# MARS GLOBE
## EDUCATOR GUIDE

NATIONAL GEOGRAPHIC

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Help students research and explore twenty-two features on the surface of the red planet with the *Mars Globe*.

## Contents

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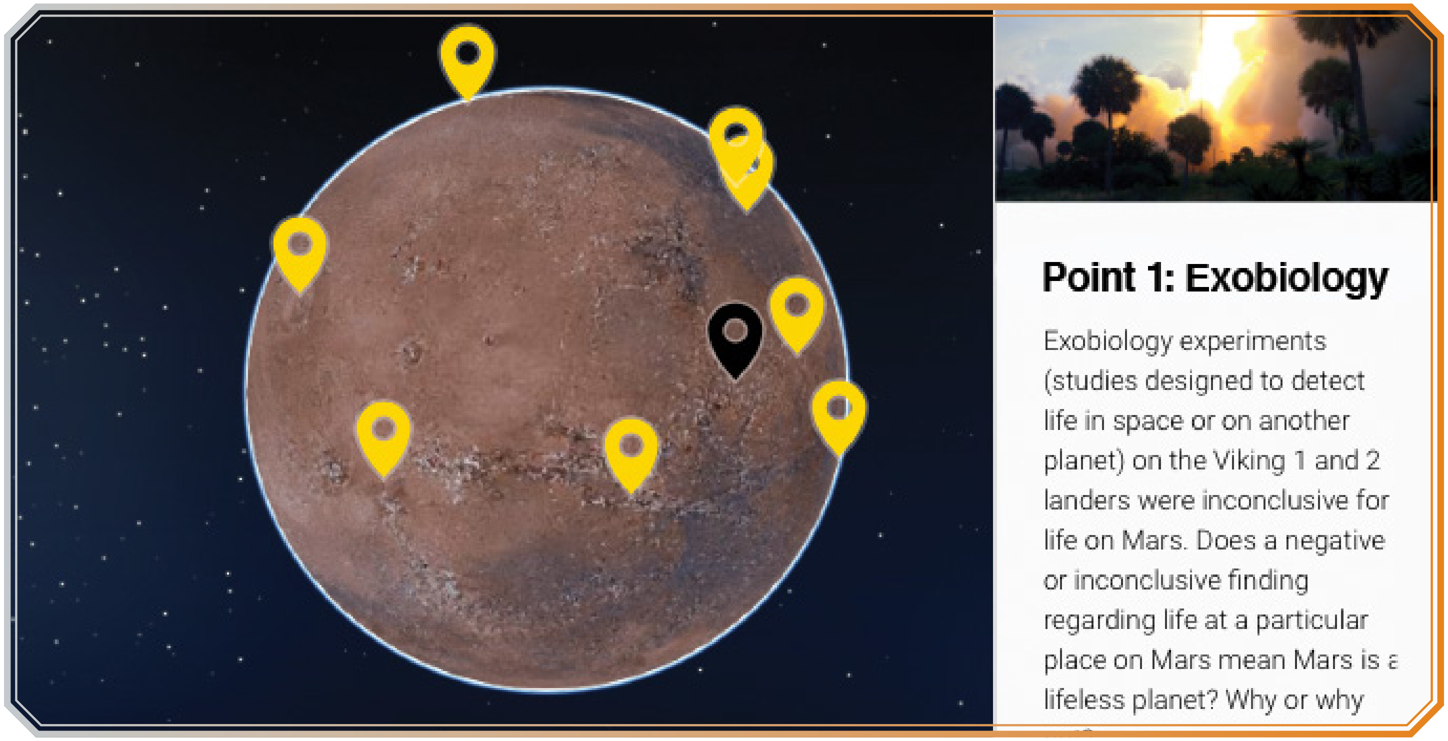


Each point on the *Mars Globe* contains a NASA image, the instruction question, and resources for students to begin research. The points link to the *Mars Globe* Points and Resources handout.

## Overview

The *Mars Globe* is an online, interactive globe of the planet Mars. Students can click, zoom, and spin to explore the planet. Each point on the globe offers a question or questions related to the geology or exobiology of Mars pertaining to that location. To find the answers, students can explore the concepts behind the questions in materials provided. They can also draw from reasoning and evidence from their own research. These questions offer a glimpse into some of the topics that currently interest Mars scientists. Mars mysteries abound, but some answers may lie in unraveling its past. Was Mars ever truly Earth-like?

# Rationale

Using an interactive globe to investigate Mars both engages students and gives them some perspective. So much of our neighboring planet remains unexplored. Revisiting places from which scientists have already gathered information gives students the opportunity to add their observations and questions to the growing body of knowledge. It also makes clear that any current ideas about Mars are subject to change as new data becomes available. This approach is key to effective science education. It helps students see firsthand that our scientific understanding of our world and other worlds develops over time as new information and insights are gained. New information about both Mars and Earth challenges our ideas about what life is and informs our understanding of the complex geologic processes on both planets.

The instructional questions included in the *Mars Globe* are designed to engage students in arguments based on evidence. Engaging students in this way introduces them to how science works in the real world. Scientists construct explanations for natural phenomena based on their own research and the research and theories of others. Whether creating models or making sense of new information, creating arguments based on reasoning and evidence helps scientists challenge their own thinking. It also helps the scientific community arrive at the best possible explanations and ideas. Similarly, asking students to form arguments based on evidence leads them to look more closely at competing scientific arguments, think more deeply about the evidence they find, and critically evaluate information. Mars is a particularly appealing gateway to students constructing this kind of argument. Both NASA and Space X are currently building programs designed to send humans to Mars. Rovers and satellites on or above Mars send new data all the time. Since new information about the planet keeps coming in, many of the questions students are asked to investigate are still up for debate in the scientific community.

**Grade level**
**9-12**

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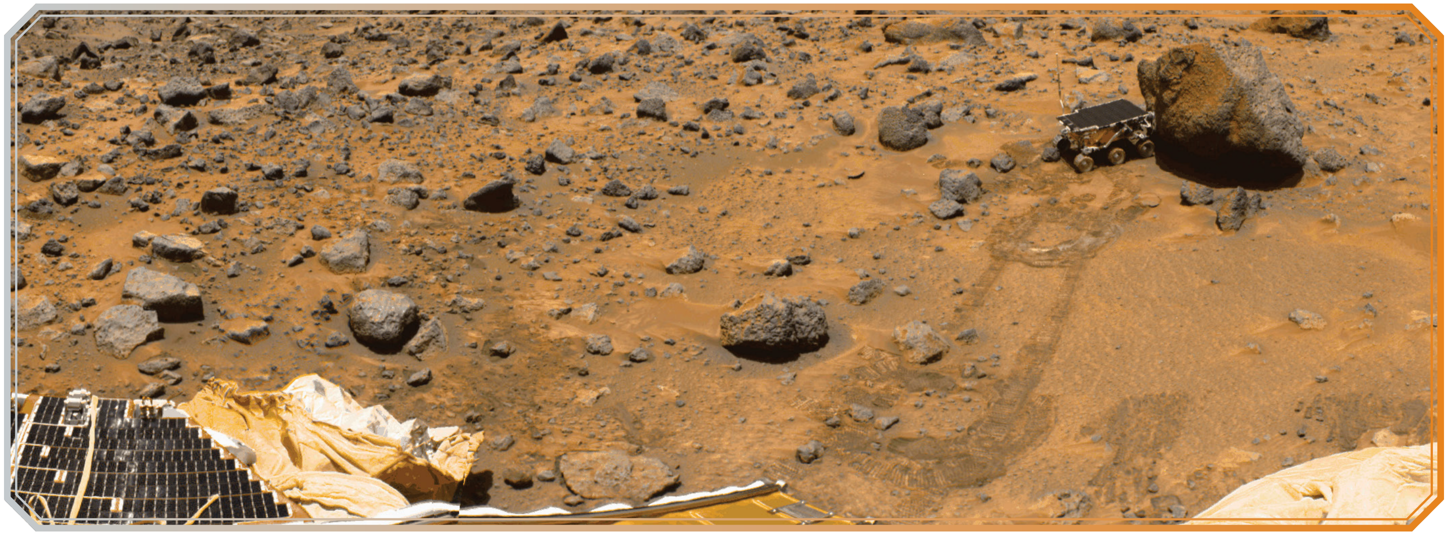

Mars rover Sojourner examines a boulder-strewn section of the martian landscape during the 1997 Pathfinder mission. Photograph courtesy of NASA.

# Instructional Questions

Below you will find the instructional questions and the resources included in each point on the *Mars Globe*. You will also find examples of possible claims students may include in their answers, as well as brief additional information for the educator. The examples provided in the "possible claims" sections are only a few of the explanations students may present. Students may submit other legitimate explanations with sources that support their reasoning.

## Point 1: Exobiology

Exobiology experiments (studies designed to detect life in space or on another planet) on the Viking 1 and 2 landers were inconclusive for life on Mars. Does a negative or inconclusive finding regarding life at a particular place on Mars mean Mars is a lifeless planet? Why or why not?

### Point Coordinates

22.269° N, 312.049° E

### Resources

***Exobiology: It's Life…isn't it?*** (article) http://www.nature.com/nature/journal/v430/n6997/full/430288a.html

**Astrobiology at NASA *Viking Project*** (webpage) https://astrobiology.nasa.gov/missions/viking-1-and-2/

## Possible Claims

- A spacecraft might not have the right/best instruments to detect life.
- Life outside Earth's atmosphere might be different enough to escape detection.
- Life might exist infrequently, at levels too low for detection, or be present elsewhere but not at the location of testing.

## For the Educator

The Viking program sent probes to Mars before the discovery of extremophiles on Earth, so researcher expectations of where and how life could exist then were more limited than they are today. Also, imagine sending a probe to a random location on Earth to detect life. A probe landing in a harsh environment, such as the Sahara Desert or an ice sheet, would have a more difficult time finding life than one landing in the Amazon rain forest. Many scientists think that while the surface environment of Mars is hostile to life, simple single-celled extremophiles could be present underground.

## Point 2: Water Ice Frost

The Viking 2 lander detected water ice frost on Mars. What does the presence of water ice frost tell scientists about the presence of water in the atmosphere of Mars today or in the past?

## Point Coordinates

47.668° N, 134.280° E

## Resources

***Frost at Utopia Planitia on Mars*** (image) http://nssdc.gsfc.nasa.gov/imgcat/html/object_page/vl2_p21873.html

**The Viking 1 and 2 Missions Page from NASA** (webpage) http://mars.nasa.gov/programmissions/missions/past/viking/

**National Geographic Society Encyclopedia Entry – *Frost*** (article) http://nationalgeographic.org/encyclopedia/frost/

***NASA Mars Rover Finds Mineral Vein Deposited By Water*** (article) http://mars.nasa.gov/mer/newsroom/pressreleases/20111207a.html

## Possible Claims

- Water must be present in the atmosphere for water ice frost to form.
- There is evidence of abundant surface water in the past, so the little water in the atmosphere today must mean the rest went somewhere else, such as underground or lost to space.

## For the Educator

On Earth, frost is frozen water vapor that forms when an outside surface cools past the dew point. Its presence on Mars suggests that similar processes exist there as well and indicate that there is water present in the planet's thin atmosphere. In addition to other evidence, this leads scientists to conclude that Mars had more surface water in its past.

## Point 3: Flood Channel

The Mars Pathfinder spacecraft landed in part of a suggested flood channel known as Ares Vallis. How do the large rocks found at the landing site support the interpretation that Ares Vallis was carved by a flood rather than gently flowing water?

## Point Coordinates

19.095° N, 326.747° E

## Resources

***Mars Pathfinder*** (website) http://mars.nasa.gov/MPF/

***Mars Pathfinder Science Results*** (article) http://mars.nasa.gov/MPF/science/geology.html

***Mars Pathfinder Landing Site*** (article) http://nssdc.gsfc.nasa.gov/planetary/marsland.html

## Possible Claims

- The size of rocky particles (rocks, sand, or silt) that can be carried by water depends on how fast the water is moving.

- Videos and images of floods on Earth show large debris being carried by rushing water; gently moving water can carry large debris that floats, but not debris that sinks, such as rocks.

- Pebbles much smaller than the rocks at Pathfinder's landing site can be seen staying stationary at the bottom of clear rivers and streams, not being carried along by the gently moving water.

## For the Educator

This is a great question relating to how rivers carry and deposit sediment. Two factors that influence how and when rivers deposit sediment are the rivers' volume and velocity.

## Point 4: Extremophiles

The Mars Exploration rover Spirit found evidence of hot springs on Mars. What role do hot springs play in supporting extremophiles, microbes adapted to survive in harsh environments, on Earth?

## Point Coordinates

14.6° S, 175.5° E

## Resources

***Mars Rover Investigates Signs of Steamy Martian Past*** (article) http://mars.nasa.gov/mer/newsroom/pressreleases/20071210a.html

***Spirit and Opportunity Highlights*** (webpage) http://mars.nasa.gov/mer/home/

***National Geographic Society Encyclopedia Entry – Ocean Vents*** (article) http://nationalgeographic.org/encyclopedia/ocean-vent/

***Life in Extreme Heat*** (article) https://www.nps.gov/yell/learn/nature/otherlifeforms.htm

***Microbial Life in Extremely Hot Environments*** (website) http://serc.carleton.edu/microbelife/extreme/extremeheat/index.html

***What is a Hydrothermal Vent?*** (article) http://oceanservice.noaa.gov/facts/vents.html

## Possible Claims

- Life as we know it needs both water and energy, and hot springs provide both.

- Examples of hot spring environments on Earth include places like the Grand Prismatic Spring in Yellowstone National Park and hydrothermal vents under the ocean.

- Hot springs on the ocean floor (called hydrothermal vents) can support entire ecosystems without energy from the Sun.

## For the Educator

Microorganisms living in hot spring environments are called thermophiles. Learn more about these organisms from the resources above.

# Point 5: Martian Equator

The Mars rovers Spirit and Opportunity landed near the Martian equator. Why do you think a landing site near the equator would be important for large, solar-powered machinery intended to operate for many months on the surface of the planet?

## Point Coordinates

1.9462° S, 354.4734° E

## Resources

***Technologies of Broad Benefit: Power*** (article) http://mars.nasa.gov/mer/technology/bb_power.html

***Spirit and Opportunity Highlights*** (webpage) http://mars.nasa.gov/mer/home/

## Possible Claims

- Mars and Earth have similar tilts, and the equator receives more concentrated sunlight on average than the mid-latitudes or the poles.

- The equator receives more concentrated sunlight year round.

## For the Educator

This topic can tie into studies of seasons and how different latitudes on Planet Earth receive different average amounts of the Sun's energy.

## Point 6: Martian Dust

Dust accumulating on solar panels was expected to limit the Mars Exploration Rover Mission to less than a year, but both rovers operated years longer. In fact, Opportunity is still active as of fall 2016. What role do you think Martian winds played in keeping solar-powered Spirit and Opportunity active longer than expected?

## Point Coordinates

53.6° N, 147.9° E

## Resources

***Opportunity: The Amazing Self-Cleaning Mars Rover*** (article) http://www.space.com/25577-mars-rover-opportunity-solar-panels-clean.html

***Spirit and Opportunity Highlights*** (webpage) http://mars.nasa.gov/mer/home/

## Possible Claims

- Wind can carry dust onto a rover, or carry it away from a rover.

- The amount of power available to the rover varies, depending on the amount of dust on the solar panels and day length.

- Images taken of Opportunity show its solar panels looked significantly cleaner after a wind event.

## For the Educator

Mars is well-known for its massive dust storms. In reality, these planet-wide dust storms happen only about every three Martian years, though there are large continent-size dust storms more frequently. The top wind speeds recorded on Mars are about 60 miles per hour (96.5 kilometers per hour), which is less than half the speed of some hurricanes on Earth, and not strong enough to damage most heavy equipment. Martian winds are both a blessing and a curse for the rovers exploring the red planet. The winds can either deposit dust onto the solar panels of the machine or blow it off and this process affects the power supply. Less dust allows the panels to more efficiently gather sunlight for power and has kept the spacecraft operational.

## Point 7: Water Detection

In 2008, the Phoenix Mars lander provided the first direct detection of water ice on Mars. Why is the direct detection of water ice important to astronomers?

### Point Coordinates

68.22° N, 234.25° E

### Resources

***NASA Phoenix Mars Lander Confirms Frozen Water*** (article) http://www.nasa.gov/mission_pages/phoenix/news/phoenix-20080620.html

### Possible Claims

- Indirect evidence involves more interpretation than direct evidence.
- Direct detection of water ice is proof that water exists on Mars.
- Phoenix verified that previous inferences about water on Mars were likely correct.

### For the Educator

In 2008, the Phoenix Mars Lander scraped away a layer of Martian soil revealing a bright white substance scientists hoped was water ice (rather than dry ice). The rover photographed the segment over the course of four days and the ice noticeably sublimated. While the Phoenix Mars Lander provided the first direct evidence of water ice, there had been previous indirect indicators of water. Mariner 9 and the Viking landers provided the first indirect evidence of water - geologic features typically associated with water on Earth. Subsequent Mars missions provided additional indirect evidence.

## Point 8: Link Outcrop

Rounded pebbles in what appears to be an ancient stream were documented near the Curiosity rover site. What does the presence of rounded pebbles suggest about the flow of water in the streambed?

### Point Coordinates

4.59° S,137.44° E

### Resources

***Pebbly Rocks Testify to Old Streambed on Mars*** (article) https://www.nasa.gov/mission_pages/msl/news/msl20130530f.html#.V_eQYZMrI_U

***Rock Outcrops on Mars and Earth*** (image) http://www.nasa.gov/mission_pages/msl/multimedia/pia16189.html

***Curiosity's Landing Site: Gale Crater*** (webpage) http://mars.nasa.gov/msl/mission/timeline/prelaunch/landingsiteselection/aboutgalecrater/

## Possible Claims

- Rounded pebbles can form in rivers and streams on Earth when flowing water knocks rocks together, blunting their edges. Rounding pebbles takes time, so the similar-shaped pebbles on Mars would not form in a short-lived flood, but more likely in a river, stream, or through similar processes.

- To polish pebbles in a rock tumbler, the rocks must hit each other over and over again knocking off rough edges and smoothing the surface.

## For the Educator

On Earth, rounded stones are present in streams and rivers as well as in the geologic record that tells us where streams and rivers used to exist on Earth. We interpret features that preserve Earth's history based on the assumption that those processes behaved in the past as they do in the present. We make the same assumption about Mars. When interpreting the evidence collected, we draw conclusions based on what we know about how the mechanisms function on Earth.

## Point 9: Valles Marineris

How does the Martian canyon system Valles Marineris compare with Earth's Grand Canyon? How does Valles Marineris compare with the East African rift zone?

## Point Coordinates

10.55°N, 288.11°E

## Resources

***Valles Marineris*** (webpage) http://mars.jpl.nasa.gov/gallery/atlas/valles-marineris.html

**Grand Canyon: *Geographic Formations*** (article) https://www.nps.gov/grca/learn/nature/geologicformations.htm

***The Grand Canyon: How It Formed*** (video) http://unctv.pbslearningmedia.org/resource/ess05.sci.ess.earthsys.canyon/the-grand-canyon-how-it-formed/

***East African Rift System*** (article) https://www.britannica.com/place/East-African-Rift-System

**National Geographic Society Encyclopedia Entry – *Rift Valley*** (article) http://nationalgeographic.org/encyclopedia/rift-valley/

## Possible Claims

- The Grand Canyon is much smaller than Valles Marineris.

- The Grand Canyon was carved by tectonic uplift and erosion caused by the Colorado River. In contrast, scientists think Valles Marineris formed as a result of a tectonic rift. On Earth, a rift valley is a lowland region that forms when Earth's tectonic plates move apart.

- The East African Rift is a tectonic rift closer in size to Valles Marineris than the Grand Canyon.

## For the Educator

Many Mars researchers think that Valles Marineris formed as a tectonic rift, a giant crack in the crust of Mars. Unlike the East African Rift, this Mars rift would have formed not because of plate tectonics, but likely because of the Tharsis Bulge. See more at http://www.space.com/20446-valles-marineris.html. Also note that tectonics means movement in the crust of a planet. Plate tectonics, seen on Earth, is a special type of tectonics.

## Point 10: Martian North Pole

Layers of ice cover the Martian North Pole. How can layers in ice help us understand changes in climate on Mars or Earth?

## Point Coordinates

84.4° N, 343.4° E

## Resources

***Blockfall on the North Polar Layered Deposits*** (image) http://www.jpl.nasa.gov/spaceimages/details.php?id=PIA18586

***North Polar Layers of Mars*** (image) http://www.nasa.gov/multimedia/imagegallery/image_feature_1731.html

***Paleoclimatology – The Ice Core Record*** (article) http://earthobservatory.nasa.gov/Features/Paleoclimatology_IceCores/

## Possible Claims

- Polar ice on both Earth and Mars traps seasonal layers of dust.
- Layers of ice, dust, and other materials accumulate and tell scientists a story of past climates and environments.
- Both the thickness and the composition of icy layers tell researchers about the temperatures at the time the ice was deposited.

## For the Educator

Interpreting polar layered deposits on Mars and ice cores on Earth have similarities to interpreting tree rings.

***About Tree Rings*** (article)
http://ltrr.arizona.edu/about/treerings

## Point 11: Olympus Mons

Olympus Mons is a Martian volcano about the same width as the state of Arizona and approximately two-and-a-half times taller than Mount Everest. Why might Olympus Mons be so big compared to similar volcanoes on Earth, such as Mauna Kea on the “Big Island” of Hawaii?

## Point Coordinates

18.65°N, 226.2°E

## Resources

***Olympus Mons*** (webpage) http://mars.jpl.nasa.gov/gallery/atlas/olympus-mons.html

***Olympus Mons – The Caldera in Close – Up*** (webpage) http://m.esa.int/Our_Activities/Space_Science/Mars_Express/Olympus_Mons_-_the_caldera_in_close-up

## Possible Claims

- The crust on Earth moves relative to a hot spot below, but the crust of Mars is stationary, allowing for one large volcano to form over a hot spot.
- Olympus Mons is estimated to be older than the Hawaiian islands.
- Gravity on Mars is lower than it is on Earth.

## For the Educator

The Hawaiian Islands are part of a chain of islands and seamounts formed by volcanoes when the Pacific plate moved over the Hawaiian hot spot. See more at http://geology.com/usgs/hawaiian-hot-spot/. Olympus Mons and the Hawaiian volcanoes are examples of shield volcanoes built from basaltic rock, the same type of rock as the oceanic crust. The oldest volcanoes produced by the Hawaiian hot spot are approximately 70 million years old, and all of the Hawaiian Islands are less than 10 million years old. In contrast, Olympus Mons is billions of years old. Sometimes the extreme height of Olympus Mons is attributed to greater stability for such a large amount of volcanic rock because of the lower gravity of Mars. This is not the primary reason for the difference between Olympus Mons and the Hawaiian volcanoes, but one that students may bring up based on their research.

# Point 12: Polar Ice Cap

Both Mars and Earth have permanent polar ice caps. How does the northern polar ice cap of Mars compare with the polar ice caps of Earth?

## Point Coordinates

84.9°N, 359.1°E

## Resources

***Polar Regions*** (article) http://phoenix.lpl.arizona.edu/mars121.php

***Strange Martian Spirals Explained*** (article) http://science.nasa.gov/science-news/science-at-nasa/2010/16jun_martianspirals/

***NASA Orbiter Penetrates Mysteries of Martian Ice Cap*** (article) http://mars.jpl.nasa.gov/mro/news/index.cfm?FuseAction=ShowNews&NewsID=1001

***All About Sea Ice*** (webpage) http://nsidc.org/cryosphere/seaice/index.html

***Quick Facts on Ice Sheets*** (webpage) https://nsidc.org/cryosphere/quickfacts/icesheets.html

## Possible Claims

- Both polar caps are made of water ice.
- The northern polar cap of Earth covers both land and sea. The Mars cap covers only land.
- The northern polar cap of Mars has deep canyons in a spiral pattern.

## For the Educator

Earth's ice caps are a combination of ice sheets and sea ice. The ice sheets form over thousands of years in areas where winter snowfall does not melt entirely over the summer and accumulates. These large bodies of ice are not stationary, but flow downhill due to their own weight. Sea ice is frozen ocean water found in polar oceans. It forms slowly as salt water sinks as it becomes cooler rather than floats like fresh water (glaciers, icebergs, and lake ice). As a result, the ocean must cool to 28.8°F (-1.8°C) down 300 to 450 feet (100 to 150 m) for the sea ice to form.

## Point 13: South Pole

Unlike the northern polar ice cap, Mars' southern polar ice cap is covered by dry ice (frozen carbon dioxide) year-round. What possible explanations might there be for why the southern polar ice cap stays cold enough for carbon dioxide ice through the summer?

## Point Coordinates

83.9°S, 160.0°E

## Resources

***NASA Radar Finds Ice Age Record in Mars' Polar Cap*** (article) http://www.jpl.nasa.gov/news/news.php?feature=6519

***Mars Polar Lander Science Goals*** (article) https://mars.jpl.nasa.gov/msp98/lander/science.html

***Impacts of a Warming Arctic*** (webpage) http://climate.nasa.gov/resources/education/pbs_modules/lesson2Engage/

***Thermodynamics: Albedo*** (webpage) https://nsidc.org/cryosphere/seaice/processes/albedo.html

## Possible Claims

- The southern polar cap of Mars is brighter, reflecting more light, than the northern polar cap. This makes it colder, so dry ice stays around all year.
- Geographical features (e.g., volcanoes, craters, or plains) can affect weather patterns and may prevent dust from settling on the southern polar cap.
- Unlike Earth, Mars has an orbit that is not close to a perfect circle. Mars is farther away from the Sun in the southern hemisphere winter, making the southern winter colder than northern winter.

## For the Educator

On both worlds, seasons are caused by the tilt of the planet relative to the sun, which results in differing hours of daylight and the concentration of sunlight, and not distance from the sun. However, the orbit of Mars is a more pronounced ellipse that-in comparison to Earth's orbit-changes its distance from the Sun significantly enough to impact the severity of the seasons. More information on seasons and the Mars orbit can be found at http://www.planetary.org/explore/space-topics/mars/mars-calendar.html.

## Point 14: Hellas

The Hellas impact basin is a giant impact crater on the surface of Mars. What does the presence of ancient impact basins like Hellas suggest about how much Mars has been resurfaced by geologic processes?

## Point Coordinates

42.4°S, 70.5°E

## Resources

***Lunar Orbiter: Impact Basin Geology*** (article) http://www.lpi.usra.edu/lunar/missions/orbiter/lunar_orbiter/impact_basin/

***The Moon's Major Impact Basins*** (image) http://www.planetary.org/multimedia/space-images/earth/lunar-impact-basins.html

***Hellas*** (article) https://www.britannica.com/place/Hellas-impact-basin-Mars

## Possible Claims

- Erosion erases features from the surface of Earth over time.

- Plate tectonics creates new crust, destroys old crust, and builds mountain ranges and volcanoes that destroy or bury old features on Earth.

- A deep basin like a crater would likely be filled in with sediment on Earth due to the movement of sediment by wind and water.

## For the Educator

The Hellas impact basin is a giant impact (2,300 km or 1,400 mi) crater on the surface of Mars. Ancient impact basins like Hellas are also seen on the Moon, but are not as apparent Earth, because they have been erased or obscured by erosion, tectonics, or volcanism.

## Point 15: Impact Craters

What similarities and differences do you see between the ancient, heavily cratered highlands on Mars and the surface of the Moon?

### Point Coordinates

3.7 °N, 53.4°E

### Resources

***Impact Features*** (image) http://www.lpi.usra.edu/publications/slidesets/redplanet2/slide_17.html

***Why is the Moon so Scarred with Craters?*** (webpage) http://spaceplace.nasa.gov/craters/en/

***Impact Cratering*** (article) http://www.lpi.usra.edu/education/explore/shaping_the_planets/impact_cratering.shtml

### Possible Claims

- The highlands of Mars and the surface of the Moon have many visible impact craters, with craters on top of other craters.

- The craters on Mars are eroded compared with the craters on the Moon. They are flatter and shallower (partially filled in with sediment) when compared with craters on the Moon, and the crater rims appear to be eroded.

- Evidence of water erosion, such as river-like features, can be seen in highlands on Mars, but not on the Moon.

### For the Educator

Erosion and sediment transport can result from both wind and water on Mars. Both forces are absent on the Moon.

## Point 16: Ejecta Blanket

An "ejecta blanket" is material forced outside of an impact crater that extends from the rim of the depression. What about the shape of this "ejecta blanket" might indicate that ice or liquid water was present when it formed?

### Point Coordinates

41.521°N, 4.9399°E

### Resources

***Rampart Crater*** (image) http://www.jpl.nasa.gov/spaceimages/details.php?id=PIA20261

***Themis: Concentric Rims*** (image) http://redplanet.asu.edu/?p=17014

**National Geographic Society Encyclopedia Entry –** ***Crater*** (article) http://nationalgeographic.org/encyclopedia/crater/

## Possible Claims

- Rampart craters have ejecta blankets with a "mud splash" appearance, often referred to as "fluidized ejecta."

- Impact events release a lot of energy that could heat the ground and melt ice. The water could then flow until it re-froze.

- The raised edge and curved shapes of rampart craters look different from the ejecta of regular impact craters seen on Mars or the Moon.

## For the Educator

Impact craters with "rampart" ejecta blankets are used as evidence for water ice below the surface of Mars. The ejecta blankets surrounding craters on Mars look similar to the ejecta blankets surrounding some impact craters on icy bodies, such as Jupiter's large moons Ganymede and Europa.

## Point 17: Martian Gullies

Gullies on the sides of canyons and craters are some of the youngest features seen on Mars. What does the evidence suggest for some of the possible ways Mars gullies might have been formed? Do you think all gullies on Mars are formed by one process, or could multiple mechanisms be responsible for these features?

## Point Coordinates

35.156°S, 324.676° E

## Resources

***Light-Toned Gully Materials on Hale Crater Wall*** (image) http://www.uahirise.org/PSP_002932_1445

***Adding Composition Data About Mars Gullies*** (image) http://www.nasa.gov/image-feature/jpl/pia20763/adding-composition-data-about-mars-gullies

***Will the Real Culprit Behind Mars' Gullies Please Stand Up?*** (article) http://www.astronomy.com/news/2016/08/will-the-real-culprit-behind-mars-gullies-please-stand-up

***How do Gullies Form on Mars?*** (article) https://eos.org/research-spotlights/how-do-gullies-form-on-mars

***Mars Gullies Likely Not Formed by Liquid Water*** (article) http://www.jpl.nasa.gov/news/news.php?feature=6580

## Possible Claims

- Some Mars gullies show no evidence of salts, hydrated minerals, or clay minerals, all of which are usually associated with liquid water.

- Carbon dioxide ice (dry ice) frost can accumulate in the areas where gullies form, and when it sublimates it creates a gas-lubricated debris flow.

## For the Educator

How and why Mars gullies form is an area of active research, and likely has more than one formation mechanism.

## Point 18: Dust Storm

Continent-size and even planet-size dust storms are common on Mars. Why might dust storms on Mars be so much larger than dust storms on our own world?

### Point Coordinates

5.35°S, 357.69°E

### Resources

***The Fact and Fiction of Martian Dust Storms*** (article) http://mars.nasa.gov/news/whatsnew/index.cfm?FuseAction=ShowNews&NewsID=1854

***Martian Dust Storm*** (image) http://www.nasa.gov/mission_pages/msl/multimedia/vasavada-4.html

***Scientists Track "Perfect Storm" on Mars*** (article) http://hubblesite.org/newscenter/archive/releases/2001/31/text/

***NASA Mars Orbiters Reveal Seasonal Dust Storm Pattern*** (article) http://www.jpl.nasa.gov/news/news.php?release=2016-146

**National Geographic Society Encyclopedia Entry – *Dust*** (article) http://nationalgeographic.org/encyclopedia/dust/

***Dust Storm Sweeps from Africa into Atlantic*** (image) http://visibleearth.nasa.gov/view.php?id=53872

***The Dust Bowl*** (film) http://www.pbs.org/kenburns/dustbowl/

### Possible Claims

- In the absence of water and vegetation on Mars, loose, dry soil is easily eroded by the wind and can travel large distances.
- Dust and sand storms are common in desert regions on Earth. All of Mars is a desert.
- Large, regional dust storms actually *are* seen on Earth, sometimes in times of drought, in agricultural areas, or where there is little vegetation.

### For the Educator

Comparison to the 1930s Dust Bowl in the Great Plains region of United States is one choice to support evidence for the third possible claim. Mars only has dust storms because the atmosphere is too thin to support sand storms.

### Resources

***Surviving the Dust Bowl, 1931-1939*** (timeline) http://www.pbs.org/wgbh/americanexperience/features/timeline/dustbowl/

## Point 19: Northern Plains

The vast lowland plains of northern Mars are smoother than the heavily cratered highlands of the south. What are some possible explanations for these differences in landscape?

### Point Coordinates

42.2°N, 330°E

### Resources

***Fractured Northern Plains, Mars*** (image) http://nssdc.gsfc.nasa.gov/imgcat/html/object_page/vo1_035a64.html

***Mars Geologic Map of the Northern Plains*** (map) http://astrogeology.usgs.gov/search/map/Mars/Geology/year-2000/Mars-Geologic-Map-of-the-Northern-Plains

***Vastitas Borealis*** (article) https://www.britannica.com/place/Vastitas-Borealis

### Possible Claims

- The northern plains could be the site of an ancient ocean on Mars.
- The northern plains of Mars could be volcanic lava plains.
- Extensive erosion and deposition could have occurred in the northern plains.

### For the Educator

The northern hemisphere of Mars is notably less cratered than the southern hemisphere. Surfaces in space (e.g., the surface of planets, moons, or other celestial bodies) with fewer craters are assumed to be younger because they have had less time to be hit by space debris (e.g., meteorites). The northern hemisphere is characterized by a large plain and has several large volcanoes. While the exact process that caused the plain to form is unknown, scientists are considering the presence of an ocean, volcanism, and erosion and deposition as possible mechanisms that created the younger surface.

## Point 20: Glacier

Some scientists suggest that a glacier exists below the Martian surface, where rock and soil insulate it from sunlight. Similar features, called rock glaciers, are present on Earth. Do you think this landform is actually a Martian glacier covered with rock and soil?

### Point Coordinates

42.2°N, 50.5°E

### Resources

***Found it! Ice on Mars*** (article) http://science.nasa.gov/science-news/science-at-nasa/2002/28may_marsice/

***Glacier?*** (image) http://www.uahirise.org/ESP_018857_2225

***Glacier Types: Rock*** (article) https://nsidc.org/cryosphere/glaciers/gallery/rock.html

## Possible Claims

- The feature appears to have a similar shape to rock glaciers on Earth and appears to flow down a slope.

- The landscape is marked with features interpreted as stream lines that indicate flow of ice down hill.

## For the Educator

Please examine the point image of the Martian feature or navigate to http://www.uahirise.org/ESP_018857_2225 to see a larger version. This image is seen from above. The rock glaciers on Earth are much warmer, so the ice would be softer and flow more easily, especially on a steep slope.

## Point 21: Tharsis Region

How might the giant volcanoes in the Tharsis region of Mars be related to the “Tharsis bulge” in the planet’s crust?

## Point Coordinates

10°S, 250°E

## Resources

***Tharsis*** (image) http://photojournal.jpl.nasa.gov/catalog/PIA00408

***Olympus Mons*** (webpage) http://mars.jpl.nasa.gov/gallery/atlas/olympus-mons.html

***Tharsis*** (article) https://www.britannica.com/place/Tharsis

## Possible Claims

- Similar to Hawaii, the Tharsis region is thought to have a large mantle plume (hot spot) pushing up the surface and providing the source of heat for Olympus Mons and the three smaller shield volcanoes.

- Lava flows from the volcanoes of Tharsis built the Tharsis Montes, a volcanic construct, over billions of years.

## For the Educator

The former is an earlier idea. More recent models suggest that loading and flexing of the lithosphere is likely the primary reason for the bulge today, though the plume may have originally been the source of the bulge.

## Point 22: Avalanche

The HiRISE camera on the Mars Reconnaissance Orbiter has captured many avalanches in action. What might be possible causes for an avalanche on Mars?

## Point Coordinates

83.738°N, 235.776°E

## Resources

***Caught in Action: Avalanches on North Polar Scarps*** (image) http://www.uahirise.org/PSP_007338_2640

***Dynamic Mars*** (image) http://www.uahirise.org/ESP_042572_2640

***Frost Avalanche on Mars*** (article) http://www.nasa.gov/image-feature/frost-avalanche-on-mars

**National Geographic Society Encyclopedia Entry – *Avalanche*** (article) http://nationalgeographic.org/encyclopedia/avalanche/

## Possible Claims

- Avalanches on Mars could be caused by new ice and dust accumulation, similar to how new snow accumulation influences avalanches on Earth.
- Avalanches on Mars could be caused by ice (water or carbon dioxide) expanding as it becomes a gas (the process of sublimation), or melting in the case of water ice, resulting in a collapse of remaining material.
- Avalanches on Mars could be caused by a Marsquake.

## For the Educator

Though the precise reason for Martian avalanches is unknown, they all have natural causes, unlike Earth.

*The Mars Globe Points and Resource handout contains the questions and resources for each point on the Mars Globe Interactive.*

The Phoenix spacecraft hangs upside down in the Payload Handling Servicing Facility at NASA's Kennedy Space Center in Florida. Photograph by NASA/George Shelton.

# Activities

This section includes suggested classroom activities to support the use of the interactive *Mars Globe* in the classroom. The activities are divided into: approaches to using the instructional questions; activities using the instructional questions; activities to build background knowledge; and activities to apply knowledge to building human settlements on Mars.

## Approaches to Using the Instructional Questions

Below are some suggestions for ways to incorporate the *Mars Globe* into the classroom.

- Assign the questions as homework. Use class time to discuss students' findings or to extend the learning.
- Assign one or two points to pairs or groups of students. Have students research and craft their arguments then report their findings to the class.
- Since Mars is a high-interest topic, use the questions as a way to spark interest in topics related to space.

- Use the questions as a way to integrate language arts and science topics. Have students apply research skills, reading analysis, their knowledge of scientific principles to write answers that rely on evidence and reasoning.

## Activities Using the Instructional Questions

Below are suggestions for activities that can be done as students are responding to the questions or as a follow-up, building on students' responses.

- Have students use the claim + evidence + reasoning model (CER) to answer the given questions. In this model, students make a claim (what they know), provide evidence (how they know it) and tie these together with reasoning, using scientific principles to explain why the evidence supports their claim. More information about this model is available in the resources section.

- The Argument-Driven Inquiry (ADI) model is also well-suited to the *Mars Globe* investigative questions. Use the questions from the globe as guiding questions and have students collect data using the given links to resources. Then have students analyze the data to create a tentative argument based on evidence and reasoning to justify how the evidence fits their claim. Next, have students share and critique each other's arguments in small groups. Allow them time to refine their arguments based on these critiques, and then reflect as a class about the core ideas underlying the guiding question. Ask students to write their findings in a report and then peer-review the reports. Finally, have students revise their reports based on the peer review. More information about this model is available in the resources section.

- Once students have written their arguments, divide them into small groups made up of students who investigated the same question. Have students share their answers and take note of any areas of difference. Then have each student do additional research and come back together to try to convince each other of the validity of their claim using the additional evidence.

- Use the questions as a springboard to a lesson on key wording strategies and source evaluation. Give students a simple topic and have them generate a list of keywords related to the topic. Demonstrate how to narrow a topic down using multiple keywords. Then demonstrate how to quickly evaluate the search results page to identify, which resources are likely to contain the information you are looking for, rather than simply clicking on the first link returned. Next, have students evaluate one of the resources from the search results. They should look for who is responsible for the resource, what their credentials are, and any biases they may have; whether the site is .org, .gov, .com, or .edu; whether the site format is well-done, with a good graphic interface and no spelling errors; and what the purpose of the resource is, such as to persuade or inform. Have students apply these key wording and source evaluation strategies to find an additional resource to help answer one of the questions on the globe or additional Mars-related questions they generate.

- Have students select one of the questions and refine their answer into a formal written argument.

- Mars has been a popular topic in science fiction for decades. Have students read a fictional work featuring Mars. Then have them create a list of characterizations or information about the planet from the fictional work. Next, have them mark each characterization as fact or fiction, using evidence from their own research. Finally, have them focus on the year the book was originally published to determine whether the characterizations of Mars in the fictional account did or did not match common ideas about Mars in the scientific community at the time. Students can organize this information into a table. If students select different books to read, they can discuss the differences in scientific understanding about Mars and in how the planet is depicted in fiction over the years. Some books that would work well for this activity include: *A Princess of Mars* by Edgar Rice Burroughs (1912); *The Martian Chronicles* by Ray Bradbury (1950); *The Sands of Mars* by Arthur C. Clarke (1951); *Martian Time-Slip* by Philip K. Dick (1964); *Moving Mars* by Greg Bear (1993); and *The Martian* by Andy Weir (2011).

## Activities to Build Background Knowledge

Below are activities that can be used to introduce concepts found in the *Mars Globe* instructional questions.

- Have students investigate how rivers carry sediment and how deposition depends on the speed of the flow and the amount of water flowing. Have students demonstrate what they have learned using a stream table.

- Assign small groups of students an extreme environment (an environment in which humans could not live), and have them investigate life forms that live in those environments. Some examples of extreme environments include: black smokers/ hydrothermal vents in the ocean; geothermal pools in Yellowstone; the frozen Arctic ocean; barren salt flats; high-methane environments, such as swamps or a cow's intestines; and inside rocks under the surface of the Earth. Have students share what they found with the class, and discuss how studying these extremophiles could help scientists in their search for life on other planets.

- Have students review plate tectonics and create a model to explain how plate tectonics works.

- As an entry ticket into class, have students draw or write a brief explanation of why we have seasons on Earth. Check these for understanding and discuss any misconceptions.

- Have students research America's dust bowl of the 1930s and compare it to dust storms on Mars.

## Activities to Apply Knowledge to Building Human Settlements on Mars

Below are some suggestions for activities about visiting and building human settlements on Mars. These activities take advantage of this current and high-interest topic to give students an opportunity to apply what they have learned using the *Mars Globe*.

- Have students investigate the planned Mars habitation efforts. Then have them work in groups to develop an application for potential residents. What would be important for NASA to know about the candidates? What knowledge of Mars should the applicants have? What other topics should the settlers be knowledgeable about?

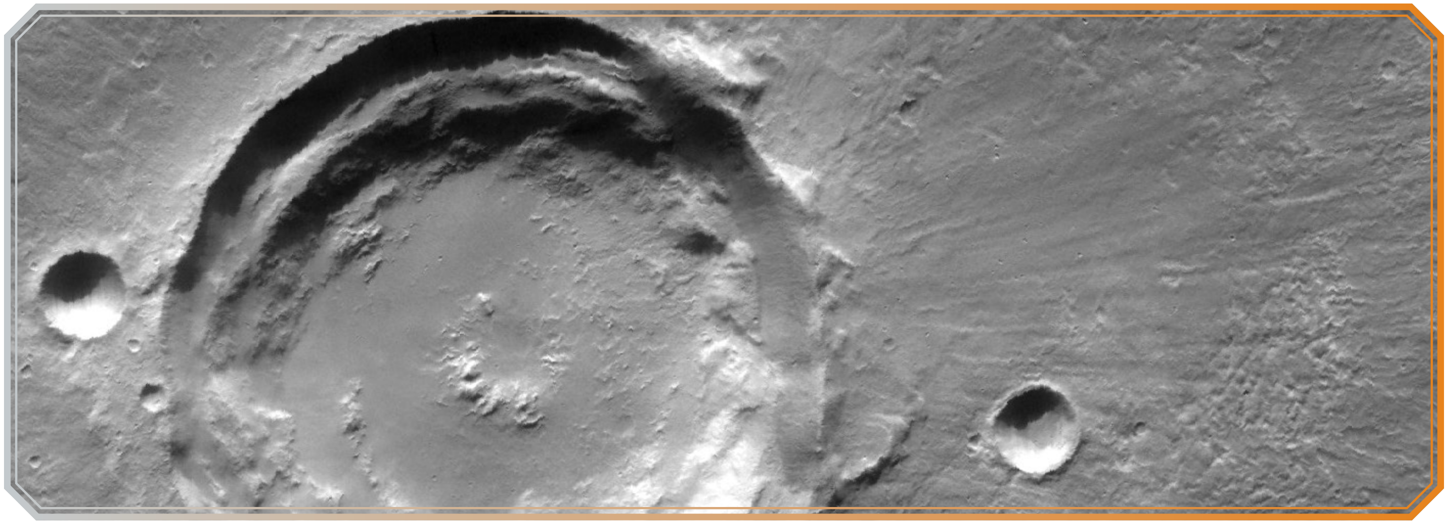
- Have students fill out one of the applications to become a Mars resident that was created by another group. Have groups gather all the completed applications and select which applicants they would like to have in their settlement. To keep it fair, you may want to have students use a pseudonym on their applications.

- Have students write an essay, similar to one they might write for college admissions, in which they explain how a life experience they have had will inform their contribution to the Mars community.

- Have students select a site for the first human settlement on Mars and defend their choice with evidence.

NATIONAL GEOGRAPHIC

# MARS GLOBE EDUCATOR GUIDE



This image shows an unnamed crater near Acheron Fossae that displays a central pit and concentric rims. Photograph by NASA/JPL-Caltech/ASU.

## Vocabulary

**Ares Vallis**
*- ancient flood plain on Mars investigated as part of the Mars Pathfinder mission.*

**black smoker**
*- type of ocean vent that ejects black mineral fluid (not smoke) into the surrounding water.*

**ejecta blanket**
*- material forced outside of an impact crater.*

**erosion**
*- act in which earth is worn away, often by water, wind, or ice.*

**exobiology**
*- branch of biology concerned with the search for life outside the earth and its atmosphere, and with the effects of extraterrestrial environments on living organisms.*

**gully**
*- small ditch or ravine usually formed by running water.*

**HiRISE camera**
*- (High Resolution Imaging Science Experiment) telescopic camera mounted on the Mars Reconnaissance Orbiter, which has photographed Mars' surface in unprecedented detail.*

**ice frost**
*- thin coat of water ice covering objects when the dew point is below freezing.*

**impact basin**
*- structures more than 300 kilometers in diameter created when a large object strikes the surface of the planet.*

**Mars Exploration Rover**
*- one of two robots (Spirit and Opportunity) sent by NASA to explore the surface and atmosphere of Mars.*

**Mars Pathfinder**
*- (1997) U.S. robotic spacecraft developed as part of a low-cost approach to planetary exploration and demonstrate the usefulness of a microrover on the surface of Mars.*

**Mars Reconnaissance Orbiter**
*- (2005) U.S. satellite that orbited Mars and studied tis geography and climate.*

**microorganism**
*- a very tiny living thing.*

**Olympus Mons**
*- largest known volcano in the solar system and the highest point on the planet Mars.*

**Opportunity**
*- (2004-ongoing) six-wheeled Mars rover equipped with cameras and a suite of scientific instruments to study the chemical and physical composition of the Martian surface.*

**Phoenix**
*- (2007) U.S. space probe developed to collect and analyze soil samples in the north polar region of Mars, in order to answer the questions of whether the Martian arctic can support life.*

**polar ice cap**
*- ice cap in a high-latitude region*

**rampart crater**
*- impact crater whose ejecta lobes are bordered with a low ridge, or rampart. The lobe-shaped ejecta suggests the presence of water under the surface.*

**Spirit**
*- (2004-2010) six-wheeled Mars rover equipped with cameras and a suite of scientific instruments to study the chemical and physical composition of the Martian surface.*

**sublimate**
*- to change state from a solid state to a gas state, without becoming liquid.*

**Tharsis Bulge**
*- plateau on Mars that contains three of the planet's most massive volcanoes.*

**thermophile**
*- organism capable of thriving at a high temperature (between 41°C and 122°C, or 106°F and 252°F). Most thermophiles are archaea and bacteria.*

**topography**
*- shape of the surface of an area.*

**Valles Marineris**
*- largest canyon in the solar system, found along the equator of Mars.*

**Viking landers**
*- two robotic U.S. spacecraft (Viking 1 and Viking 2) launched for the extended study of Mars.*

# National Standards

## Next Generation Science and Engineering Practices

Practice 7 Engaging in Argument from Evidence

## Common Core State Standards

**CCSS.ELA-Literacy.RST.9-10.1**
Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.

**CCSS.ELA-Literacy.RST.11-12.1**
Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.

# For Further Exploration

- NASA's Mars Exploration Program: http://mars.jpl.nasa.gov/gallery/atlas/
- NASA's Mars Trek Interactive: http://marstrek.jpl.nasa.gov
- NASA's JMars: https://jmars.asu.edu
- Google Mars Map: https://www.google.com/mars/
- Curiosity Rover Landing Sites: http://mars.nasa.gov/msl/mission/timeline/prelaunch/landingsiteselection/
- Mars Lander Coordinates: http://ode.rsl.wustl.edu/mars/pagehelp/quickstartguide/index.html?landing_sites.htm
- Mars Education: https://marsed.asu.edu
- NASA's Mars Exploration: http://mars.jpl.nasa.gov
- Claim, Evidence & Reasoning (CER): http://www.activatelearning.com/claim-evidence-reasoning/
- Argument-Driven Inquiry: http://www.argumentdriveninquiry.com/adi-overview.html (click the link to the one-page overview in PDF format)

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