Teaching Science with History

Using Mars and Saturn to teach about the relationship between theory and observation

HELPING STUDENTS DEVELOP adequate understandings of nature of science has been and continues to be a central goal for science education. The *National Science Education Standards* (National Research Council, 1996) and the *Benchmarks for Science Literacy* (American Association for the Advancement of Science, 1993) emphasize nature of science as a central theme in K–12 science teaching. Moreover, science educators have long advocated the use of history to promote students' views of the scientific enterprise.

Some attempts to use history in science teaching have been successful in promoting students' conceptions of nature of science (Klopfer and Cooley, 1963); however, research indicates that science teachers should not expect students to derive lessons about nature of science simply by exposure to historical materials. Rather, students should be explicitly guided to realize the ways in which these materials shed light on particular aspects of nature of science (Abd-El-Khalick, 1998).

Historical vignettes coupled with such explicit guidance can serve as useful tools to enhance students' understandings of nature of science. Vignettes can highlight one or a few aspects of nature of science and substantiate abstract claims about these aspects with concrete examples. In addition to adding variety to science teachers' instructional strategies, vignettes are practical because they do not require extended time commitments on the part of students and teachers. Two episodes from the history of science, namely the observation of the "Martian canals" between 1877 and 1905, and the discovery of Saturn's rings, can be used to help high school students develop a more sophisticated view of the relationship between theoretical constructs and observation. Research indicates that students mostly subscribe to a naive empiricist view of this relationship (Lederman, 1992). According to this simplistic view, objective and reliable scientific knowledge can be generated from sensory, theory-free observations of the natural world. Philosophers and historians of science alike have thoroughly discounted this and similar simplistic, unidirectional views of the relationship between theory and observation and have advanced instead more sophisticated models or notions in which theories affect and are affected by observations (Kuhn, 1970).

BY FOUAD ABD-EL-KHALICK

For example, the notion of scientific paradigms advanced by Thomas Kuhn, a physicist turned historian and philosopher of science, admits, among other things, theory-laden observations as part of the scientific endeavor (Kuhn, 1970). From this paradigmatic view of science, theories and observations are intimately related. Observations are theory-laden, that is, observations are never neutral or theory-free; rather, they are filtered through the expectations that ensue from theory—the lens through which scientists examine the natural phenomena relevant to their investigations. In this way, observations gain relevance and meaning only in relation to the theory or question guiding an investigation. Observations deemed critical to a certain question under one theoretical framework may be dismissed as irrelevant to the same question under another. Moreover, simple observations rarely, if ever, lead to meaningful claims about the natural world. Observations make sense or contribute to our understanding of natural phenomena only when interpreted from within relevant theoretical constructs. The following episodes highlight the interdependence of theory and observation.

MARTIAN CANALS

In 1877, when Mars was at opposition (its closest point to Earth), Giovanni Schiaparelli, an astronomer at the Milan Observatory in Italy, created a new chart of the planet. He observed markings on the surface that he called *canali*, an Italian word that can mean "channels" as well as "canals" in English. Initially the *canali* seemed to be natural features of the planet, but as Schiaparelli continued his observations, they seemed to take more regular and geometric forms. The then recent completion of the Suez Canal in 1869 predisposed some observers, possibly even Schiaparelli himself, to make the "obvious" extension. The *canali* were thought to be true Martian artifacts—Martian canals created by intelligent life-forms.

For a few years, skepticism prevailed because no one else observed the canals. But the fascination with the possibility of intelligent life existing on Mars (implied by the "artificial canals") drove many observers to further scrutinize the planet's surface. By 1886 several reports—complete with charts as fanciful as anything Schiaparelli had produced—verified the existence of the canals. One person who invested enormous energy and resources in mapping the canals and was mainly responsible for publicizing their existence was American astronomer Percival Lowell.

The excitement over the Martian canals took hold of Lowell. He was wealthy enough to build his own observatory and carry on Schiaparelli's investigation, the latter having given up the study of Mars due to failing eyesight. Lowell completed his observatory in Flagstaff, Arizona, in 1894. By then he had become captivated with

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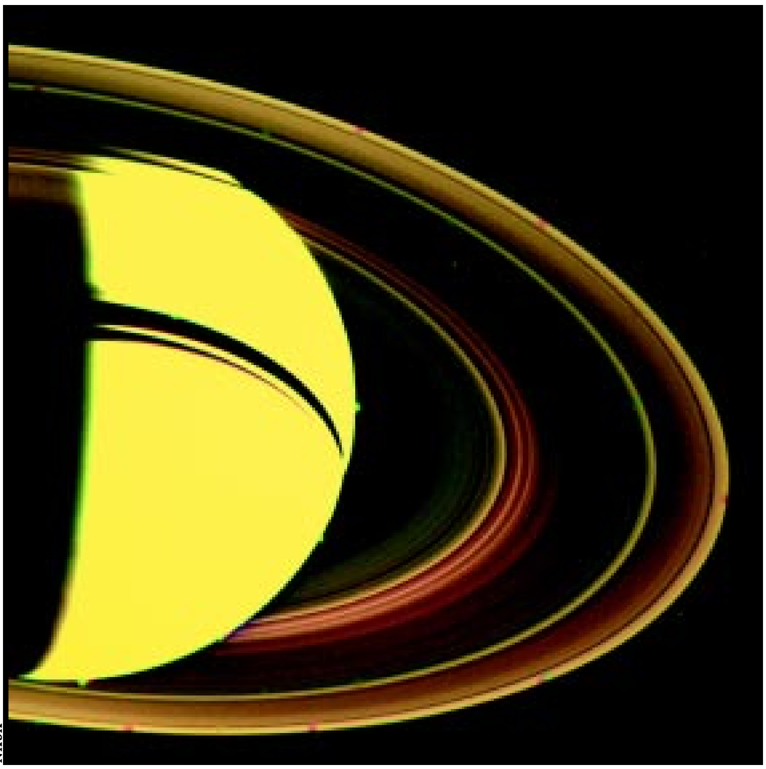
the hypothesis of intelligent life on the red planet and was certain that the canals offered the "proof." In a paper published before his work at the observatory began, Lowell wrote, "the most self-evident explanation from the markings themselves is probably the true one; namely, that in them we are looking upon the result of the work of some sort of intelligent beings" (Sheehan, 1988, 179).

It is important for students to realize that Lowell embarked on his study of Mars after having already committed himself to the hypothesis of intelligent life on Mars. It was not surprising then that he found further evidence supporting that hypothesis. After all, that is exactly what he set out to do. Lowell studied the physical



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nature of the planet and proceeded to draw elaborate maps of its surface. The polar caps contained ice, he noted, yet the rest of the planet was a desert.

Rather than even entertain the possibility of the absence of life on a planet that was mostly desert, Lowell reasoned that this observation actually justified the existence of the canals. The Martians apparently had to resort to large-scale irrigation to make their planet habitable. The canals were constructed to carry water from the polar caps, the planet's water repository, to the rest of the land. Lowell wrote that the vast network of lines he observed were not the canals themselves, which were too narrow to be seen, but the wide paths of cultivated land that the canals irrigated. From his study of those lines on the planet's surface, Lowell divined much about the Martian society. He believed theirs to be an advanced civilization; a planet-wide irrigation system meant that all of Mars must be under one government.

Lowell lectured and wrote tirelessly on the subject. He published articles and books about life on Mars, defending his hypothesis and generating controversy. Later on, Lowell reported observing similar structures on other planets. In his elaborate drawings of Venus, the planet started to show canals as well. These latter observations did much to discredit his earlier work on Martian canals. He endured ridicule in the press and was disappointed by the scientific community's lack of acceptance of his ideas.

Still, the hypothesis of life on Mars had procured wide popular support, inspiring such writers as H.G. Wells and E.R. Burroughs. Beyond popular writings, the hypothesis also gained the support of other astronomers who confirmed Lowell's observations. American astronomer William Pickering (1858–1938), for instance, reported observing a series of lakes occurring at the intersection of the Martian canals. In 1965, the issue was finally resolved when *Mariner 4* flew within 10 000 kilometers of Mars and sent back photographs of the surface. Mars showed no signs of canals, channels, or civilization, advanced or otherwise.

At this point students should be helped to realize that Lowell was an accomplished astronomer and that his hypotheses and observations (as well as those of the other scientists who supported his ideas) should not be simply dismissed as being a result of non-rigorous scientific investigations. Indeed, the calculations that Lowell made, based on his trans-Neptunian hypothesis later led to the discovery of the planet Pluto. Moreover, following Lowell's hypothesis that white nebulae were solar systems in formation, Vesto Slipher, Lowell's assistant, made one of the most impressive discoveries of the century. Through his spectroscope, Slipher discovered the large red shift in those objects (now dubbed galaxies), a finding that eventually lent crucial support to the theory of the expansion of the universe (Sheehan, 1988). Alternatively, students should be guided to realize that Lowell and his supporters' prior commitment to the hypothesis of life on Mars formed a mindset through which their observations of the red planet were interpreted as supportive of that very hypothesis.

In light of this information, some students may argue that this account indicates that theory-laden observations should not be admitted as part of legitimate science. After all, in the above case, such observations led many astronomers astray for years. Some students may even argue that neutral or theory-free observations might guarantee more valid scientific knowledge. What would it be like if scientists, not predisposed by any theories or commitments, depended on raw data or neutral observations for generating knowledge claims? The discovery of Saturn's rings is a case that sheds some light on this question.

SATURN'S RINGS

In 1610, Galileo used his 20× telescope to make observations of Saturn. In his drawings, he showed the planet with what appeared to be a pair of ears or handles attached to its globe. Galileo concluded that these were two large moons on either side of Saturn. This conclusion was not surprising given that he had recently discovered the four moons of Jupiter. However, while observing Saturn two years later, Galileo was astounded to find that the moons he had earlier observed had now disappeared. He wrote, "Were the appearances indeed illusion or fraud with which the glasses have long deceived me, as well as many others to whom I have shown them?" (Alexander, 1962, 86). In 1616, the two moons that Galileo thought he had first observed reappeared, but then his drawings showed them as half ellipses. Galileo was not able to account for his seemingly disparate observations.

In the following four decades, astronomers like Pierre Gassendi, Giovanni Riccioli, Francesco Fontana, and Johannes Hevelius made extensive observations of the planet and elaborate drawings of what was on either side. The drawings varied greatly, and those observers, like Galileo, were incapable of making any sense of their sundry observations.

Students can be guided to discern that the observers' eyes were not deceiving them; it was rather that, lacking any theoretical framework on which to fall back, their minds did not know how to interpret what they had observed. A set of observations by itself, it seems, may hardly have any meaning and may consequently tell very little about the phenomenon observed. Scientists usually have to fall back on some theory or hypothesis to make sense of their observations or data.

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Almost half a century after Galileo's observation of Saturn's "ears," Christian Huygens advanced the hypothesis that the planet is surrounded by a "thin, flat ring, nowhere touching" (Sheehan, 1988, 18). Huygens explained that every 14 to 15 years, the Earth passes through the plane of Saturn's ring. Thus, when Galileo failed in 1612 to observe the two "moons" he had seen two years earlier, he was actually the first person to observe a Saturn ring plane crossing.

SCILINKS
THE WORLD'S A CLICK AWAY

NSTA has launched a bold new project that blends the best of the two main educational "drivers"—textbooks and telecommunications—into a dynamic new educational tool for all children, their parents, and their teachers. This effort, called *sci*LINKS, links specific textbook and supplemental resource locations with instructionally rich Internet resources. *sci*LINKS represents an enormous opportunity to create new pathways to learners, new opportunities for professional growth among teachers, and new modes of engagement for parents.

NSTA is now incorporating *sci*LINKS into its journals. Each month, you will find an icon near several concepts in one of the articles you are reading. (This month, there are two icons in this article, beginning on p. 18.) Under the icon, you will find the *sci*LINKS URL (www.scilinks.org/) and a code. Go to the *sci*LINKS website, sign in, type the code from the page you are reading, and you will receive a list of URLs that are selected by science educators. Sites are chosen for accurate and age-appropriate content and good pedagogy. The underlying database changes constantly, eliminating dead or revised sites or simply replacing them with better selections. The ink may dry on the page, but the science it describes will always be fresh.

The selection process involves four review stages:

1. First, a cadre of undergraduate science education majors searches the World Wide Web for interesting science resources. The undergraduates submit about 500 sites a week for consideration.

2. Next, packets of these webpages are organized and sent to teacher-webwatchers with expertise in given fields and grade levels. The teacher-webwatchers can also submit webpages that they have found on their own. The teachers pick the jewels from this selection and correlate them to the *National Science Education Standards.* These pages are submitted to the *sci*LINKS database.

3. Then scientists review these correlated sites for accuracy.

4. Finally, NSTA staff approve the webpages and edit the information provided for accuracy and consistent style.

Who pays for *sci*LINKS? *sci*LINKS is a free service for textbook and supplemental resource users, but obviously someone must pay for it. Participating publishers pay a fee to the National Science Teachers Association for each book that contains *sci*LINKS. The program is also supported by a grant from the National Aeronautics and Space Administration (NASA).

After Huygens advanced his hypothesis, astronomers could immediately discern the ring. Earlier drawings of the planet were no longer a puzzle, and the various pieces fell into place. Students should know that Huygens's telescope was not superior to those used by other observers, so the simple suggestion that improved instrumentation resolved the issue can be dismissed. Rather it was the theoretical model that Huygens devised to explain the set of available observations that largely contributed to the discovery of the ring.

Students need to realize that, with Huygens's theoretical model in mind, astronomers knew what to expect when they observed the planet. Rapid refinements of the structure of Saturn's ring followed. In 1660, Jean Chapelain (a French poet and assistant to the secretary of the Montmortain Academy) offered the insightful suggestion that the ring is made up of a large number of very small satellites.

In 1664, Italian optician and astronomer Giuseppe Campani made the observation that the outer half of Saturn's ring is less bright than the inner half, but did not go beyond this initial observation. It was Giovanni Cassini, chair of astronomy at the University of Bologna, Italy, who in 1676 discerned a gap in the ring, which would later be named the Cassini Division. Saturn, it turns out, has not only a single ring but rather two concentric rings. Other astronomers went further to estimate the thickness of the rings and determine their period of rotation.

From the 1600s through the present, investigations have focused on producing more accurate accounts of the characteristics of the rings. Thus, students can see how theory helped scientists assess seemingly unrelated observations and served to turn subsequent efforts into a productive investigation that ended up in an almost complete description of the structure of Saturn's rings.

At this point, it should be emphasized that these two historical episodes do not suggest that one method of scientific inquiry is superior to another. Students should be guided to realize that attempts to characterize "the scientific method" that is common to all scientific disciplines is grossly inadequate and misleading.

Finally, it cannot be overemphasized that students need explicit guidance for their readings of historical episodes to be fruitful in helping them fully comprehend important aspects of nature of science. Otherwise, students will be unguided, like Saturn's observers before 1659, and left with a set of unrelated observations or stories of which many will make little sense, or which may lead many of them to draw invalid conclusions about science. Science students need explicit frameworks that help them thoughtfully interpret their readings and draw their attention to the important aspects of the workings of science that those readings highlight. ✧

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