planet a planet? After all, a dwarf star is a star to all astronomers, and a dwarf galaxy is a galaxy. What did we well-meaning astronomers do in Prague in August? Did we plunge ourselves and billions of astronomy fans and schoolchildren around the world into a linguistic morass?

I may be prejudiced, because my research team of faculty and students from Williams College and MIT has observed both Pluto and Charon over the last few years. We found a big change in Pluto's atmosphere from our observations from Hawaii when Pluto went in front of a star, and we are now studying newer observations that we took in June from Australia of a similar stellar occultation. In addition, our careful measurements from Chile last year of Charon showed its size accurately but found no trace of an atmosphere. So I can make a clear distinction between the Solar System objects with atmospheres in the past (Mercury) or present (Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto) and those without atmospheres, such as Ceres and Charon.

Why does the IAU have the right to define *planet*, anyway? It divided up the sky into 88 constellations in 1929, only a decade after the union was formed, and nobody has challenged that ruling, which may therefore be the *Marbury v. Madison* of astronomy. I've been asked over the years from time to time to downgrade Pluto, and my response always was that I was trying, in my textbooks, to report on situations and knowledge in astronomy accurately rather than trying to change anything myself other than in my own research. No organization of geologists defines *continent* or tries to change India's status from *subcontinent*. Why do I live on the "Eastern Seaboard"? I have never heard of a "Western Seaboard."

Public usage doesn't necessarily follow technical rulings, and confusing two-word names like *dwarf planet* and technical terms like *hydrostatic equilibrium* (which is merely a fluid balancing act) won't win the public's collective heart. I've revised my field guide, whose new printing went to press the next week,

and I've revised my textbook's Web site to report on the recent events, but I also say that the future terminology that is accepted remains to be seen.

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11. Cary Sneider
Museum of Science, Boston

The new designation of Pluto as a dwarf planet provides an opportunity for science teachers to begin, if they haven't already, a "current events in astronomy" feature as a regular part of their science teaching. Because astronomy deals with such huge structures, vast time scales, and enormous energies, people tend to believe that the world of astronomy is unchanging. Not true! Redefining the term *planet* is just the latest, and perhaps not even the most exciting, current event in the celestial realm.

Preparation for a current events class on the topic of what a planet is should not take long. It will certainly be covered in the *New York Times* Tuesday science supplement, in *Science News* weekly, and *Scientific American*. Teachers may also want to check out the Museum of Science's Current Science & Technology Center Web site (see Appendix 2) to hear an interview with Owen Gingerich, chairman of the International Astronomical Union's Planet Definition Committee, to learn a little something about the background of this decision.

Names tell us something about the nature and origin of things. Pluto has long been an odd duck in the Solar System. With its strange eccentric orbit, small size, and huge moon, it doesn't seem to fit with the gas giants or the rocky inner worlds. Today we know a lot more about the denizens of the Solar System that was known when Clyde Tombaugh announced the discovery of a ninth planet. Teachers can use this "current event" to describe what we've learned about the Solar System since then, and why it's about time that Pluto was put in its place.

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12. Dale Cruikshank
NASA Ames Research Center

The official definition of a new class of Solar System body, the "dwarf planet," of which Pluto is the type example, affords a new and positive opportunity for classroom instruction. The controversy in astronomical circles, described in the popular media, has drawn attention to Pluto and the outer Solar System in a way not experienced by the public since 1930, when the ninth "planet" was discovered.

As an example of what students were learning before the IAU vote, I looked at McGraw-Hill's fifth-grade school text, *Science*. It simply defines a planet as a "large body orbiting a star, such as the Sun," and then distinguishes the terrestrial planets from the giant planets. Unfortunately, an image in the section on comparing the planets shows Uranus and Neptune both larger than Saturn, and Pluto half the size of Neptune. Pluto is noted to have ice on its surface. The comets, "balls of rock and ice that orbit the Sun," are said to originate in the Kuiper Belt and the Oort Cloud, but there is no connection made between Pluto and the KB or the comets.

The discussion in the classroom now can explore these connections while impressing upon the students the extreme cold at large solar distances, the fact that even common gases (notably the nitrogen and oxygen in our atmosphere) are frozen solid on Pluto and Kuiper Belt objects, and the surprising discovery that many of these bodies have companions (satellites). At the same time, students and instructors can explore the

effects of Neptune’s gravity on the KB to perturb objects into the Centaur population and into the inner Solar System, where they become active as comets.

In a further exploration of "what are these dwarf planets and where do they come from?", the connection of the icy component materials to the solar nebula and the origin of the Solar System can expand students’ perceptions of our place in the galaxy. The many extraordinary images of star-forming regions and giant molecular clouds, proplyds, circumstellar disks, and related phenomena now available can be added to the discussion to ensure that the student understands the hierarchical links from planet to Galaxy.

My own experience in teaching university freshman non–science majors has shown me that the relationship of the Solar System to the Galaxy is generally not known or understood, and that for many students, there appear to be barriers to embracing this concept, even when special efforts (supported by careful choices of words and by excellent animated video) are taken to explain it. The Pluto affair could serve as a useful tool in forging a clearer understanding of the Solar System and our place in the Universe.

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13. William Hartmann
Planetary Science Institute

For textbooks, I incline away from legislating and toward reporting to students "why scientists think what they do," although there is a feedback loop in which texts no doubt tend to consolidate usage. In our past editions, I’ve reported, for example, on why scientists question how to use the term *planet* and why it might not be suitable to Pluto, without emphasizing my position or saying, "this is the way it should be." It seems like a dangerous road to go down, if we move toward multiple textbooks proclaiming different "views" or uses of terminology. (It’s a little bit like the situation in American journalism, in which you can choose the channel to give you the version of reality you want to hear.) In a popular trade book on science, one can, of course, be more opinionated, but a text needs to be an overview of the state of the scientific community’s knowledge and paradigms so that students can understand and even step into the community.

I am convinced that descriptions of the main historical advances, observations, and experiments are really important. In talking about planet motions, for example, I think it’s important not just to discuss the Newton’s law of gravity, but it is also just as important, under the same subject, to explain how profoundly Galileo’s observations forced people to give up the Earthcentric views, a step that then led toward Newton and our modern paradigm that Earth is only part of a larger cosmic system. To give another example, in talking about the age of the Earth, I’d say it’s important not just to cite and explain radiometric results, but just as important to explain how geologists’ measures of sedimentation rates by late 1600s started to force them toward ages greater than Ussher’s 1650s figure of 6,000 years.

In the same way, with Pluto, we shouldn’t just say "Pluto’s a planet" or " Pluto’s not a planet." Instead, we should use a few sentences to say, "Here’s what Tombaugh saw, but here’s what we began to understand about accretion in the 1960s and to see in the Kuiper Belt in the 1990s--advances that forced people to reconsider how we use the term." Admittedly, semantics is a matter of choice, but there are important historic movements in our understanding at work here, too.

In each case, the emphasis we need to get across (to counter the popular media on many issues) is that, although we can define words how we like, scientists do not get to choose what to believe about nature. Instead, we are forced into debate--and, we hope, toward conclusions--by accumulation of observations and understanding. The more we get into an era in which various social forces want to replace

evidence-based understanding by ideology, the more important it is to get that message across instead of being perceived as capriciously authoritarian ourselves.

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14. Paul Knappenberger
Adler Planetarium

Visitors to the Adler Planetarium have long enjoyed the Alphonso Ianelli sculpture in our lobby, a bronze relief depicting eight planets that was commissioned before Tombaugh made his famous discovery on February 18, 1930. Because of the IAU decisions, our prized Ianelli sculpture is for the first time in its history an accurate depiction of the planets in our Solar System!

The concept of a planet has changed throughout history. Before astronomers accepted that the Earth orbits the Sun, their list of planets (meaning "wanderers") included Mercury, Venus, Mars, Jupiter, Saturn, and the Sun and the Moon. This earlier list of seven planets leaves its legacy in the names of the days of the week in many languages, even though the Sun and Moon have not been considered planets for hundreds of years! When Uranus, Neptune, and Pluto were discovered, the list of planets and our knowledge of the Universe expanded. Even though we've shortened the list (for now), our understanding of our cosmos continues to increase as we continue to explore it.

The relatively large amount of attention that the media paid to this IAU action has created an opportunity for museums, planetaria, and schools to use the event to teach about science and how science is conducted. Science is a method for gaining a better understanding of how nature works. Scientists do not work in isolation, but in a social and historical context. They are influenced by cultural, political, and economic factors. Their individual perspectives and emotions are reflected in their work. These contextual influences are especially strong in selecting names for objects. Frequently, the name has little to do with the nature of the object, but is more indicative of the scientists' imagination. The names of the planets in our Solar System are good examples of this.

The Adler is applying temporary "What's New" labels to all our exhibits that address Pluto or planetary topics--drawing attention to the fact that astronomy is always changing--and is providing current information to our visitors. Narratives in our planetarium shows have been modified to reflect these recent events.

So, the ongoing Pluto story is an opportunity to help the public and students gain insights into the ever-improving understanding that scientists are gaining of our Solar System and the formation of such systems; how the work of scientists impacts (and is influenced by) other areas of our culture; and the interesting human interactions, sometimes quite emotional, among the scientists themselves.

An Invitation to Join In

The Editors of the *Astronomy Education Review* invite you to join this discussion about the implications of the new definition of a planet in our Solar System for education. We reserve the right to select only certain contributions for publication and to edit the ones we do publish. Please note that we are not conducting a debate about the definition itself, the fairness of the IAU's actions, or the reasonableness of the petition to oppose it. Other forums exist for such a discussion.

The *AER* is devoted to an examination of astronomy and space science education. We will therefore publish only those messages that concern the use and meaning of this definition in educational contexts. Analogies of similar debates from other fields are also welcome.

To join in, send an e-mail of no more than 300 words to aeropinion@noao.edu.

APPENDIX 1

A Brief History of the Number of Planets Being Taught

Time Period	Number of Planets	Explanation
Most of human history	7	Sun, Moon, Mercury, Venus, Mars, Jupiter, Saturn
After the work of Copernicus, Kepler, & Galileo	6	Mercury, Venus, Earth, Mars, Jupiter, Saturn
1781–1801	7	Uranus added
1801–1802	8	Ceres added
1802-1804	9	Pallas added
1804–1807	10	Juno added
1807–1846	11	Vesta added
1846 to 1850s	12+	Neptune added (other asteroids discovered)
1850s to 1930	8	All asteroids become minor planets
1930–2004	9	Pluto added
2004–2006	10?	Eris announced and its category debated
2006 on	8	Pluto and Eris become dwarf planets
Note: The information in this table is based on discussions in Hilton's article (see Web site listed in Appendix 2) and suggestions by members of the roundtable.		

APPENDIX 2

RESOURCES FOR EDUCATORS ON ADDRESSING THE DEFINITION OF A PLANET

Andrew Fraknoi (Foothill College)

1. Web-Based Resources

News item from the IAU about the vote on planet definition:
http://www.iau2006.org/mirror/www.iau.org/iau0603/index.html

Questions and answers from the IAU about the new planet definition (good place to start):
http://www.iau2006.org/mirror/www.iau.org/iau0603/iau0603_Q_A2.html

Space.com report on the IAU vote and reactions to it:
http://www.space.com/scienceastronomy/060824_planet_definition.html

Sky & Telescope news story on the IAU vote: http://skytonight.com/news/3728231.html
and on the petition to reverse it: http://skytonight.com/news/3805531.html

Internal IAU Report on the Controversy by the IAU press officer Lars Lindberg Christensen (155-page PDF document):
http://www.spacetelescope.org/about/further_information/techdocs/html/iau_po_report.html

Eyewitness Report on the IAU Meeting by German journalist Daniel Fischer:
http://www.thespacereview.com/article/703/1

The petition by professional planetary scientists and astronomers protesting the IAU definition:
http://www.psi.edu/~sykes/planetprotest

2003 Position statement of the Working Group on Extrasolar Planets on the definition of a planet:
http://www.dtm.ciw.edu/boss/definition.html

"The Eight Planets": http://www.gps.caltech.edu/~mbrown/eightplanets/ Commentary on the decision by Michael Brown (Caltech), the co-discoverer of the object formerly known as the 10th planet. See also "A Requiem for Xena": http://www.gps.caltech.edu/~mbrown/whatsaplanet/requiem.html, in which Brown mourns the declassification of his discovery.

"Last Planet Standing"--Linguist Geoffrey Nunberg comments on the new definition for NPR's *Fresh Air* program: http://www-csli.stanford.edu/~nunberg/pluto.html

"Pluto: Classification and Exploration"--An essay by NASA Chief Historian Steven J. Dick with useful historical analogs: http://www.nasa.gov/mission_pages/exploration/whyweexplore/Why_We_23.html

Pluto controversy T-shirts (on a site where anyone can suggest a T-shirt design):
http://www.cafepress.com/buy/dwarf+planet

Gibor Basri's essay on the general issue of how to define a planet:
http://astro.berkeley.edu/~basri/defineplanet/

Basri's aid to the debate for teachers, in the Astronomical Society of the Pacific's "Universe in the Classroom": http://www.astrosociety.org/education/publications/tnl/59/planetdefine.html

Short debate between astronomers Alan Stern and Michael Brown from *Air & Space* Magazine: http://airspacemag.com/issues/2006/october-november/FEATURE-PlutoDebate.php

Boston Museum of Science's Current Science & Technology Center page, featuring an interview with Owen Gingerich: http://www.mos.org/cst/2006/08/25/oil-eating-bacteria-and-the-problems-with-pluto/

Earlier commentary on the definition of a planet and a giant comet by Dan Green in the *International Comet Quarterly*: http://cfa-www.harvard.edu/cfa/ps/icq/ICQPluto.html

"When Did the Asteroids Become Minor Planets?"--Historical essay by James Hilton: http://aa.usno.navy.mil/hilton/AsteroidHistory/minorplanets.html

Children's song: Pluto's Not a Planet Anymore: http://www.songramp.com/mod/mps/viewtrack.php?trackid=49124

2. Written Resources

Basri, G. "What is a Planet?" in *Mercury*, Nov/Dec. 2003, p. 27. Discusses possible ways of looking at the definition, both inside and outside our Solar System.

Gingerich, O. "Losing It in Prague: The Inside Story of Pluto's Demotion" in *Sky &Telescope*, Nov. 2006, p. 34. The chair of the second IAU committee gives an insider's view of what happened.

Krupp, E. C. "Second Place" in *Sky & Telescope*, July 2006, pp. 50-51. Discusses how the discovery of the second asteroid is like the discovery of the "tenth planet" and gives history.

Reddy, F. "The Tenth Planet" in *Astronomy*, Nov. 2005, p. 68. About the new planet; features a debate about whether it should be called a planet, with some of the key players involved in the current debate.

Reddy, F. "Pluto Gets the Boot" in *Astronomy*, Dec. 2006, p. 78. News story about the IAU meeting.

Stern, S. & Levinson, H. "Toward a Planet Paradigm" in *Sky & Telescope*, Aug. 2002, p. 42.

Whitman, D. "King of the Kuiper Belt" in *Mercury*, May/June 2004, p. 17. Preview of New Horizons mission; discusses the lack of a clear definition of what a planet is.

Reader Responses

"A First Glimpse of Student Attitudes About Pluto's 'Demotion'" by Michael LoPresto.
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