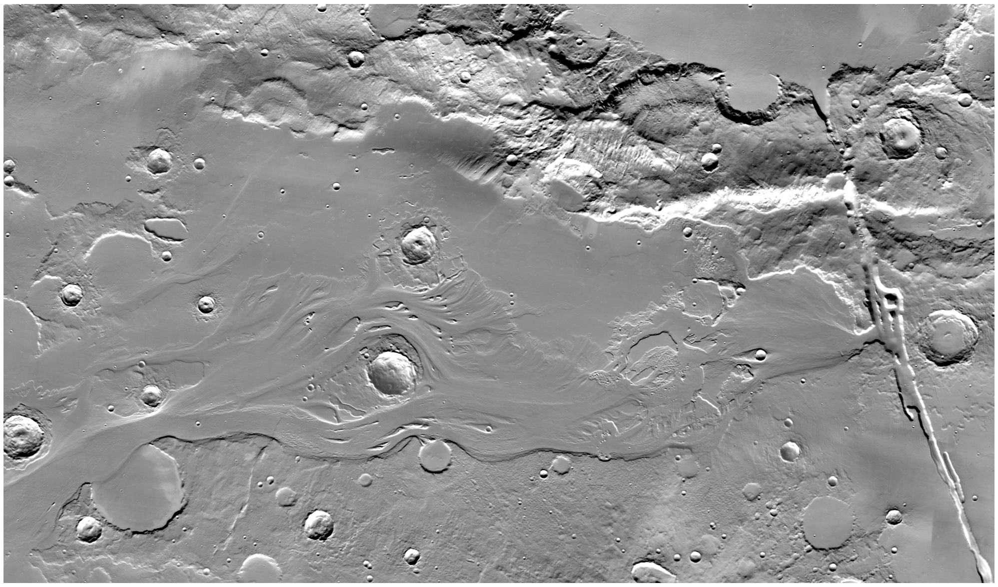
Question Mars

Grades: 5-12 Prep Time: ~10 Minutes Lesson Time: 3 Hours



WHAT STUDENTS DO: Generate a Research Question and/or Hypotheses for Mars

In this activity, students step into the shoes of real planetary scientists and experience one of the first steps in the process of science; developing hypotheses and testable questions. Students are tasked with using the topic identified in the Mars Image Analysis activity (Lesson 11) to establish hypotheses and a question about the surface of Mars. The purpose of this lesson is for students to use a critical thinking and a collaborative approach to scientific research in planetary geology. Using scientific observations and inferences students will:

- Generate a “big picture” question related to Mars;
- Generate hypotheses related to Mars geology; and
- Generate a research question related to Mars geology based on scientific observations.

NRC CORE & COMPONENT QUESTIONS	INSTRUCTIONAL OBJECTIVES
WHAT IS THE UNIVERSE, AND WHAT IS EARTH’S PLACE IN IT? *NRC Core Question: ESS1: Earth’s Place in the Universe*	*Students will be able*
How do people reconstruct and date events in Earth’s planetary history? *NRC ESS1.C: The History of the Planet Earth*	**IO1: to generate** a research question and testable hypothesis based on Mars geology
Asking Questions and Defining Problems *NRC Practice 1: Science Practices*	

See Section 4.0 and Teacher Guide at the end of this lesson for details on Instructional Objective(s), Learning Outcomes, Standards, & and Rubrics.

1.0 About This Activity

The Mars lessons leverage *A Taxonomy for Learning, Teaching, and Assessing* by Anderson and Krathwohl (2001) (see *Section 4* and *Teacher Guide* at the end of this document). This taxonomy provides a framework to help organize and align learning objectives, activities, and assessments. The taxonomy has two dimensions. The first dimension, cognitive process, provides categories for classifying lesson objectives along a continuum, at increasingly higher levels of thinking; these verbs allow educators to align their instructional objectives and assessments of learning outcomes to an appropriate level in the framework in order to build and support student cognitive processes. The second dimension, knowledge, allows educators to place objectives along a scale from concrete to abstract. By employing Anderson and Krathwohl's (2001) taxonomy, educators can better understand the construction of instructional objectives and learning outcomes in terms of the types of student knowledge and cognitive processes they intend to support. All activities provide a mapping to this taxonomy in the Teacher Guide (at the end of this lesson), which carries additional educator resources. Combined with the aforementioned taxonomy, the lesson design also draws upon Miller, Linn, and Gronlund's (2009) methods for (a) constructing a general, overarching, instructional objective with specific, supporting, and measurable learning outcomes that help assure the instructional objective is met, and (b) appropriately assessing student performance in the intended learning-outcome areas through rubrics and other measures. Construction of rubrics also draws upon Lanz's (2004) guidance, designed to measure science achievement.

How Students Learn: Science in the Classroom (Donovan & Bransford, 2005) advocates the use of a research-based instructional model for improving students' grasp of central science concepts. Based on conceptual-change theory in science education, the 5E Instructional Model (BSCS, 2006) includes five steps for teaching and learning: Engage, Explore, Explain, Elaborate, and Evaluate. The Engage stage is used like a traditional warm-up to pique student curiosity, interest, and other motivation-related behaviors and to assess students' prior knowledge. The Explore step allows students to deepen their understanding and challenges existing preconceptions and misconceptions, offering alternative explanations that help them form new schemata. In Explain, students communicate what they have learned, illustrating initial conceptual change. The Elaborate phase gives students the opportunity to apply their newfound knowledge to novel situations and supports the reinforcement of new schemata or its transfer. Finally, the Evaluate stage serves as a time for students' own formative assessment, as well as for educators' diagnosis of areas of confusion and differentiation of further instruction. This five-part sequence is the organizing tool for the Mars instructional series. The 5E stages can be cyclical and iterative.

The format for developing a question was guided by statements made by Bybee in "Scientific and engineering practices in K-12 classrooms: Understanding a framework for K-12 science education" publish by NSTA. Here Bybee explained that the term "practices" was a much more accurate explanation of scientific inquiry. These practices "involve doing and learning in such a way that cannot be really separated." The process for reaching a scientific research question in this lesson has been discussed and vetted through planetary scientists actively involved in research.

2.0 Rationale

Question Mars is intended to be a follow on lesson to the Mars Image Analysis. In Mars Image Analysis, students learn how to make strong scientific observations in addition to becoming acquainted with the geology of the planet Mars. At the end of the lesson students establish a topic of interest for their research. This topic will be necessary for the Question Mars lesson. This lesson is designed to mirror the process many scientists go through in establishing a research question. It is important to note that these scientists have had many years of experience in the field and typically come to a research question in a very organic and chaotic way. This lesson is structured to grow novice experience so that they too may one day ask questions in this same organic way.

In Question Mars, we will focus primarily on hypothesis development and question writing. We will attempt to avoid the pitfalls of question writing by looking at hypotheses. A distinction that needs to be made with students from the traditional scientific method to the iterative process of science is that more often than not, scientists develop hypotheses and questions simultaneously. Examples have been provided in the student guide. The intention is for students to see the shift in their own thinking. They should recognize from the examples that the scientist generated an hypothesis with their observations at the same time as they are asking questions.

Starting the Lesson:
All science begins with a question or a hypothesis. Keep in mind that it is a natural part of science to refine or even change your question as your research progresses. The process of science continues with designing an experiment to answer that question and test your hypotheses. For this activity, the focus is on generating a high-quality research question and hypothesis. Students will need the Mars Image Analysis materials for this lesson and should be grouped in small groups (approximately 3-4) for brainstorming and development of hypotheses and questions.

Figure 1. Pathways

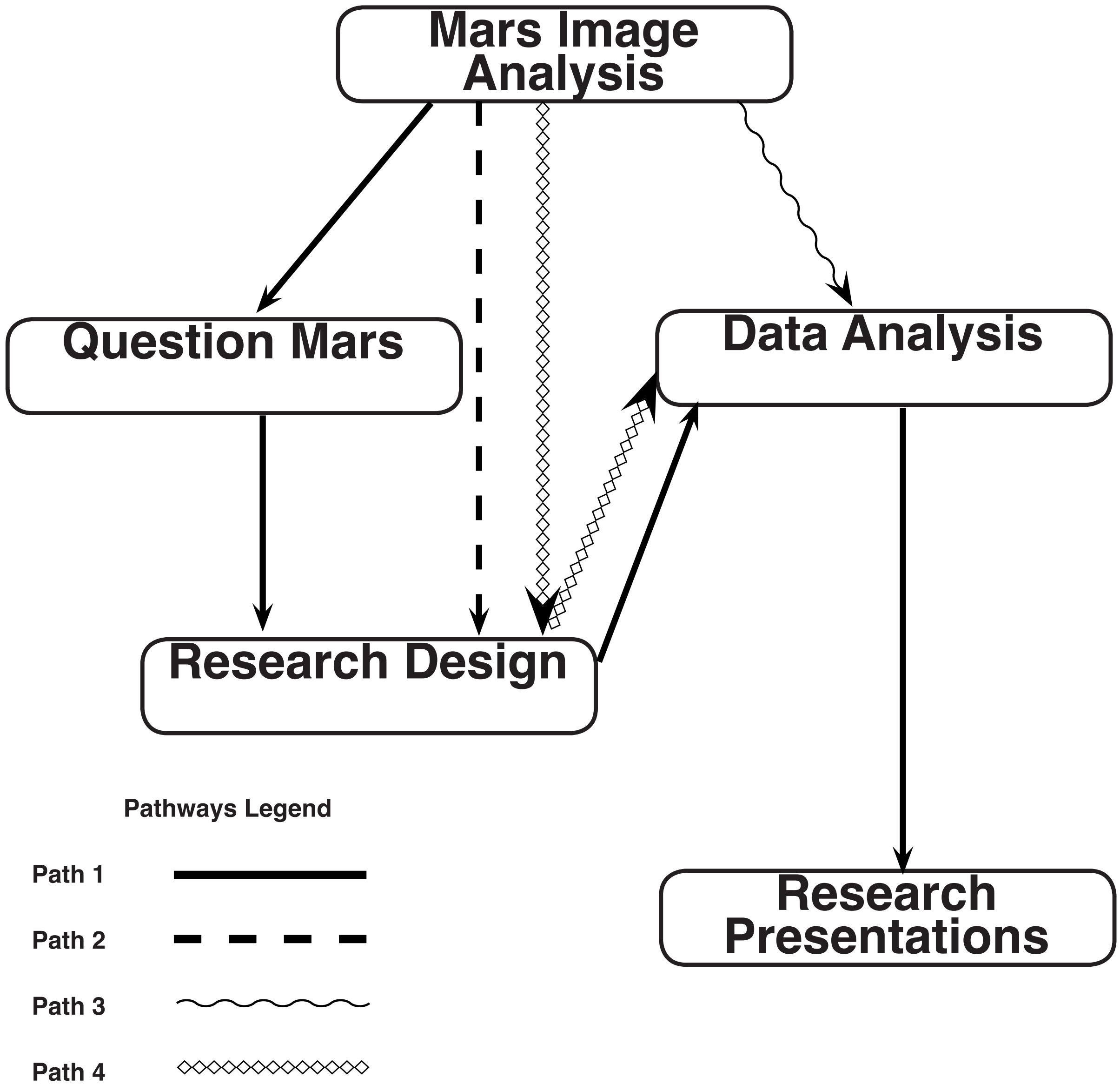


Figure 2. Pathways

Figure 2 - Pathways			
Emphasis	**Lessons in the Path**	**National Standards**	**Est. # of Class periods (45 min segments)**
Path 1: Full scientific process of research	Mars Image Analysis Question Mars Mars Research Design Mars Data Analysis Mars Research Publication	**Science** **Dimension 1: Practices** 1, 2, 3, 4, 5, 6, 7, 8 **Dimension 2: Concept** 1, 2, 3, 4 **Dimension 3: ESS** ESS1C Some types of research: ESS2A, ESS2B, ESS2C, ESS2D	25
Path 2 Developing observation skills and controlled experimental procedures	Mars Image Analysis Mars Research Design	**Science** **Dimension 1: Practices** 2,3 **Dimension 2: Concept** 2, 3, 4 **Dimension 3: ESS** ESS1C	5
Path 3 Developing observation skills, graphing techniques, and graphical interpretation	Mars Image Analysis Mars Data Analysis	**Science** **Dimension 1: Practices** 4, 5, 6 **Dimension 2: Concept** 1, 2, 3, 4 **Dimension 3: ESS** ESS1C	5
Path 4 Developing observation skills, controlled experimental procedures, graphing techniques, and graphical interpretation	Mars Image Analysis Mars Research Design Mars Data Analysis	**Science** **Dimenstion 1: Practices** 2, 3, 4, 5, 6, 7 **Dimension 2: Concept** 1, 2, 3, 4 **Dimension 3: ESS** ESS1C	8

3.0 Materials

Required Materials

Please supply resources from Mars Image Analysis Lesson (per group of students):

- Completed Mars Image Analysis Student Data Log
- Completed Mars Image Analysis Observation Sheets
- Completed Mars Image Analysis Topic Selection Sheets
- Mars Orbital Laser Altimeter (MOLA) maps

Facility

- A room or computer lab where students can easily access *JMARS* http://jmars.asu.edu/download-jmars (Refer to Quick Start Guide to JMARS provided at http://marsed.asu.edu/msip-home. Click "resources.")

Please Print:

From Student Guide:

(A)	Introduction	– 1 per student
(B)	Questions and Hypotheses	– 1 per student
(C)	Identifying the Big Picture Question	– 1 per student
(D)	Identifying the Explanations	– 1 per student
(E)	Writing a Research Question	– 1 per student
(F)	Writing a Testable Hypothesis	-- 1 per student

Optional Materials

From Teacher Guide:

(G) Questions and Hypotheses Sample Answers
(H) Evaluation Criteria Rationale
(I) "Question Mars" Assessment Rubrics
(J) Alignment of Instructional Objective(s) and Learning Outcome(s) with Knowledge and Cognitive Process Types

4.0 Vocabulary

Big Picture Question	general/overarching questions that are typically asked based on scientific observations
Hypothesis	a possible explanation defining a relationship between features and geologic processes, must be testable
Mission	a spacecraft designed to explore space, seeking to answer scientific questions
Observations	specific details recorded to describe an object or phenomenon
Orbiter	a spacecraft designed to explore space, seeking to answer scientific questions
Planet	a sphere moving in orbit around a star (e.g., Earth moving around the sun)
Research Question	a specific testable question based on careful observations of phenomena

5.0 Instructional Objectives, Learning Outcomes, Standards, & Rubrics

Instructional objectives, standards, and learning outcomes are aligned with the National Research Council's *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*, which serves as a basis for upcoming "Next-generation Science Standards." Current National Science Education Standards (NSES) and other relevant standards are listed for now, but will be updated when the new standards are available.

The following chart provides details on alignment among the core and component NRC questions, instructional objectives, learning outcomes, and educational standards.

- Your **instructional objectives (IO)** for this lesson align with the NRC Framework and education standards.
- You will know that you have achieved these instructional objectives if students demonstrate the related **learning outcomes (LO)**.
- You will know the level to which your students have achieved the learning outcomes by using the suggested **rubrics** (see Teacher Guide at the end of this lesson).

Quick View of Standards Alignment:

The Teacher Guide at the end of this lesson provides full details of standards alignment, rubrics, and the way in which instructional objectives, learning outcomes, 5E activity procedures, and assessments were derived through, and align with, Anderson and Krathwohl's (2001) taxonomy of knowledge and cognitive process types. For convenience, a quick view follows:

WHAT IS THE UNIVERSE, AND WHAT IS EARTH'S PLACE IN IT?
NRC Core Question: ESS1: Earth's Place in the Universe

How do people reconstruct and date events in Earth's planetary history?
NRC ESS1.C: The History of the Planet Earth

Asking Questions and Defining Problems
NRC Practice 1: Science Practices

Instructional Objective *Students will be able*	**Learning Outcomes** *Students will demonstrate the measurable abilities*	**Standards** *Students will address*	
IO1: **to generate** a research questions and testable hypothesis based on Mars geology	**LO1a.** **to use** scientific observations of phenomena to guide the scientific question **LO1b.** **to differentiate** between big picture questions and research questions **LO1c.** **to generate** a testable hypothesis based on Mars geology	**NSES (A): SCIENCE AS INQUIRY:** **Abilities Necessary to Do Scientific Inquiry** **Grades 5-8:** A1a, A1e **Grades 9-12:** A1a, A1d **Understandings about Scientific Inquiry** **Grades 5-8:** A2a **NSES (D): EARTH AND SPACE SCIENCE:** **Structure of the Earth System** **Grades 5-8:** D1c, D1d **Earth's History** **Grades 5-8:** D2a **The Origin and Evolution of the Earth System** **Grades 9-12:** D3b, D3c	***Rubrics in Teacher Guide***

This activity also aligns with:

NRC SCIENCE & ENGINEERING PRACTICES

1) Asking questions (for science) and defining problems (for engineering)
6) Constructing explanations and designing solutions
7) Engaging in argument from evidence

NRC SCIENCE & ENGINEERING CROSSCUTTING CONCEPTS

1) Patterns
2) Cause and effect

AAAS BENCHMARKS FOR SCIENCE LITERACY

1.A The Scientific World View
1.B Scientific Inquiry
4.A The Universe
4.B The Earth
4.C Processes that Shape the Earth
12.C Manipulation and Observation
12.D Communication Skills
12.E Critical-Response Skills

21ST CENTURY SKILLS

- Critical Thinking and Problem Solving
- Communication
- Collaboration
- Initiative and Self-Direction

6.0 Procedures

STEP 1: ENGAGE (~30 minutes)

Review Examples

A. Give each student *(A) Introduction and (B) Questions and Hypotheses* worksheets, pages 1 and 2.

B. As a class, review (A) *Introduction* to explain that scientists don't use a contrived process of developing a question and an hypothesis, but instead they make observations that guide their hypotheses and their questions.

C. Examine page 1 of *(B) Questions and Hypotheses* to define terms. Ask students to think, pair, share the similarities and differences between the types of questions.

D. Share the examples from page 2 of *(B) Questions and Hypotheses* to establish a model. Engage in conversations with the students about these examples to ensure they understand the difference between the big picture question, hypothesis, and research question.

STEP 2: EXPLORE (~45 minutes)
Identify the "Big Picture" Question

A. Give each student pages 3 and 3 of *(B) Questions and Hypotheses* to use a guide for their initial questioning.

B. Explain that the prompts provided are not the only prompts students can use, but these cover the major types of question asked while making observations.

C. Review the definition of "Big Picture" questions
   a. Remind students that these big picture questions are important questions, but are not research questions. These are very broad questions that require a significant amount of research to answer.

D. In this case, the students will be investigating one small aspect of their big picture question.

E. Give students the opportunity work together in a group for brainstorming to complete the worksheets. As a team, the students will need to make decisions, so debate and collaboration will be extremely important.

STEP 3: EXPLAIN (~45 minutes)
Develop explanations

A. Give each student *(C) Identifying the Big Picture Question* and direct students to get out completed Student Data Log, Observation Sheets, and Topic Selection Sheets from the Mars Image Analysis lesson

B. Explain that students will begin developing explanations for their big picture questions. These will eventually be hypotheses, but for now, they will most likely just be ideas.

C. Review the prompts on page 1 of *(C) Identifying the Big Picture Question* and give examples of questions.

D. Explain to students that they may add more questions at the bottom of the page.

E. Allow groups the time to complete page 1.

F. Direct students to page 2 of *(C) Identifying the Big Picture Question* and give them time to narrow their questions down to their top 2 choices.

G. Students will need the opportunity to work in JMARS (http://jmars.asu.edu/download-jmars) to check that these explanations have measurable attributes and data is available.

H. Remind students that they will need to make decisions together, so debate and collaborations are extremely important.

STEP 4: ELABORATE (~30 minutes)

Write hypothesis and research question.

A. Give students page 1 of *(D) Identifying the Explanations* and tell them that their team needs to choose one big picture question for the group.

B. Once the group has reached consensus, they should write the question on page 1 and proceed to brainstorming explanations.

C. Give students pages 2 and 3 of *(D) Identifying the Explanations* and explain that they will use JMARS to see if there are tools available to test their explanations.

D. Using computers or iPads, give students access to JMARS (http://jmars.asu.edu/download-jmars) to check that these explanations have measurable attributes and data is available. They should record information in the chart of page 2 of *(D) Identifying the Explanations* and page 3 to narrow down possible explanations worth investigating.

E. Working as a group, students should share their top explanations and choose one for a primary hypothesis for the group.

F. Give students *(E) Writing a Research Question* and explain that these questions will need to be testable and that they will need to establish what will be measured in the experiment to learn if their explanation is true.

G. Refer to the lists of possible variables (in a simplified form) provided on page 1. Explain that research questions are not limited to these variables. These are a guide to move the in the right direction.

H. Working individually, give students time to complete both pages.

Teacher Tip: You will need to inform students how much time they will have to complete the entire research project so they can evaluate their questions. You may want to write the time in the chart on page 2 of *(E) Writing a Research Question*

I. Direct students to regroup and complete page 3 of *(E) Writing a Research Question*

J. See the final page of the Teacher's Guide for the rationale on the evaluation criteria.

STEP 5: EVALUATE (~30 minutes)

Write testable hypothesis.

A. Give students *(F) Writing a Testable Hypothesis* and review instructions to write a formal hypothesis.

Teacher Tip: The "if.....then...." statement has been provided as a guide, but is not 100% true in all cases. There is no need to use it if it doesn't make sense.

B. By the end of this sheet, students should have a final research question and a matching, testable hypothesis

Student Sheet #1 (~30 minutes)
Questions and Hypotheses

The intention of this sheet is to help students understand that scientists don't use a contrived process of developing a question and an hypothesis, but instead they make observations that guide their hypotheses and their questions. Examples have been provided for students to work with and to establish a model. It would be helpful to have conversations with the students about these examples to ensure they understand the difference between the big picture question, hypothesis, and research question.

Student Sheet #2 (~45 minutes)
Identifying the Big Picture Question

These sheets are provided to give students a guide for their initial questioning. The prompts provided are not the only prompts students can use, but these cover the major types of question students will ask while making their observations. These big picture questions are important questions, but are not research questions. These are very broad questions that require a significant amount of research to answer. In this case, the students will be investigating one small aspect of the their big picture question. Give students the opportunity work together in a group for brainstorming. As a team, the students will need to make decisions, so debate and collaboration will be extremely important.

Student Sheet #3 (~45 minutes)
Identifying the Explanations

In this sheet, students will begin developing explanations for their big picture questions. These will eventually be hypotheses, but for now, they will most likely just be ideas. These ideas will be critical in developing high quality research questions and hypotheses. Students will need the opportunity to work in JMARS (http://jmars.asu.edu/download-jmars) to check that these explanations have measurable attributes and data is available. As a class, they will need to make decisions together, so debate and collaboration will be extremely important.

Student Sheet #4 (~30 minutes)
Writing a Research Question

Students will use the explanations they have established in the previous sheet to create research questions. These questions will need to be testable and the students will need to establish what will be measured in the experiment to learn if their explanation is true. Lists of possible variables (in a simplified form) have been provided in the lesson, but research questions are not limited to these variables. These are a guide to move the students in the right direction. As a class, students will need to make decisions together, so debate and collaboration will be extremely important. See the final page of the Teacher's Guide for the rationale on the evaluation criteria.

Student Sheet #5 (~30 minutes)
Writing a Testable Hypothesis

Now that students have a research question, they can write a formal hypothesis. The "if.....then...." statement has been provided as a guide, but is not 100% true in all cases. There is no need to use it if it doesn't make sense. By the end of this sheet, students should have a final research question and a matching, testable hypothesis. As a class, they will need to make decisions together, so debate and collaboration will be extremely important.

7.0 Extensions

As a homework activity, ask students to follow their curiosity about Mars. Ask them to go online (with parents or guardians, if their age suggests it), and ask "Dr. C" at least 3 questions about Mars. Have them write down the following url: http://marsdata1.jpl.nasa.gov/DrC

8.0 Evaluation/Assessment

Use the *(I) Question Mars Rubric* as a formative and summative assessment, allowing students to improve their work and learn from mistakes during class. The rubric evaluates the activities using the National Science Education Standards.

9.0 References

Anderson, L.W., & Krathwohl (Eds.). (2001). *A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives.* New York: Longman.

Bybee, R., Taylor, J., Gardner, A., Van Scotter, P., Carson Powell, J., Westbrook, A., Landes, N. (2006) *The BSCS 5E instructional model: origins, effectiveness, and applications.* Colorado Springs: BSCS.

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(G) Teacher Resource. Questions and Hypotheses Sample Answers (1 of 2)

Below you will find 2 examples of stories from real research on Mars. These examples are stories about how the scientists came up with their questions for research. Read through each of these scenarios looking for the hypothesis and research question. The big picture question has been provided for you. Be prepared to share your findings with the class. Don't forget, sometimes the question may not be written in the form of a question, but more as a statement.

Gale Crater Landing Site of Curiosity (MSL) Rover

Whether life has existed on Mars is an open question that this mission, by itself, is not designed to answer. NASA's Mars Science Laboratory mission will study whether the Gale Crater area of Mars has evidence of past and present habitable environments. Curiosity will look for three conditions that are crucial for habitability; liquid water, a source of energy and other chemical ingredients utilized by life, such as carbon, amino acids, nitrogen, phosphorus, sulfur, and oxygen.

Big Picture Question: Is there evidence of a past or present habitable environment in Gale Crater?

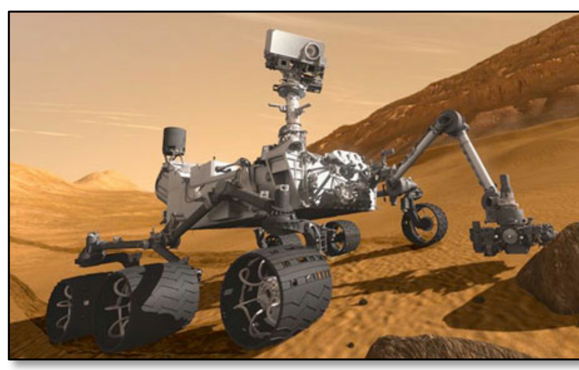
Hypothesis: ***If carbon, amino acids, nitrogen, phosphorus, sulfur, and or oxygen are present in Gale Crater, then there is or may be been a habitable environment.***

Research Question: ***Is carbon, amino acids, nitrogen, phosphorus, sulfer or oxygen present in Gale Crater?***

Photos Courtesy of NASA's Jet Propulsion Laboratory

Image left: Gale Crater

Image right: Curiosity Rover (MSL)



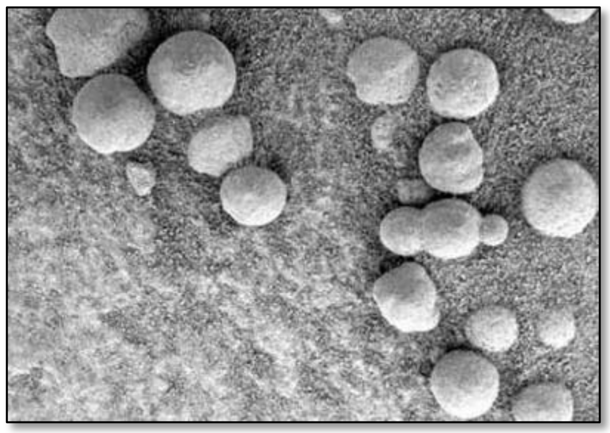
(G) Teacher Resource. Question and Hypotheses Sample Answers (2 of 2)

NAME:________________________________

Meridiani Planum Landing Site of Opportunity (MER) Rover

Meridiani Planum interested scientists because it contains an ancient layer of hematite. This hematite was identified using Thermal Emission Spectrometer (TES) data. Hematite is an iron oxide that, on Earth, almost always forms in an area containing liquid water. So how did the hematite get there? There were five or six hypotheses to explain this hematite on Mars. For example, the hematite could have been produced directly from iron-rich lavas. This process would not require liquid water. But if water was involved, then the hematite either formed from the iron-rich waters of an ancient lake, or it formed when Martian groundwater bubbled up though layers of volcanic ash. Another idea was to look for minerals such as goethite and magnetite. If goethite were found among the hematite, which would mean that it was formed in watery conditions, but if magnetite were found instead, a watery past was not likely.

On the ground, Opportunity discovered the hematite is in BB-sized spheres, also called "blueberries" by scientists. These loose blueberries are all over the landing site, making what geologists call a lag deposit. It is thought the blueberries formed when strongly acidic groundwater soaked the basaltic sandstone. This sandstone was rich in goethite, another iron-bearing mineral. The water altered the goethite into hematite, forming spherules within the rocks. Then, over time, as the acid-rotted sandstones weathered away, the tougher spherules came free and collected on the surface.



Hematite spheres (blueberries) photographed by Opportunity Rover.
Photo Courtesy of NASA's Jet Propulsion Laboratory

Big Picture Question: Is there evidence for long standing water in Meridiani Planum?

Hypothesis: ***If Meridiani Planum had a watery past, then goethite will be found in the area.***

Research Question: ***Is there evidence of goethite (water-rich environment) or magnetite (volcanic rich environment) in Meridiani Planum?***

(H) Teacher Resource. Evaluation Criteria Rationale

The following table has been developed to explain the rationale behind the evaluation criteria. The rationale may be helpful in your explanations to students regarding high quality research questions.

Evaluation Criteria	Rationale
Question can be answered using materials available an in the time allotted.	Focus on questions that can be answered using an image. Consider the amount of data that will be necessary to answer the question. For example, global (looking at all of Mars) questions are very time consuming and many scientists will spend their careers collecting this kind of data.
Question focuses on specific features that can be found using the THEMIS camera images.	Not all questions can be answered using a picture. If students ask a question that would require video or a direct presence on the planet to observe (such as height of a dust devil), then it is typically not investigable by looking at an image.
Question does not focus on ***how*** the feature formed.	These are often the big picture questions we are trying to answer. We want to know if the processes are the same or different from those we see on Earth, therefore we look for evidence (variables) that then tells us how the feature are formed. A great example of this is "How did Valles Marineris form?" There are many hypotheses as explanations, each it's own research question. See *(B) Student Worksheet. Question and Hypotheses (3 of 4)*
Question includes one of the following words: evidence, similarities, differences, relationships, patterns, etc.	This is a small list, but covers many of the general terms students could use in their question. These are directly related to evidence they could collect. Students will need to plug variables in with these. An example would be "is there evidence that Valles Marineris was formed as a rift valley?"
Question is not a ***why*** or ***how come***?	These are often the big picture questions we are trying to answer. We want to know if the processes are the same or different from those we see on Earth, therefore we look for evidence (variables) that then tell us why we see that feature. These are similar to the questions about how a feature formed.

(I) Teacher Resource. Question Mars Rubrics (1 of 3)

You will know the level to which your students have achieved the **Learning Outcomes**, and thus the **Instructional Objective(s)**, by using the suggested **Rubrics** below.

Instructional Objective 1: To generate a research question and testable hypothesis

Related Standard(s) (will be replaced when new NRC Framework-based science standards are released):

National Science Education Standards (NSES)
(A) Science as Inquiry: Abilities Necessary to Do Scientific Inquiry
Identify questions that can be answered through scientific investigations (Grades 5-8: A1a).
Think critically and logically to make the relationship between evidence and explanations (Grades 5-8: A1e).

Identify questions and concepts that guide scientific investigation (Grades 9-12: A1a)
Formulate and revise scientific explanations and models using logic and evidence (Grades 9-12: A1d)

National Science Education Standards (NSES)
(A) Science as Inquiry: Understandings about Scientific Inquiry
Different kinds of questions suggest different kinds of scientific investigations. Some investigations involve observing and describing objects, organisms, or events; some involve collecting specimens; some involve experiments; some involve seeking more information; some involve discovery of new objects and phenomena; and some involve making models (Grades 5-8: A2a).

Related Rubrics for the Assessment of Learning Outcomes Associated with the Above Standard(s):

Learning Outcome	Expert	Proficient	Intermediate	Beginner
LO1a: to use scientific observations of phenomena to guide the scientific question	Research questions are based on specific scientific observations	Research questions are based on specific observations.	Research questions are based on specific everyday observations.	Research questions are based on everyday observations.

(I) Teacher Resource. Question Mars Rubrics (2 of 3)

Related Standards (will be replaced when new NRC Framework-based science standards are released):

National Science Education Standards (NSES)
(A) Science as Inquiry: Abilities Necessary to Do Scientific Inquiry
Identify questions that can be answered through scientific investigations (Grades 5-8: A1a).
Think critically and logically to make the relationship between evidence and explanations (Grades 5-8: A1e).

Identify questions and concepts that guide scientific investigation (Grades 9-12: A1a)
Formulate and revise scientific explanations and models using logic and evidence (Grades 9-12: A1d)

National Science Education Standards (NSES)
(A) Science as Inquiry: Understandings about Scientific Inquiry
Different kinds of questions suggest different kinds of scientific investigations. Some investigations involve observing and describing objects, organisms, or events; some involve collecting specimens; some involve experiments; some involve seeking more information; some involve discovery of new objects and phenomena; and some involve making models (Grades 5-8: A2a).

Related Rubrics for the Assessment of Learning Outcomes Associated with the Above Standard(s):

Learning Outcome	Expert	Proficient	Intermediate	Beginner
LO1b: to differentiate between big picture questions and research questions.	Research question is a specific variable or hypothesis that helps to answer the big picture question.	Research question is specific to the big picture question.	Research question is loosely related to the big picture question.	Only a big picture question is provided.

(I) Teacher Resource. Question Mars Rubrics (3 of 3)

National Science Education Standards (NSES)
(A) Science as Inquiry: Abilities Necessary to Do Scientific Inquiry
Think critically and logically to make the relationship between evidence and explanations (Grades 5-8: A1e).
Formulate and revise scientific explanations and models using logic and evidence (Grades 9-12: A1d).

National Science Education Standards (NSES)
(A) Science as Inquiry: Understandings about Scientific Inquiry
Different kinds of questions suggest different kinds of scientific investigations. Some investigations involve observing and describing objects, organisms, or events; some involve collecting specimens; some involve experiments; some involve seeking more information; some involve discovery of new objects and phenomena; and some involve making models (Grades 5-8: A2a).

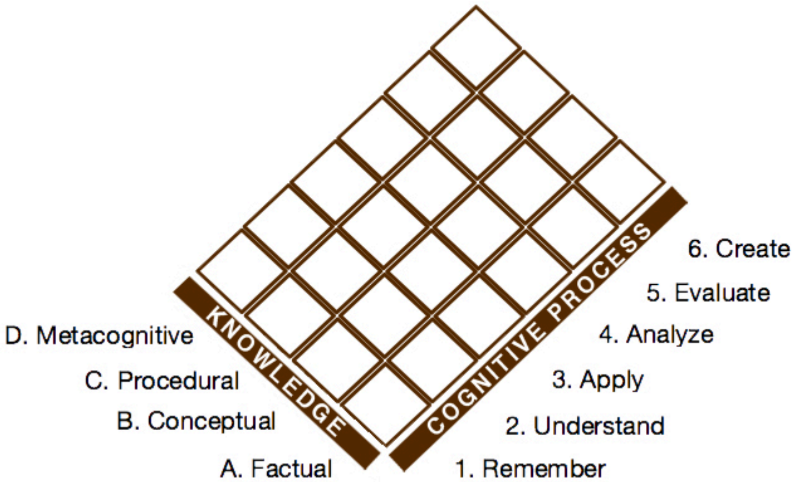
National Science Education Standards (NSES)
(D) Earth and Space Science: Structure of the Earth System
Landforms are the result of a combination of constructive and destructive forces. Constructive forces include crustal deformation, volcanic eruption, and depositions of sediment, while destructive forces include weathering and erosion (Grades 5-8: D1c).
Some changes in the solid earth can be describes as the "rock cycle." Old rocks at the Earth's surface weather, forming sediments that are buried, then compacted, heated, and often recrystallized into new rock. Eventually, those new rocks may be brought to the surface by the forces that drive plate motions, and the rock cycle continues (Grades 5-8: D1d).

National Science Education Standards (NSES)
(D) Earth and Space Science: Earth's History
The earth process we see today, including erosion, movement of lithospheric plates, and changes in atmospheric composition, are similar to those that occurred in the past. Earth history is also influenced by occasional catastrophes, such as the impact of an asteroid or comet (Grades 5-8: D2a).

National Science Education Standards (NSES)
(D) Earth and Space Science: The Origin and Evolution of the Earth System
Geologic time can be estimated by observing rock sequences and using fossils to correlate the sequences at various locations. Current methods include using the known decay rates of radioactive isotopes present in rocks to measure the time since the rock was formed (Grades 9-12: D3b).
Interactions among the solid earth, the oceans, the atmosphere, and organisms have resulted in the ongoing evolution of the earth system. We can observe some changes such as earthquakes and volcanic eruptions on a human time scale, but many processes such as mountain building and plate movements take place over hundreds of millions of years (Grades 9-12: D3c).

Learning Outcome	Expert	Proficient	Intermediate	Beginner
LO1c **to generate a testable hypothesis based on Mars geology.**	Hypothesis uses an understanding of Mars geology and can be answered.	Hypothesis can be answered using images.	Hypothesis can be answered and geology concepts are based on Earth.	Hypothesis is disconnected from Mars geology and cannot be answered.

(J) Teacher Resource. Placement of Instructional Objective and Learning Outcomes in Taxonomy (1 of 3)



This lesson adapts Anderson and Krathwohl's (2001) taxonomy, which has two domains: Knowledge and Cognitive Process, each with types and subtypes (listed below). Verbs for objectives and outcomes in this lesson align with the suggested knowledge and cognitive process area and are mapped on the next page(s). Activity procedures and assessments are designed to support the target knowledge/cognitive process.

Knowledge	Cognitive Process
A. Factual **Aa:** Knowledge of Terminology **Ab:** Knowledge of Specific Details & Elements **B. Conceptual** **Ba:** Knowledge of classifications and categories **Bb:** Knowledge of principles and generalizations **Bc:** Knowledge of theories, models, and structures **C. Procedural** **Ca:** Knowledge of subject-specific skills and algorithms **Cb:** Knowledge of subject-specific techniques and methods **Cc:** Knowledge of criteria for determining when to use appropriate procedures **D. Metacognitive** **Da:** Strategic Knowledge **Db:** Knowledge about cognitive tasks, including appropriate contextual and conditional knowledge **Dc:** Self-knowledge	**1. Remember** **1.1** Recognizing (Identifying) **1.2** Recalling (Retrieving) **2. Understand** **2.1** Interpreting (Clarifying, Paraphrasing, Representing, Translating) **2.2** Exemplifying (Illustrating, Instantiating) **2.3** Classifying (Categorizing, Subsuming) **2.4** Summarizing (Abstracting, Generalizing) **2.5** Inferring (Concluding, Extrapolating, Interpolating, Predicting) **2.6** Comparing (Contrasting, Mapping, Matching **2.7** Explaining (Constructing models) **3. Apply** **3.1** Executing (Carrying out) **3.2** Implementing (Using) **4. Analyze** **4.1** Differentiating (Discriminating, distinguishing, focusing, selecting) **4.2** Organizing (Finding coherence, integrating, outlining, parsing, structuring) **4.3** Attributing (Deconstructing) **5. Evaluate** **5.1** Checking (Coordinating, Detecting, Monitoring, Testing) **5.2** Critiquing (Judging) **6. Create** **6.1** Generating (Hypothesizing) **6.2** Planning (Designing) **6.3** Producing (Constructing)

(J) Teacher Resource. Placement of Instructional Objective and Learning Outcomes in Taxonomy (2 of 3)

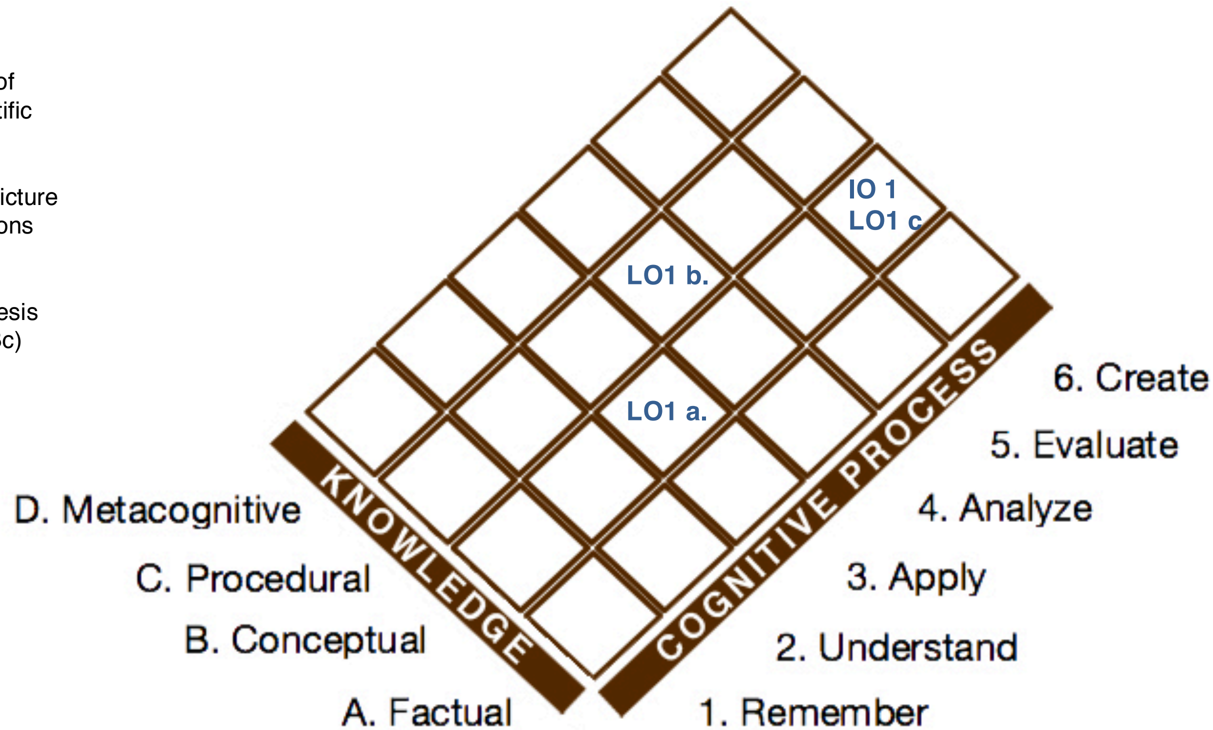
The design of this activity leverages Anderson & Krathwohl's (2001) taxonomy as a framework. Pedagogically, it is important to ensure that objectives and outcomes are written to match the knowledge and cognitive process students are intended to acquire.

IO1: to generate a research questions and testable hypothesis based on Mars geology (6.1; Bc)

LO1a. **to use** scientific observations of phenomena to guide the scientific question (3.2; Bc)

LO1b. **to differentiate** between big picture questions and research questions (4.1; Cc)

LO1c. **to generate** a testable hypothesis based on Mars geology (6.1; Bc)



(J) Teacher Resource. Placement of Instructional Objective and Learning Outcomes in Taxonomy (3 of 3)

The design of this activity leverages Anderson & Krathwohl's (2001) taxonomy as a framework. Below are the knowledge and cognitive process types students are intended to acquire per the instructional objective(s) and learning outcomes written for this lesson. The specific, scaffolded 5E steps in this lesson (see 5.0 Procedures) and the formative assessments (worksheets in the Student Guide and rubrics in the Teacher Guide) are written to support those objective(s) and learning outcomes. Refer to (J, 1 of 3) for the full list of categories in the taxonomy from which the following were selected. The prior page (J, 2 of 3) provides a visual description of the placement of learning outcomes that enable the overall instructional objective(s) to be met.

At the end of the lesson, students will be able

IO1: to generate a research questions and testable hypothesis based on Mars geology

6.1: to generate

Bc: knowledge of theories, models, and structures

To meet that instructional objective, students will demonstrate the abilities:

LO1a: to use scientific observations of phenomena to guide the scientific question

3.2: to use

Bc: knowledge of theories, models, and structures

LO1b: to differentiate between big picture questions and research questions

4.1: to differentiate

Cc: knowledge of criteria for determining when to use appropriate procedures

LO1c: to generate a testable hypothesis based on Mars geology

6.1: to generate

Bc: knowledge of theories, models, and structures