A Martian Invasion of Teachable Moments for Environmental Science and Related Issues

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Abstract

The recent missions to Mars have produced a mass of data and information in all forms and have forced the minds of many people world-wide to rethink their own perspectives on life itself. This drama unfolding about 35 million miles from Earth, and digitally on our TV screens, is offering a growing reservoir for teachable moments. The curiosity and wonder of every image received prompts innumerable opportunities for inquiry. In this paper we share some of our ideas on how to bring into the classroom these exciting resources emanating from the Red Planet. Opportunities to reflect on myth and hypothesize about possibilities are obvious places to start when teaching about the potential of life on Mars. The explosion of resources and information (previously unavailable) from recent explorations of Mars stimulates students to examine further the environment around them. We share some of the activities we have been using in our classrooms to motivate readers to develop their own ideas on how to take advantage of the Mars missions for their classrooms. We offer strategies to create authentic learning experiences to engage students. In addition, we intend the activity to inspire teachers to use other contemporary teachable moments that may capture the imagination of their students as they discover science. Whether you are teaching topics related to desertification or deforestation, design and technology, or space travel or colonization, to name a few, the planet Mars and the recent missions to its environment will become part of your continually expanding resources in teaching science.

Helping teachers develop ways to utilize and capitalize on emerging scientific data as it materializes is very useful. The learning activities we describe and discuss in this paper integrate some of the recently available photographs from Mars (including some from the Mars Rover missions) to pose thought-provoking questions that are environmental and geological in nature. It is our particular goal to use this and similar activities to dispel a couple of pervasive misconceptions that we have observed, and that some students (and the general public) might still hold about science and the environment. In one of these misconceptions, science is perceived as static and thus answers can be found in textbooks and memorized in order to learn science. Another misconception is that environmental change happens largely or solely as a result of people doing bad things, and that geological, and in turn environmental, change does not happen without human intervention (Berry, 2009; Cherif, Adams, & Loehr, 2001; Chew & Laubichler, 2003; Miller, 2005; Shuttleworth, 2009).

Strategy and Pedagogical Approach

The main idea of this learning module is to provide students with a set of unidentified photographs from two different planets, Earth and Mars. To encourage comparative thinking, the photographs are paired; each pair of photographs in the set features one general landscape from planet Mars and one from planet Earth (one of the pairs features Mars and the Moon instead) that share some recognizable landform features. While we tried to select photographs that contain visual features that are familiar to people on planet Earth, there are surely unfamiliar landforms on Mars, and also on the planet Earth (for some students), and that is why it is innovative and exciting to look at these photographs. Because the students are uncertain how any of the landscapes formed and evolved, it is conjecture, deduction, and justified reasoning that we wish the students to apply in their inquiry and exploration of these photographs.

The pedagogical approach is for students to study the photographs and then try to answer several open-ended questions about what they observe. Students first describe what the landscape looks like, consider of what it might be made, and then speculate about how it came to be formed. Encouraging them to speculate on what processes might have formed particular landform features on the photographs (including craters, relatively smooth surfaces, mountains, valleys, etc.), and to guess the planet represented in each photograph, is essential for promoting the development of scientific inquiry and critical thinking. Then, following a brief introduction to geomorphology and various landscape-forming processes, students are asked to propose multiple, alternative hypotheses about how some of the observed features had formed. Finally, they are asked to propose locations for future planetary lander missions on Mars that might provide data to help decide among their competing hypotheses. This helps students to learn how to focus on decision-making by engaging in thinking about evidence and applying ideas for a purpose. Through a combination of pedagogical approaches, the students are likely to learn a range of fundamental concepts and principles about the geology of the planets Earth and Mars and also achieve the scientific process learning objectives of the activity.

Intended Learning Outcomes

There are two strands of intended student outcomes in the proposed learning module, one set about the process of scientific inquiry itself, and a second set about the nature of change in the environment. In the “science as a process” intended student outcomes, we want students to experience, appreciate, and internalize that: 1) science is an ongoing and active process, not just memorized answers to questions; 2) answers to one question often lead us to ask more and better questions; and 3) science is a collaborative process. In the “earth and environmental science” intended student outcomes, we want students to understand that: 1) processes on many planets’ surfaces produce recognizable landscape features, many of which are similar from planet to planet; 2) differences among landscapes come about as a result of the different conditions that formed each landscape, just as similarities can be related to similar processes; and 3) recognize that the presence of living things, and particularly of humans and human civilization, is not necessary for landscape, climate, and other changes to occur. In general, landscapes (natural, city, urban, rural) form as a result of time and interplay between various physical forces and climatic conditions (that may include human or biological influences, but do not necessary do so).

Finally, the proposed learning module is intended to illustrate how teachers can use emerging evidence about new planets to stimulate their own creativity and imagination, rather than to be applied as a static package in its entirety to teachers’ individual situations. As an end result, we hope that the learning module will also model for instructors how to use the observations from ongoing planetary missions (like Cassini), and other sources of publicly accessible research, in order to stimulate students to become active, scientific thinkers. But first, to understand how science works, what distinguishes a scientific inquiry approach from non-science in understanding the world around us, it is essential to begins with a consideration of the nature of science. After all, scientists share certain basic beliefs and attitudes about what they do and how they view their work (American Association for the Advancement of Science [AAAS], 1999).

The Nature of Science

Either consciously or unconsciously, all scientists conduct their work based on the underlying assumption that nature can be understood, and more particularly, that natural events are orderly and occur as a result of consistent, knowable causes. This assumption is the familiar principle of cause and effect, and is one of the cornerstone beliefs of Western civilization. Therefore, through science, which means to know through the exercise of reason, scientists aim to find better explanations for the natural phenomena and the world around us based on actual observations, the use of reason, and the discovery of objective knowledge and the elucidation of natural laws of causation (Futuyma, 1983; Moore, 1993; National Academy of Sciences, 1998; Trefil, 2003, 2007). This choice is based on the proposition that the application of reason that we call science can only be effective when directed toward objective observations (that do not change from one observer to another). For a proposal to be called a scientific hypothesis, it must satisfy a few, rather straightforward criteria: 1) the proposal must involve natural occurrences; 2) the proposal must be testable, by agreed-upon standards, so that it can be contradicted; 3) the proposal must be subject to revision or rejection based on the outcomes of such tests or the acquisition of new, objective observations (Kieffer, 1985; National Academy of Sciences, 2008; Trefil, 2003).

Science, simply, seeks to reveal all of the causes of all the events that have such causes. The practice of this search involves observation of events (or the acquisition of data), followed by inference of the possible causes of the events (forming alternative hypotheses), and finally, testing the inferred causes (to reject insufficient hypotheses, and select the best explanation). As Cherif, Adams, and Loehr (2001) have argued:

> Acceptance of a proposal (hypothesis or theory) in science involves several steps: 1) recognition of the body of evidence that gave rise to the proposal; 2) understanding the process of inference by which the proposal was created from the evidence; 3) ability to reproduce the process by which the proposal was tested; 4) ability to reach the same conclusion about the outcome of the test(s). Furthermore, acceptance of the proposal is still provisional, because the testing process and the acquisition of new information can and do lead to revision of an hypothesis, or its replacement by a more effective alternative. (p.15)

One of the critical components of the scientific reasoning process is that in order for a hypothesis to be called scientific, it must be capable of being contradicted. Thus, “the objectivity of science lies in its willingness to subject every aspect of the hypothesis to rigorous testing, [and] if the predictions derived from the hypothesis are not confirmed by observation and experiment, the hypothesis is rejected and a new model sought” (Bowler, 1992, p.17). The ability of an explanation to be contradicted in this way helps scientists distinguish between scientific and non-scientific claims or proposals.

Another critical aspect of the scientific process is repeatability; that is, the ability for all other researchers to obtain the same result, using the same scientific procedures in a given experiment. The conclusions drawn by one researcher about a given hypothesis are only accepted if the same results can be achieved by other researchers using the same methods. (While strict repeatability is not always possible in the historical sciences like geology, palaeontology, evolutionary biology, and others, other researchers should be able to repeat the observations made by the original researcher.) Repeatability is central to scientific inquiry as well as scientific integrity, accountability, and responsibility (AAAS, 1990; Cherif, 1998). As a result, scientists most often present their discoveries and experimental results by submissions that follow agreed upon formats, and which are subject to critical scrutiny by editors and by other scientists in the field (peer reviewers) to be validated. This approach of presenting scientific studies makes it easy for the researcher and for other scientists to read, critically analyze, and repeat the experiments or observations as necessary to confirm the results. The publication of scientific results also ensures another important characteristic of science; that of transferability. Other scientists can read about and use both the knowledge and the methodology of any published study (with proper citation) in their own work, regardless of what field they pursue.

In summary, modern science offers a mechanism to interpret natural events and to see the world in an objective way as it is (not how it ought to be), and to understand and cope with that world. In the activities that follow, we use the preceding description of the processes of scientific inquiry to explore with students the formation and testing of their own hypotheses. Students also examine the steps that scientists take before accepting a given hypothesis or a theory in science. Finally, before we start any activity, we make sure that students understand that scientists generally accept (by common consent, and without it being provable) that nature can be understood, and that all observable events occur as a result of consistent, natural causes (colloquially, the law of cause and effect). Still, as Einstein is often quoted as saying, “no amount of experimentation can ever prove me right; a single experiment can prove me wrong” (Kaplan, 2001, p. 181).

A Martian Invasion of Teachable Moments: The Teaching and Learning Module

The Teaching and Learning Module is divided into a number of activities, each with specific learning goals and objectives, and each could be targeted to a wide range of different student audience and school levels. The level and the depth of discussion is left to the discretion of the teachers based on their types of students. However, borrowing a phrase from one of the manuscript reviewers, “the differentiation between levels will be in the assessment of, and the sophistication of, responses.” The authors have used several of the activities, in part or in their entirety, in freshman- and sophomore-level college classes, but each could by readily adapted to middle school and high school levels.

Activity I: Tapping Into Students' Curiosity

(This activity is suggested for any introductory science course, particularly in the earth and environmental sciences.)

In this three-part activity, we capitalize on students’ past experiences to stimulate their thinking and activate their prior knowledge to encourage them to become active learners. The class is divided into groups of 4 students, and each group is given an identical set of photographs. Table 1 contains the suggested photographs for this activity. The photographs are given to students a total of three times during the activity: first without any identification, then with titles, and finally with titles and an attached brief description. Initially, the photographs are given as a set printed on one page, and after that the photographs are given in pairs printed on separate pages.

Table 1

Suggested Photographs for Tapping Into Students' Curiosity Through Exploring Landscape

Identifier	Title	Description	Location	Source
Pair A	Dry rivers	• Example of dry rivers on Earth, a high resolution view of dry river beds crossing a desert in China Xinjiang Uyghur region. • Example of dry river channels on the surface of Mars.	http://earth.esa.int/showcase/ers/china_west.jpg http://starchild.gsfc.nasa.gov/Images/StarChild/solar_system_level2/mars_rivers_big.gif	ESA Earthnet Online NASA
Pair B	Sand dunes	• A satellite image of sand dunes in the Sahara desert on Earth. • An image of sand dunes near a polar region on Mars during a period of "defrosting" or sublimation of CO_2 ice.	http://landsat.gsfc.nasa.gov/earthasart/images/sahara_hires.jpg http://antwrp.gsfc.nasa.gov/apod/image/0803/dunes2_hirise_big.jpg	NASA HiRISE, MRO, LPL (U. Arizona), NASA
Pair C	Polar regions	• This image of the Canadian Arctic region of Ellesmere Island displays several glacial features including ice flow. • This image of the northern polar cap of Mars shows layered appearance of deposited ice and dust. The measured temperature lies above the freezing point of CO_2 ice, suggesting that the ice is water ice.	http://www.nasa.gov/images/content/271991main_wardhuntTERRA_20080905_HI.jpg http://rst.gsfc.nasa.gov/Sect19/originals/Fig19_70.gif	Jesse Allen, using data provided courtesy of the MODIS Rapid Response team NASA
Pair D	Craters	• On the Moon, the ejecta of impact craters display features that appear to have "flown" outward as a result of impact. A significant difference between craters on the Moon and Mars is due to the Moon being very dry (devoid of subsurface ice) and Mars being very wet (presence of subsurface ice). • On Mars, fluidized ejecta around impact craters suggest that the martian subsurface was saturated with water ice when the impact occurred. The appearance of the ejecta varies from crater to crater implying differences in amounts of subsurface ice content. Image taken in 1977 by the Viking 1 orbiter.	http://www.hq.nasa.gov/office/pao/History/SP-362/hrp107.jpg http://solarsystem.nasa.gov/multimedia/gallery/Mars_Rampart.jpg	NASA Headquarters Website: http://www.hq.nasa.gov/office/pao/History/SP-362/ch5.1.htm NASA http://solarsystem.nasa.gov/multimedia/display.cfm?IM_ID=824

Pair E	Surface terrain	• Sand dunes in the Namib Desert in southwest Africa. The red-orange color is the result of iron in the sand being oxidized over time. These dunes are the tallest on Earth rising as high as 300 m above the desert floor. • Martian surface terrain. This is a color image mosaic of areas traversed by Sojourner, the rover that accompanied Mars Pathfinder in 1997. Here we see rocks and dunes that are out of Pathfinder's view.	http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=16328 http://marsprogram.jpl.nasa.gov/MPF/ops/rover_traverse_area.jpg	NASA/GSFC/MITI/ERSDAC/JAROS and U.S./Japan ASTER Science Team NASA JPL
Pair F	Water erosion	• Images of the Betsiboka Estuary in northwest Madagascar. Multiple decades of rainforest logging has led to the erosion. After each heavy rain, bright red soil from hillsides wash into the tributaries and heads towards the sea. The bottom image was taken in September 2003 by the International Space Station. • A view of gullies in the Terra Sirenum region on Mars taken by MRO's HiRISE camera on October 3, 2006. This camera can image colors within shadows.	http://earthobservatory.nasa.gov/images/imagerecords/4000/4388/ISS008-E-19233.jpg http://marsprogram.jpl.nasa.gov/mro/gallery/press/20061016a/D-Gully-highlight.jpg	Image Science & Analysis Laboratory, NASA Johnson Space Center http://earth.jsc.nasa.gov/sseop/images/EO/highres/ISS007/ISS007-E-14344.JPG
Pair G	Interesting terrain	• Geegully Creek, a river tributary in north Western Australia. Several stream channels and a wide flood plain are present here, along with several dry lake beds. Other features include sand ridges and dark and light patterns, a result of brush fires. Image taken in December, 1990 by the International Space Station. • Ares Vallis, an ancient flood plain on the surface of Mars selected as the landing site for the Mars Pathfinder.	http://earth.jsc.nasa.gov/sseop/efs/photoinfo.pl?PHOTO=STS035-76-66 http://quest.nasa.gov/mars/photos/images/marspfsite.gif	Image Science & Analysis Laboratory, NASA Johnson Space Center Online resources provided by NASA Quest Project at NASA's Ames Research Center
Pair H	Volcanoes	• Kilauea Volcano, Hawaii with visible plume. Image taken on July 7, 2008 by the MODIS instrument on NASA's TERRA satellite. • Olympus Mons, the largest volcano in the solar system. This volcano in currently believed to be extinct.	http://earthobservatory.nasa.gov/images/imagerecords/20000/20217/kilauea_tmo_2008189_lrg.jpg http://nssdcftp.gsfc.nasa.gov/photo_gallery/image/planetary/mars/olympus_mons.jpg	NASA image courtesy Jeff Schmaltz, MODIS Rapid Response team NASA

Part One

1. Using your own experience and background, examine the set of photographs provided to you by your instructor, interpret them, and write a paragraph about each pair. Use a magnifying glass if necessary. In your analysis, consider the following:

    a. Identify and describe as many kinds of landscape features as possible in these photographs.
    b. What mechanisms might have formed these features?
    c. State whether the landscape reveals the existence of living organisms in the present or in the past, and evidence for your reasoning.
    d. Are there any parts or features of the photographs that seem older or newer? Why do you think so?

2. Classify the photographs into those that were taken on planet Earth and those that were taken on another planet.

3. Using Table 2, justify your selection for each photograph and write it down.

4. Share your interpretations, selections, and justifications with the other members of your group.

5. Engage in a general discussion with your group regarding the similarities and differences in members' interpretations, selections, and justifications.

6. Save your written interpretations, selections, and justifications, and keep notes on your discussion for further analysis and comparison.

Table 2
Student's Description and Categorization of the Photographs Based on His/Her Own Knowledge and Background

Photo number	Photo description	Identified landforms	Origin of the photo: Earth, Mars, others	Reasons for origin selection and description

Part Two

This stage takes place after the learners examine some basic, but specific, principles of earth science. Specifically, students should be introduced to the concepts and methods of relative dating, and to the landforms associated with impact crater formation, volcanic processes, and processes of running water and wind. Teachers who are unfamiliar with any of these concepts can readily find basic information in any general geology textbook, Wikipedia, or other online reference sources. Students then re-examine the photographs, and respond to the following questions:

1. Using your newly gained understanding, re-examine and re-interpret the photographs using what you have learned about landscape forming processes.
2. Re-evaluate the events that you think took place on the surface of the planet(s) from which those photographs were taken, and record this in Table 3.
3. Re-divide the photographs into two groups, those that you think belong to planet Earth and those that belong to another planet, and record your selection in Table 3.
4. Justify your selection for each photograph and write it in Table 3.
5. What do you conclude from comparing and analyzing your own interpretations in Tables 2 and 3?
6. Share your new interpretation, selection, and justification of the photographs, and your conclusions from comparing Tables 2 and 3, with the members of your group.
7. Engage in a general discussion with your group regarding members' interpretations and categorization of the photographs, the reasons behind them, and your final conclusions from comparing Tables 2 and 3 with the members of your group.

Table 3
Student's Description and Categorization of the Photographs Based on His/Her Newly Gained Knowledge and Information

Photo number	Photo description	Identified landforms	Origin of the photo: Earth, Mars, others	Reasons for origin selection and description

Part Three

In this part of the activity, students are provided with the locations and brief descriptions for each of the pairs of photographs, and then directed to respond to the following:

1. Identify at least two criteria for good landing sites on another planet.
2. Speculate on what processes might have formed particular landform features on the planet Mars (including craters, relatively smooth surfaces, mountains, valleys, dunes, etc.).
3. Propose alternative hypotheses about how those features had formed.
4. Propose landing sites that would provide information to help choose among the competing hypotheses.

5. Compare your selections of landing sites with those chosen by real NASA scientists, as described in the January 2004 issue of *National Geographic*. Then complete Table 4 to indicate whether or not you agree or disagree with the 6 scientists who explained where they would land a Rover on Mars and why.

Table 4
I'd Send It To … Six Scientists Explain Where They Would Land a Rover--and Why (from Morton, 2004, p. 29)

Scientist	Scientist's proposal for landing site on Mars	Agree or disagree with the given proposal and why
1. Phil Christensen, geologist, Arizona State University	"Somewhere cold enough for snow and ice but warm enough for it to melt, such as the small crater at 43º South. … Snow--and the gullies it formed--may hold clues to past climate."	
2. Agustin Chicarro, Mars Express project scientist	"Wrinkle ridges in the plains south of Valles Marineris. Such ridges indicate that the planet shrank as it cooled, a clue to the tectonic history of Mars. "I'd love to go there myself."	
3. Maria Zuber, geophysicist, MIT	"Terrain near the South Pole, where Mars Polar Lander was headed in 1999. A look at the layers of dust and dry ice will reveal the timescale of climate cycles."	
4. Michael Malin, geologist, Malin Space Science Systems	"Sediments deposited by an extinct lake in Holden crater. There are layered sedimentary rocks on the southwest floor of the crater that are easily accessible and unusually similar to terrestrial landscapes. The layers record the history of Mars."	
5. Bruce Jakosky, Astrobiology, University of Colorado	"The edge of the north polar cap. Drilling several feet down might reveal ice that was liquid water tens of millions of years ago, greatly improving the outlook for finding evidence of life on Mars."	
6. Michelle Minitti, petrologist, Arizona State University	"Some blatantly igneous place like the top of Olympus Mons. Rocks on the solar system's biggest volcano could explain Mars' interior workings, and how volcanism shaped the surface."	

Activity II: Testing for Evidence of Life on Mars

(Suggested for introductory biology, environmental science, and general and integrated science courses. This activity is adapted from Kaskel, Hummer, and Daniel, 1995, pp. 3-4.)

Biologists and astrobiologists have been searching for evidence of life in outer space for many years. Biology is the study of life and living things. Biologists use the process of testing hypotheses to study living things and how the natural world of living organisms works. They generate hypotheses and test the hypotheses using the process of deductive reasoning in which they use the hypotheses to make predictions about the outcomes of new actions or observations. We intend for this activity to stimulate student's thinking about the possibilities of life on other planets. If life were to be found on any other planet it would have profound implications for the presence of life on many other planets throughout the universe.

When the Viking Spacecraft landed on Mars, the Viking Lander obtained and tested soil samples from Mars' surface for evidence of existing, or previously existing, organic molecules. More recent Mars missions also collected and tested soil and rock samples for similar reasons.

1. If you were a biologist working for NASA biological laboratory:
    a. What types of experiments would you conduct with martian soil to test for evidence of life on Mars?
    b. Explain the reason for selecting this particular type of experiment to search for evidence of life on Mars using martian soil.
2. NASA biologists added radioactive nutrient to the soil brought from planet Mars. Explain how this simple experiment could prove to scientists whether or not living things were present in the martian soil?
3. The Lander did not find materials that make up living things.
    a. Do these results support the idea that life doesn't exist on Mars now?
    b. Do they support that life never existed on Mars? Explain.
4. Today, Mars is observed to be a desert planet with notable dust storms, freezing temperatures, and a thin carbon dioxide atmosphere. However, on Tuesday March 23, 2004, NASA scientists announced that a salty sea once existed on the surface of Mars. This announcement was greeted with much excitement, because of the possibility that such an environment could have supported life at an earlier stage of martian history (Vergano, 2004).
    a. From your own perspective, what is the significance of the salty sea environment to the concept of life as we know it?
    b. Why do you think NASA scientists suspect that a salty sea environment could have supported early life on Mars?
5. What have you learned from being engaged in this activity?

Activity III: Landing Safely on Mars in 2012

(Suggested for physics, general science, and integrated science courses.)

To allow spacecraft (and astronauts) to travel into outer space and to land safely on the Moon, Mars, or any other planet and return safely to planet Earth, scientists must understand many basic concepts. One idea that they need to understand very well is the changes that will happen in the weight of the spacecraft as it uses fuel and as occupants (if any) use food, water, air, and other resources. This will affect the influence of gravity of a given planet or moon on which the spacecraft has to safely land, and from which it needs to take off. For example, the gravitation of the Earth is the most significant barrier standing in the way of traveling in space, because, as Noordung (1995) explained:

> A vehicle that is supposed to travel in outer space must be able not only to move; it must primarily and first of all move away from the Earth--i.e., against the force of gravity. It must

> be able to lift itself and its payload up many thousands, even hundreds of thousands of kilometers! (p. 3)

Gravity is not the only fundamental force that exists in nature. There are four fundamental forces in our present Universe with very different characteristics. These forces are electromagnetic force, the strong interaction (strong nuclear) force, the weak interaction (weak nuclear) force, and the gravitational force. The gravitational force is the weakest of the four, but its effect can be felt over greater distances than any other force. Gravity, which works throughout the universe, is defined as a force of attraction that arises between objects by virtue of their masses. It is the force that keeps our feet on the ground, keeps the Moon in orbit around Earth, the planets in orbit around the sun, and even causes whole galaxies to attract each other across billions of light years throughout the cosmos. As Sir Isaac Newton first explained, gravitational force between two objects is proportional to the mass of each object divided by the square of the distance separating them. The greater each object's mass, the stronger the pull of gravity, but the greater the distance between the objects, the weaker the pull.

In a recent issue of Popular Mechanics, Lord (2009) wrote that:

> When the NASA Mars Science Laboratory rover lands on Mars in 2012, it will face a unique obstacle: With an Earth weight of nearly a ton (compared to about 400 pounds for previous Mars rovers) and a Mars weight of about 750 pounds, it is too massive for any existing space parachute. So to cushion its fall through the thin martian atmosphere (which is less than 1 percent as dense as Earth's), NASA engineers had to come up with something really big. (p.15)

To engage students in grappling with these concepts, we suggest the following questions for research and discussion:

1. Compare and contrast Mars and Earth in terms of diameter, atmosphere's main gases, planetary mass, distance from the sun, density, and surface gravity. Use Table 5 to record your answers.

2. Estimate the maximum speed with which a falling raindrop can hit a person walking in the street. Then conduct an Internet search to find estimations that have been made by other people of the maximum speed with which a falling raindrop can hit a person walking in the street. Compare your estimation with the estimations made by other people, including your own classmates.

3. From your own perspective, describe why it might be that "incoming meteoroids that would burn up as fireballs in Earth's atmosphere often make it to the ground on Mars and create small craters just a few meters wide" ("Very Fresh Martian," 2009, p. 16). Then conduct an Internet search to find out why scientists think that incoming meteoroids that would burn up as fireballs in Earth's atmosphere often make it to the ground on Mars. Compare your own answer and the answers of your classmates with what you have found out through literature.

4. Working in small groups, suggest a well-thought-out proposal of how NASA engineers might solve the problem of landing a heavy spacecraft on Mars.

5. Share and discuss each of your individual proposals with your classmates. Try to convince your classmates that your individual proposal is the most promising in solving the problem and thus should be accepted by the whole class.

6. Conduct an Internet search to find out how NASA engineers have proposed to solve the problem. (You could start by looking at the July, 2009 issue of *Sky & Telescope*.)
7. Does your individual proposal agree or disagree with how NASA engineers have proposed to solve this problem?
8. Does the agreed-upon proposal by the whole class agree or disagree with how NASA engineers proposed to solve this problem?
9. What have you learned from this activity?

Table 5
Comparative Properties of Planet Earth and Planet Mars

Property	Planet Earth	Planet Mars
Diameter		
Atmosphere's main gases		
Mass		
Distance from the Sun		
Density		
Surface gravity		

Activity IV: Traveling in Space

It is only a matter of time before traveling in space becomes a common occurrence, especially for those who can afford it. With the help of our advances in science and technology, we will be able to solve many problems that might become obstacles to our traveling in space. However, new challenges will also arise. In this activity, you are in charge of identifying and solving the problems of astronauts who will travel and spend more time in space than what is usual today (a few days to a few months). From your perspective, identify some of these problems and propose how you will deal with and (hopefully) solve at least three of them. An example of one possible problem and a proposed solution are given in Table 6, which you can use for your own answers.

Note for Teachers

Some of the astronaut problems that your students will most likely identify are as follows:

1. Providing adequate supplies of energy, air, and nutrition.
2. Controlling temperature in both space suits and spacecraft.
3. Dealing with gravity and weightlessness in space.
4. Providing adequate space in the spacecraft for healthy resting and sleeping.
5. Preparing and packaging food in a way that takes less space and weighs less (dehydration and freeze-dried techniques).

6. Dealing with high doses of radiation during the long duration of the space flight.

Table 6
Problems and Proposed Solutions for Extended Travel in Space (adapted from Adams, Cherif, & Johnson, 2001)

Problem	Proposed solution	Investigation	Applicability in other traveling situations
Example: Packaging & preparing food	Use dry food.	Measure the volume and weight of dry noodle soup. Then add hot water and re-measure the volume and weight to calculate the difference.	Traveling across the oceans and deserts.

Student Assessment and Evaluation

McCormack and Yager's (1989) taxonomy for science education is very useful and effective in assessing students' learning in these activities, and Figure 7 contains examples for each domain. Note that many assessment tasks could fall into more than one domain, depending upon how the tasks are formed. These questions will help you, as an educator, to build tasks that you would use within an assessment instrument.

Final Remarks

Satellite and on-location imagery of landforms on Earth and Mars provide us with a contrast in worlds that make them good teaching and learning objects. We see evidence of change everywhere on Earth, as landscapes are subject to atmospheric weathering, erosion, volcanism, or even plate tectonics (and human activity), all of which erase and rewrite Earth's surface features. Orbiting imagery of landforms on other planets provide a picture of our uniqueness in the Solar System, and of the potential for Mars. Mars does not appear to be subject to plate tectonics (as we perceive that process on earth). Atmosphere is one one-hundredth as dense as Earth's. Mars does not have a magnetic field that can deflect solar charged particles. We see evidence of less change on Mars, as there are heavily cratered areas dating back to the early bombardment of the solar system. There are also instances of change on Mars, albeit over longer time scales, and the evidence includes the volcanic plains and valleys eroded by liquid water in the distant past. There is also evidence for seasonal changing of the martian polar caps, and imaging that suggests liquid water in the more recent past. The recent Phoenix lander mission found evidence of water ice on (Phoenix Mars Mission, n.d.).

We send space probes to Mars to learn more about outer space and life elsewhere, which in turn might help us learn about ourselves on Earth. Only in the overall scope of exploring several planets do we truly begin to get a true picture of our own planet, and of our place in the cosmos. We are also acquiring further data that might inform possible views of our future as we explore other worlds and prepare for extending the human species upon some of these other worlds.

Table 7
McCormack and Yager's (1989) Taxonomy for Science Education

Domain	Description	Examples of assessment tasks
I. Knowledge	What concepts did students learn and how well did they understand them? How well did the students integrate knowledge from different subject areas? To what extent did students demonstrate the understanding of multiple relationships of various bodies of knowledge? What kind of explanations did students offer for the relationships and/or phenomena they observed and understood?	When students proposed processes for land formation in Activity 1, Part Three, did they use correct connections between the processes they cited and the land forms they observed? Did the students use appropriate terminology?
II. Process	How did members of a given group compile data and information? Was there cooperation in putting the information together? How efficient was each group in presenting and communicating the collected data and information? Was the delivery of their statements and arguments smooth and coherent? How well did the students use knowledge meaningfully? Did all members participate in the activity?	Share your interpretations, selections, and justifications with the other members of your group. Engage in a general discussion with your group regarding the similarities and differences in members' interpretations, selections, and justifications.
III. Creative	In what new ways did students use information and ideas generated during the activity to enlarge their understanding? How imaginative were students in identifying relevant problems and solutions, and conceptualizing new ideas?	What do you conclude from comparing and analyzing your own interpretations in Tables 2 and 3?
IV. Attitudinal	How persuasive were group members in articulating their positions in order to justify these and/or to change the attitudes of the others? How effectively did each group function? Did members of a given party demonstrate skills and abilities to resolve conflicts with others constructively? How might each group have functioned more effectively?	Share and discuss each of your individual proposals with your classmates. Try to convince your classmates that your individual proposal is the most promising in solving the problem and thus should be accepted by the whole class.
V. Application and connection	Did the students come up with practical and workable solutions? To what extent did the students utilize their personal experiences and collective group understanding in making decisions related to the activity? How well did the students integrate knowledge from different disciplines in problem-solving strategies? How well did the students learn to negotiate constructive solutions to conflicts? Were the students able to demonstrate their understanding using means other than speaking and writing?	Propose landing sites that would provide information to help choose among the competing hypotheses. Compare your selections of landing sites with those chosen by real NASA scientists, as described in the January 2004 issue of *National Geographic*. Then complete Table 4 to indicate whether you agree or disagree with the 6 scientists who explained where they would land a Rover on Mars and why.

Throughout recorded human history, there has always been a thirst for knowledge and a spirit of adventure. One of the distinguishing features of our species is the intellect, the reasoning circuitry in our brains that makes observations and attempts to explain phenomena. Throughout the process of science we are continually designing and conducting new experiments, making new observations, and attempting to explain these observations in the form of existing, modified, or new models or theories. In some cases, textbooks become obsolete even before they are published. All of us, teachers and students, continue to learn throughout our lifetimes.

As is the case in all fields of science, in the experience of the planetary space program, as soon as some questions are resolved, new surprises with new questions always emerge out of the throngs of data aching for explanation. We see something interesting and try to explain it in the form of a hypothesis. To test the validity of the hypothesis, we devise and conduct new experiments. If a positive result is produced by the experiment, the hypothesis is reinforced, although not proved. If the experiment produces a negative result, the hypothesis may be revised or scrapped, with any new hypothesis being likewise subjected to testing.

Why are we exploring space? There are the obvious simple answers to this question such as "to see what is there." There are also deeper yearnings of curiosity tucked away in the crevices of our psyche. "Are we alone?" "Did life once exist elsewhere sometime in the past?" "Is the human race destined for the stars as it embarks upon a colonization of other worlds that is likely to first include the Moon and Mars?" Should we follow the advice of Dr Carl Sagan, the famous American scientist and champion of space exploration until his death, and aggressively start preparing for colonizing the Moon, Mars, and other planets?

Why do we send space probes to Mars? First let us answer "why do we send space probes to Earth in the form of orbiting satellites?" We image storm systems such as hurricanes and weather trends that allow us to predict and alert people to danger. Satellite images of our planet also help us analyze long-term trends such as deforestation, changing shorelines, and effects of erupting volcanoes and monitor levels of gases such as ozone. These capabilities did not exist just decades ago. We are exploring our planet not only to ensure our safety, both short-term and long-term, but also to learn more about our planet. And we, the educators, should take advantage of this and turn those events and images into teachable moments that help our students to better understand the solar system and the universe, and in turn the world in which we and our students live.

Web Links

Jet Propulsion Laboratory (http://www.jpl.nasa.gov/releases/2004/90.cfm) Discusses Mars rover finding that some of the surface rocks on Mars may have formed in the presence of flowing water.

Mars Global Surveyor (http://mars.jpl.nasa.gov/mgs/index.html) From NASA/JPL.

Malin Space Science Systems: Exploration Through Imaging (http://www.msss.com/) MSSS operates and processes data from instruments on planetary missions under contract to the National Aeronautics and Space Administration (NASA).

Science@NASA Stories About Mars

Unearthing Clues to Martian Fossils (http://science.nasa.gov/science-news/science-at-nasa/1999/ast11jun99_1/) The hunt for signs of ancient life on Mars is leading scientists to an other-worldly lake on Earth.

The Red Planet in 3D (http://science.nasa.gov/science-news/science-at-nasa/1999/ast27may99_2/) New data from Mars Global Surveyor reveal the topography of Mars better than many continental regions on Earth.

Search for Life on Mars will Start in Siberia (http://science.nasa.gov/science-news/science-at-nasa/1999/ast27may99_1/) NASA funds permafrost study to support astrobiology research.

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References

Adams, G., Cherif, A., & Johnson, W. (2001). Revisiting the Moon: An interdisciplinary learning activity. *The Spectrum Journal, 28*(1), 34-43.

American Association for the Advancement of Science (AAAS). (1990). *Science for all Americans*. Retrieved from http://www.project2061.org/publications/sfaa/online/chap1.htm .

Berry, C. R. (2009). Four misconceptions about science. *Out of Door*, *49*(9), 1-3.

Bowler, P. J. (1992). *The history of the environmental science*. New York: W. W. Norton.

Cherif, A. (1998). Science, scientists, and society: Ensuring integrality in scientific endeavors through human factor development. *Review of Human Factor Studies*, *4*(2), 1-31.

Cherif, A., Adams, G., & Loehr, J. (2001). What on "Earth" is evolution? The geological perspective of teaching evolutionary biology effectively. The *American Biology Teacher*, *63*(8), 569-591.

Chew, M. K., & Laubichler, M. D. (2003). Perceptions of science: Natural enemies--Metaphor or misconception? *Science*, *301*(5629), 52-53. doi: 10.1126/science.1085274

Futuyma, D. J. (1983). *Science on trial: The case for evolution*. New York: Pantheon.

Kaplan, R. (2001). *Science says: A collection of quotations on the history, meaning, and practice of science*. New York: Stonesong Press.

Kaskel, A., Hummer, L., & Daniel, P. (1995). *Biology: An everyday experience*. New York: Glencoe/McGraw-Hill.

Kieffer, G. H. (1985). *Towards a biological awareness*. Champaign, IL: Stipes.

Lord, M. (2009, July). Tech watch: How to land on Mars. *Popular Mechanics*, p. 15.

McCormack, A. J., & Yager, R. E. (1989). Toward a taxonomy for science education. *B.C. Catalyst*, *33*(1), 16-17.

Miller, K. B. (2005, September 22). Countering public misconceptions about the nature of evolutionary science. *Georgia Journal of Science*. Retrieved from http://www.accessmylibrary.com/article-1G1-138728333/countering-public-misconceptions-nature.html .

Moore, J. A. (1993). *Science as a way of knowing: The foundation of modern biology*. Cambridge, MA: Harvard University Press.

Morton, O. (2004, January). Mars revisited: Planet ice. *National Geographic*, 2-31.

National Academy of Sciences. (1998). *Teaching about evolution and the nature of science*. Washington, DC: National Academy Press.

National Academy of Sciences. (2008). *Science, evolution, & creationism*. Washington, DC: National Academy Press.

Noordung, H. (1995). *The problem of space travel: The rocket motor* [The NASA History Series, NASA SP-4026]. Washington, DC: National Aeronautics and Space Administration.

Phoenix Mars Mission. (n.d.). Retrieved from http://phoenix-web.jpl.nasa.gov/index.php .

Shuttleworth, M. (2009). *Science misconceptions*. Retrieved from http://www.experiment-resources.com/science-misconceptions.html .

Trefil, J. (2003). *The nature of science*. Boston: Houghton Mifflin Harcourt.

Trefil, J. (2007). *Why science*. New York: Columbia University, Teachers College Press.

Vergano, D. (2004, March 24). Traces of long-lost "salty sea" found on Mars. *USA Today*, pp. A-1 & D-1.

Very fresh martian ice craters [News notes]. (2009, July). *Sky & Telescope*, p. 16.