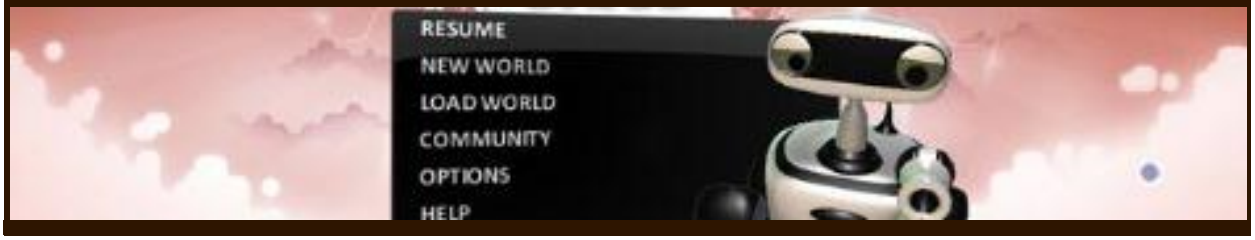
An Educational Collaboration between Microsoft and NASA/JPL-Caltech

Lesson 1

Search and Explore Mars

Grades: 5-8 Prep Time: ~15-60 Minutes Lesson Time: 60 minutes



WHAT STUDENTS DO: Determine the Most Effective Set of Commands to Navigate a Rover Across Terrain To Collect Scientific Data.

In this lesson, students use a computer game to explore Martian terrain and earn points for studying different types of rocks. They learn about Earth Science concepts such as rocks' value in answering the question of Mars' habitability. Some terrain will slow down the Rover, so learners must plan their route accordingly. Building in standards related to principles of technological design, the success of their search depends on their ability to plan, test, and revise their plan to score the most points in the allotted time.

NRC CORE & COMPONENT QUESTIONS	INSTRUCTIONAL OBJECTIVES
HOW DO ENGINEERS SOLVE PROBLEMS? *NRC Core Question: ETS1: Engineering Design* **What Is a Design for? What are the criteria and constraints of a successful solution?** *NRC ETS1.A: Defining & Delimiting an Engineering Problem* **How Can the Various Proposed Design Solutions be Compared and Improved?** *NRC ETS1.C: Optimizing the Design Solution* **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* **HOW AND WHY IS EARTH CONSTANTLY CHANGING?** *NRC Core Question: ESS2: Earth's Systems* **How do Earth's major systems interact?** *NRC ESS2.A: Earth Materials and Systems*	*Students will be able* **IO1: to execute** a procedure that reflects Earth Science-related criteria and engineering constraints

1.0 About This Activity

This activity is a collaboration between NASA's Jet Propulsion Laboratory and Microsoft to inspire and educate students about STEM (Science, Technology, Engineering, and Mathematics). Students create interactive worlds using a 3D programming environment called Kodu Game Lab. The lesson integrates the NRC Conceptual Framework for New K-12 Science Education Standards, the P21 21st Century Learning Skills, and the CSTA K-12 Computer Science Standards. Students create worlds that reflect the Martian terrain and program a virtual Rover model. They learn how the different landforms and rock types on the surface of Mars provide clues to past environments that were perhaps able to support life. Students also learn about robotics and how to create algorithms using code. Kodu Game Lab makes programming fun and approachable for novices through a tile-based user interface, engaging characters, and simple 3D terrain editing.

This Kodu lesson leverages *A Taxonomy for Learning, Teaching, and Assessing* by Anderson and Krathwohl (2001) (see *Section 4* and *Teacher Guide* at the end of this document). It is 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 this 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, 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:

1. Engage
2. Explore
3. Explain
4. Elaborate
5. 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.

The **Evaluate** stage is 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 Kodu instructional series. The 5E stages can be cyclical and iterative.

2.0 Materials

Required Materials

System Requirements:

- Supported operating systems: Windows 7, Windows Vista, Windows XP
- A graphics card that supports DirectX 9.0c and Shader Model 2.0 or higher
- .NET Framework 3.5 or higher
- XNA Framework 3.1 Redistributable

  Full system requirements and options for Mac can be found at: www.kodugamelab.com/About

  Basic instructions for Mac:
  - Run a Microsoft Windows OS on the Mac
  - Set "preferences" for mouse to enable double click
  - Optional: Load drivers for Xbox 360 wired control (should auto-detect in Windows OS)
  - Download Kodu and enjoy!

Please download:

- Kodu Game Lab at: www.kodugamelab.com
- Note: Kodu installer will automatically detect and install required components.

Please Print:

From Student Guide:
(A) Search and Explore Mars Evaluation - 1 per student

From Teacher Guide:
(B) Search and Explore Mars Rubric

(C) Placement of Instructional Objective and Learning Outcomes in Taxonomy

Optional Materials

Xbox 360 Wired Controller

4.0 Vocabulary

Algorithm	A series of steps to perform a task.
Analyze	To consider data and results to look for patterns and to compare possible solutions.
Beam	To emit light; in Kodu, this function activates a laser to analyze an object.
Conditional statement	A logical statement resulting from the connection of a true or false event and its resulting consequence.
Constraints	Limitations or restrictions.
Criteria	A standard on which a judgment is based.
Evaluate	To check the scientific validity or soundness.
Inspect	To examine closely; in Kodu this function activates a drill to inspect a rock.
Mineral	A naturally occurring solid with a specific chemical composition.
Organics	Carbon-based molecules that are the chemical building blocks of life as we know it.
Phyllosilicates	A special type of clay (a sedimentary rock) that can preserve signs of organics.
Program	Coded instructions to perform a task.
Robotics	The use of machines to perform manual tasks.
Rock	A naturally occurring solid composed of one or more minerals.
Rover	A small remote-controlled vehicle that roams over terrain, taking photographs and gathering data about the surface.
Scan	To examine an area or object; in Kodu this function reveals the type of rocks that are within a specific range from the Rover.
Sedimentary Rock	A type of rock formed by the accumulation of sediments on the surface (e.g., volcanic ash) or in bodies of water.
Syntax Error	An error in the sequence used to compose an instruction given to a computer.
Tele-operate	To operate remotely.
Trade-off	An exchange of one criteria for another.

Traverse	To move across.
Uplink Command	Directions sent through antennas on Earth and received by antennas on a spacecraft or Rover.
Volcanic Rock	A rock formed from magma that erupted from a volcano and cooled on the surface (also igneous rock, and often basalt).

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:

HOW DO ENGINEERS SOLVE PROBLEMS?
NRC Core Question: ETS1: Engineering Design

What Is a Design for? What are the criteria and constraints of a successful solution?
NRC ETS1.A: Defining & Delimiting an Engineering Problem

How Can the Various Proposed Design Solutions be Compared and Improved?
NRC ETS1.C: Optimizing the Design Solution

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

HOW AND WHY IS EARTH CONSTANTLY CHANGING?
NRC Core Question: ESS2: Earth's Systems

How do Earth's major systems interact?
NRC ESS2.A: Earth Materials and Systems

Instructional Objective *Students will be able*	Learning Outcomes *Students will demonstrate the measurable abilities*	Standards *Students will address*	
IO1: **to execute** a procedure that reflects Earth Science-related criteria and engineering constraints	**LO1a. to test a procedure** **LO1b. to evaluate a procedure** **LO1c. to implement refinements to a procedure** **LO1d. to explain the criteria and constraints of a successful solution** **LO1 e. to differentiate between the visual characteristics of volcanic and sedimentary rocks and their scientific significance**	**NSES: UNIFYING CONCEPTS & PROCESSES:** **K-12: Evidence, models, and explanations** **NSES (D): EARTH AND SPACE SCIENCE:** **Structure of the Earth System** **Grades 5-8:** D1c, D1d, D1e. **NSES (E): SCIENCE & TECHNOLOGY** **Abilities of Technological Design** **Design a Solution or a Product** **Grades 5-8:** E1b	***Rubrics in Teacher Guide***

This activity also aligns with:

NRC SCIENCE & ENGINEERING PRACTICES

4) Analyzing & interpreting data
5) Using mathematical and computational thinking
6) Constructing explanations and designing solutions

NRC SCIENCE & ENGINEERING CROSSCUTTING CONCEPTS

2) Cause and effect
4) Systems and system models

CSTA K-12 Computer Science Standards

L2.CT.1 Use the basic steps in algorithmic problem solving to design solutions (e.g., problem statement and exploration, examination of sample instances, design, implementing a solution, testing, evaluation).

L2.CT.3 Define an algorithm as a sequence of instructions that can be processed by a computer.

L2.CT.6 Describe and analyze a sequence of instructions being followed.

L2.CL.3 Collaborate with peers, experts, and others using collaborative practices such as pair programming, working in project teams, and participating in group active learning activities.

L2.CPP.5 Implement problem solutions using a programming language, including: looping behavior, conditional statements, logic, expressions, variables, and functions.

L2.CPP.8 Demonstrate dispositions amenable to open ended problem solving and programming (e.g., comfort with complexity, persistence, brainstorming, adaptability, patience, propensity to tinker, creativity, accepting challenge).

L2.CPP.9 Collect and analyze data that is output from multiple runs of a computer program.

21ST CENTURY SKILLS

- Creativity and Innovation
- Critical Thinking and Problem Solving
- Communication
- Collaboration

5.0 Procedure

PREPARATION (~15-60 minutes)

Installing and Learning the Basics of Kodu

A. Download and install Kodu Game Lab from www.kodugamelab.com

B. Organize students into groups of two. Create mixed-ability pairs based on familiarity with game development, computer programming, and use of the Xbox 360 controller (if it is being used).

C. Students do not require any previous Kodu experience, but you may choose to have them complete the basic introductory tutorials at http://www.kodugamelab.com/About

STEP 1: ENGAGE (~5 minutes)

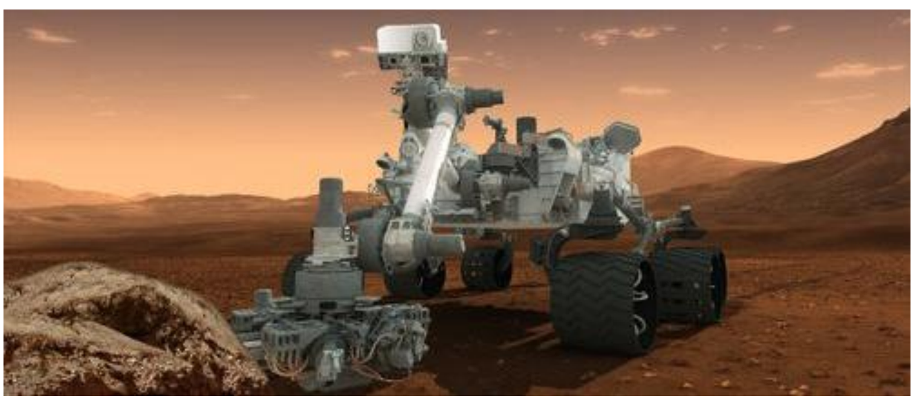
A Rover Explores the Surface of Mars

A. To elicit prior knowledge of other robotic vehicles, have students name other robotic vehicles, such as robotic drones used in surveillance or robotic submarine probes used to explore the deep ocean.

B. Have students brainstorm how a robotic vehicle like a Mars Rover might be controlled when no human is there to drive it.

C. Share information on Mars exploration and Mars Rovers, including NASA's Mars Rover named Curiosity: mars.jpl.nasa.gov/msl Explain they will be act like real Rover drivers:

NASA's Mars Rover Curiosity might be the size of a small car, but you don't drive it like one! Instead, the Rover relies on a set of computer commands from scientists and engineers on Earth, who plan its route to a place where they think they can make the most discoveries. By up-linking these complex plans through large communications antennas on Earth that send these daily instructions to the Rover on Mars, the mission team tells the Rover where to go, when to turn, and how to avoid hazards along its way. They also tell the Rover when and for how long to use its onboard science tools to scan and analyze rocks and soils and other environmental elements that may hold clues to a key science question: Was Mars ever a habitat (a place able to support life)?

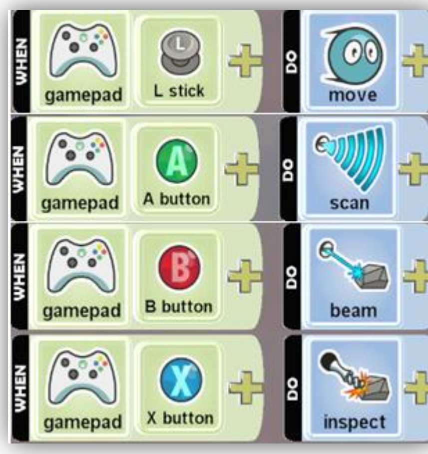


STEP 2: EXPLORE (~15 minutes)

Scientific Discovery Points

A. Describe how to play the game.

i. Explain that scientists and engineers want to make the most discoveries possible as they explore the surface of Mars. They command the Rover to move to places that are scientifically interesting so that they can study them. Explain that rocks are important to scientific discovery because they hold clues to the environment in which they formed.



ii. One of the Rover's main tasks is to examine the rocks on the surface of Mars' terrain. When you use the **Scan** tool, Rover scans a rock to determine its type: sedimentary or igneous. The **Beam** tool activates the laser spectrometer, which is used to analyze the rock. The **Inspect** tool activates a drill that will gather a sample of the rock for further experimentation.

B. Using the Xbox 360 controller:

- **i.** Use the left analog stick to move the Rover.
- **ii.** Press the A button to Scan.
- **iii.** Press the B button to Beam.
- **iv.** Press the X button to Inspect.

C. Using the keyboard:

- **i.** Use the arrow keys to move the Rover.
- **ii.** Press the A key to Scan.
- **iii.** Press the B key to Beam.
- **iv.** Press the X key to Inspect.

D. The scoring system:

- **i.** The white number represents the scientific discovery points.
- **ii.** The green number reflects how many times the Inspect tool can be used.

E. Have students load "Mars Rover: The Expedition."

F. As students play the game, ask them to observe the different landforms and where they find the different rock types.

G. Students should take turns controlling the Rover and exploring the world. Because the game is set to explore for approximately 2 minutes, they can restart and replay the game multiple times, taking turns to explore different features in the Mars terrain.

STEP 3: EXPLAIN (~10 minutes)

Rocks Have Different Scientific Significance in the Search for Habitats on Mars

A. Ask: What is a rock? What is a mineral?

- **i.** A rock is a naturally occurring solid composed of one or more minerals.
- **ii.** A mineral is a naturally occurring solid with a specific chemical composition. A rock can be an aggregate of many minerals.

B. Explain that two basic rock types are found on the surface of Mars: volcanic (igneous) rocks and sedimentary rocks. (Metamorphic rocks are possible, but have not been found in places rovers have explored so far.)

C. Have students press the ESC key on the keyboard to stop the game and reveal the Kodu tool menu.

D. Ask students to place an igneous rock where they noticed other igneous rocks were most commonly found.

i. Tell students to select the **Object** tool and click on the desired location in the world.

ii. Select **Rock** and then select **Igneous**.

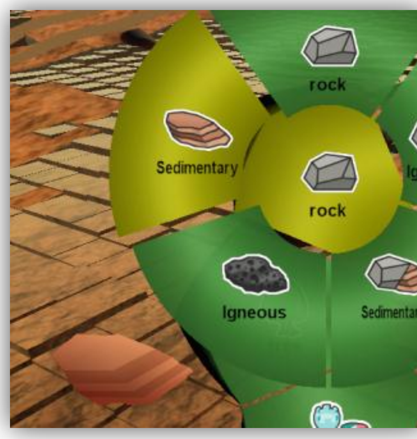
iii. Ask students to explain where they placed the igneous rock. Volcanic rocks formed when magma from volcanic eruptions cooled (solidified) on Mars a long time ago.

E. Ask students to describe the landforms where sedimentary rocks were most commonly found. Have them place a sedimentary rock at the described location.

i. Tell students to select the **Object** tool and click on the desired location in the world.

ii. Select **Rock** and then select **Sedimentary**.

iii. Ask students to explain where they placed the sedimentary rock and why. A sedimentary rock can be formed in a body of water when layers of sediment get compressed and cemented together. It can also form from deposits of volcanic ash or wind-blown deposits of small grains of rocks and minerals that also get compressed and cemented together.



Goal, Criteria, and Constraints

A. Explain that the goal of the game is to determine the best way to maneuver the Rover to search and to inspect the rocks to get the most science discovery points.

i. Have students define the criteria and compare how many points each criterion awards.

- Inspect sedimentary and igneous rocks.
- Beam sedimentary and igneous rocks.
- Scan sedimentary and igneous rocks.

(Hint: You'll want to scan and inspect sedimentary rocks to earn the most points)

b. Have students define the constraints.

i. First, discuss with your students the following real-world example. On Mars, mission teams must work within constraints such as:

- How much power is available.
- How much power each science tool needs to perform an action.
- How many times a scanning tool can be used.
- How much memory a robot's computer has to store results.
- Time limits (usually related to when an orbiter flies overhead to help transmit messages back to Earth or what the Rover can do during a day).

ii. In this experience, students can consider two constraints:

- Limited uses of the Inspect tool (drill bits, represented by green score; there are 10).
- Time limit (set to 240 seconds, and displayed as countdown timer in purple).

B. The sedimentary rocks will score more points when they are inspected because they are of greater scientific value in the search for habitats on Mars. Some sedimentary rocks are more important than others. Some can contain minerals that form in water (e.g., hematite), which tell scientists the environment had water long ago. Water is necessary to life as we know it. Some sedimentary rocks can have organics, the chemical building blocks of life. Sedimentary rocks called phyllosilicates (clay minerals) form under wet, warm, non-acidic conditions that can support life. On Mars, phyllosilicates are also of great interest because they can preserve signs of organics over millions of years, giving scientists even greater clues about when in Mars' history it might have had the right environmental conditions necessary for life.

STEP 4: ELABORATE (~20 minutes)

Simulating How a Rover Receives a Set of Instructions

A. Introduce a puzzle: tell students that Mars is hundreds of millions of miles away from Earth. It takes about 8 – 20 minutes for a signal (message) to get to a Rover on Mars (depending on how far away the planets are from each other in their orbits around the sun), and the same amount of time for any message to be returned. Also, no external camera systems are around on Mars to watch the Rover as it moves. Rover drivers on Earth must carefully plan the Rover's path, making sure it doesn't get into trouble (go over cliffs, get stuck in sand traps, run into a rock, etc.). How can they drive the Rover safely when they can't see it and when it takes so long to send the Rover a command and then receive a message back that it was successful?

B. Explain to students that rather than being commanded in real-time, due to the delay it takes for a command to reach Mars, Rovers are controlled through a series of instructions in a program. The series of instructions, also known as an algorithm, controls all of the actions that the Rover performs. Show students the notecards and explain that each note card will represent an uplink command from the scientists and engineers who decide where the Rover will move and what functions it will perform.

C. To simulate how the Rover is tele-operated from Earth, student pairs will write commands on the notecards (up to five instructions per notecard). Then, one student will act as a member of the science and engineering team on Earth by reading commands, while another student will act the part of a Rover on Mars by following them. The latter student will control the Rover using the code that was previously programmed into the Rover by the first student. If time permits, each student can have a turn at each role.

D. Collaborating, students should write up to five instructions on a notecard at a time that they think will help them score the most scientific discovery points as they explore the Martian terrain (see Teacher Tip below). You can re-use the level that the students played previously. Students do not have a preset protocol that they must follow to communicate with one another. They should write the steps they would like the Rover to perform as a natural language procedure. Tell the students that the five-instruction limit is a representation of a real-life limit on the amount of information that can be sent to the Rover at a time. (It is a representation because real Rovers can receive more instructions than that.)

✓ **Teacher Tip**

Invite a student to control a Rover being projected on a main screen as you model how to write instructions by writing them on a whiteboard and erasing them as if you were using multiple notecards. These instructions can be given through natural language, and converted to Kodu language; they can also be given through basic joystick or keyboard controls. The goal is to enable students to think of how to process and communicate commands.

Example instructions:

Move towards the cluster of rocks to the right.
Scan them.
Inspect the sedimentary rocks.
Look around for more rocks.
Go to the closest group of rocks.

As one student reads the commands, the other student, acting as the Rover, will pretend it has just received a program from Earth and execute the program exactly as is communicated on the notecard. Once the Rover has completely executed the instructions on the notecard, students can switch places and the second note card can be read and received. Students can compare how well their plan worked in avoiding areas the Rover cannot travel and in discovering new rocks.

E. If time permits, students can iteratively modify the instructions, execute them, and revise the instructions to score more points. If not, have a class discussion on how well they did in their initial trials, and have students brainstorm on how they would improve next time.

Search the Terrain

A. Students will play the prepared game within the described roles. They should continuously refine their procedure to score the greatest amount of points within the given constraints. As a general rule, more points are scored when students scan first, then inspect. Sedimentary rocks are worth more than igneous rocks.

B. Explain that an algorithm is a series of steps designed to perform a task. When they are commanding the Rover's movements and actions, they are mentally creating an algorithm. In *Programming a Rover (Lesson 2)*, students will use these mental algorithms to program the Rover in Kodu to move autonomously (without their input).

STEP 5: EVALUATE (~10 minutes)

Reflect using the Search and Explore Mars Evaluation worksheet

A. Hand out the (A) Search and Explore Mars Evaluation worksheet (1 per student)

B. Ask students:

- **i.** To list the criteria and constraints of the game.
- **ii.** To describe your strategy (algorithm) for exploring the terrain and searching for rocks.
- **iii.** What types of trade-offs among competing criteria did you have to make to maximize your score?
- **iv.** One student acted as the Rover and one student acted as a team of scientists and engineers on Earth. Why is it important to communicate clear instructions from the team on Earth to the Rover?
- **v.** Why are the sedimentary rocks of greater scientific value than the volcanic rocks in the search for habitats on Mars?

6.0 Extensions

KODU GAME LAB

A. Have students work with the When-Do statements to change the dynamics of the game and the way the Rover behaves. They can change when and how points are allotted, modify the speed of the Rover, and decide whether the Rover inspects, scans, or beams a rock using its laser spectrometer.

B. As a homework opportunity, Kodu Game Lab can be downloaded for free from home at www.kodugamelab.com. Have students explore the given tile code in the game and expand on it. They can add more rocks, edit the terrain, or even add another Rover object!

7.0 Evaluation/Assessment

Use *(B) Search and Explore Mars Rubric* as a summative assessment. The rubric aligns with the NRC Framework, National Science Education Standards, and the instructional objective(s) and learning outcomes in this lesson.

8.0 References

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(A) Search and Explore Mars Evaluation

NAME:_______________________________

1. List the criteria and constraints of the game.

2. Describe your strategy (algorithm) for exploring the terrain and searching for rocks.

3. What types of trade-offs among competing criteria did you have to make to maximize your score?

4. One student acted as the Rover and one student acted as a team of scientists and engineers on Earth. Why is it important to communicate clear instructions from the team on Earth to the Rover?

5. Why are the sedimentary rocks of greater scientific value than the volcanic rocks in the search for habitats on Mars?

(B) Teacher Resource. Search and Explore Mars Rubric (1 of 2)

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 execute a procedure that reflects Earth Science-related criteria and engineering constraints

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

National Science Education Standards (NSES)
UNIFYING CONCEPTS & PROCESSES

Grades K-12: Evidence, models, and explanations
Evidence consists of observations and data on which to base scientific explanations. Using evidence to understand interactions allows individuals to predict changes in natural and designed systems. Models are tentative schemes or structures that correspond to real objects, events, or classes of events, and that have explanatory power. Models help scientists and engineers understand how things work. Models take many forms, including physical objects, plans, mental constructs, mathematical equations, and computer simulations.

Scientific explanations incorporate existing scientific knowledge and new evidence from observations, experiments, or models into internally consistent, logical statements. Different terms, such as "hypothesis," "model," "law," "principle," "theory," and "paradigm" are used to describe various types of scientific explanations.

As students develop and as they understand more science concepts and processes, their explanations should become more sophisticated. That is, their scientific explanations should more frequently include a rich scientific knowledge base, evidence of logic, higher levels of analysis, greater tolerance of criticism and uncertainty, and a clearer demonstration of the relationship between logic, evidence, and current knowledge.

National Science Education Standards (NSES)
(E) Science and Technology
Abilities of Technological Design: Design a Solution or a Product
Students should make and compare different proposals in the light of the criteria they have selected. They must consider constraints— such as cost, time, trade-offs, and materials needed—and communicate ideas with drawings and simple models (Grades 5-8: E1b).

Related Rubrics for the Assessment of Learning Outcomes Associated with the Above

Standard(s):

Learning Outcome	Expert	Proficient	Intermediate	Beginner
LO1a. to test a procedure	Student performed multiple trials and had no difficulties with commands.	Student performed many trials and had minor difficulties with commands.	Student performed only a few trials and had some difficulties with commands.	Student only performed some trials and had a lot of difficulty with commands.
LO1b. to evaluate a procedure	Student correctly identified multiple ways to improve their scores.	Student correctly identified some ways to improve their scores.	Student identified a few ways to improve their scores.	Student incorrectly identified ways to improve their scores.
LO1c. to implement refinements to a procedure	Student successfully increased scores with subsequent trials.	Student generally increased scores with subsequent trials.	Student minimally increased scores with subsequent trials.	Student did not increase scores with subsequent trials.
LO1d. to explain criteria and constraints of a successful solution	Student could clearly and completely explain multiple criteria and constraints.	Student could clearly explain a small range of criteria and constraints.	Student could explain basic criteria and constraints.	Student could only explain a few criteria and constraints.

(B) Teacher Resource. Search and Explore Mars Rubric (2 of 2)

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

National Science Education Standards (NSES)
UNIFYING CONCEPTS & PROCESSES

Grades K-12: Evidence, models, and explanations
Evidence consists of observations and data on which to base scientific explanations. Using evidence to understand interactions allows individuals to predict changes in natural and designed systems. Models are tentative schemes or structures that correspond to real objects, events, or classes of events, and that have explanatory power. Models help scientists and engineers understand how things work. Models take many forms, including physical objects, plans, mental constructs, mathematical equations, and computer simulations.

As students develop and as they understand more science concepts and processes, their explanations should become more sophisticated. That is, their scientific explanations should more frequently include a rich scientific knowledge base, evidence of logic, higher levels of analysis, greater tolerance of criticism and uncertainty, and a clearer demonstration of the relationship between logic, evidence, and current knowledge.

National Science Education Standards (NSES)
(D) Earth and Space Science: Structure of the Earth System

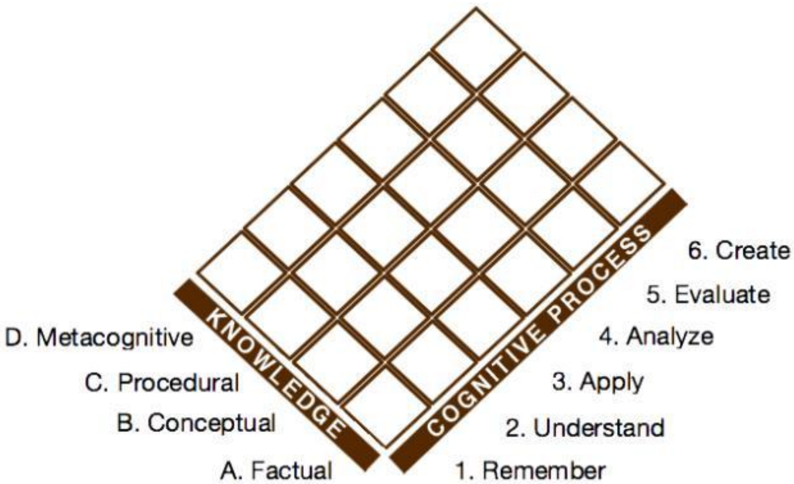
Landforms are the result of a combination of constructive and destructive forces. Constructive forces include crustal deformation, volcanic eruption, and depositions of sediment, while destructive forces include weathering and erosion (Grades 5-8: D1c).

Some changes in the solid earth can be described 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).

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

Learning Outcome	Expert	Proficient	Intermediate	Beginner
LO1e. to differentiate between the visual characteristics of volcanic and sedimentary rocks and their scientific significance.	Students accurately identify different types of rocks and select them based on their scientific significance.	Students accurately identify different types of rocks and select them somewhat based on their scientific significance.	Students somewhat accurately identify different types of rocks and select them somewhat based on their scientific significance.	Students inaccurately identify different types of rocks and do not select them based on their scientific significance.

(C) 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.

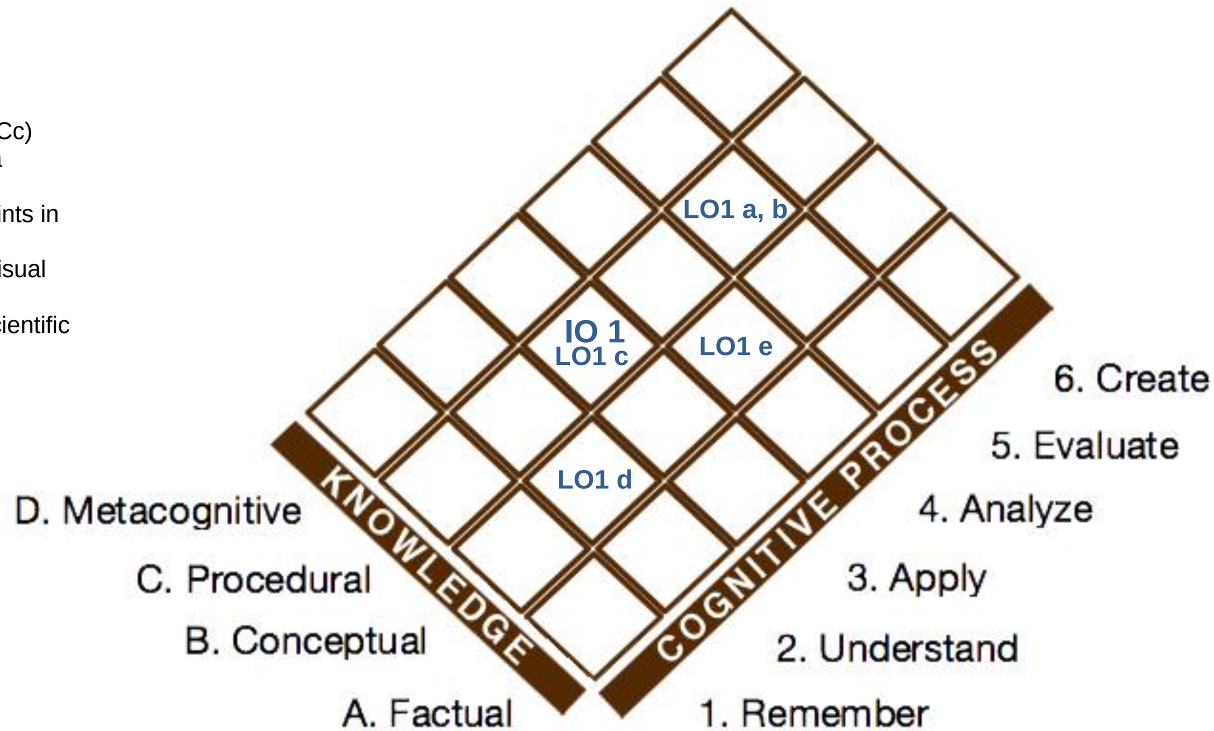
Knowledge	**Cognitive Process**
A. Factual	**1. Remember**
Aa: Knowledge of Terminology	**1.1** Recognizing (Identifying)
Ab: Knowledge of Specific Details & Elements	**1.2** Recalling (Retrieving)
B. Conceptual	**2. Understand**
Ba: Knowledge of classifications and categories	**2.1** Interpreting (Clarifying, Paraphrasing, Representing, Translating)
Bb: Knowledge of principles and generalizations	**2.2** Exemplifying (Illustrating, Instantiating)
Bc: Knowledge of theories, models, and structures	**2.3** Classifying (Categorizing, Subsuming)
C. Procedural	**2.4** Summarizing (Abstracting, Generalizing)
Ca: Knowledge of subject-specific skills and algorithms	**2.5** Inferring (Concluding, Extrapolating, Interpolating, Predicting)
Cb: Knowledge of subject-specific techniques and methods	**2.6** Comparing (Contrasting, Mapping, Matching
Cc: Knowledge of criteria for determining when to use appropriate procedures	**2.7** Explaining (Constructing models)
D. Metacognitive	**3. Apply**
Da: Strategic Knowledge	**3.1** Executing (Carrying out)
Db: Knowledge about cognitive tasks, including appropriate contextual and conditional knowledge	**3.2** Implementing (Using)
Dc: Self-knowledge	**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)

(C) 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 **execute** a procedure that reflects Earth Science-related criteria and engineering constraints (3.1; Cc)

LO1a. to **test** a procedure (5.1; Cc)
LO1b. to **evaluate** a procedure (5.2; Cc)
LO1c. to **implement** refinements to a procedure (3.2; Cc)
LO1d. to **explain** criteria and constraints in a successful solution (2.7; Cc)
LO1e. to **differentiate** between the visual characteristics of volcanic and sedimentary rocks and their scientific significance (4.1; Ba)



(C) 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 Procedure) 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 (D, 1 of 3) for the full list of categories in the taxonomy from which the following were selected. The prior page (D, 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 **execute** a procedure that reflects Earth Science-related criteria and engineering constraints
3.1: to execute
Cc: knowledge of criteria for determining when to use appropriate procedures

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

LO1a: to **test** a procedure
5.1: to test
Cc: knowledge of criteria for determining when to use appropriate procedures

LO1b: to **evaluate** a procedure
5.2: to critique
Cc: knowledge of criteria for determining when to use appropriate procedures

LO1c: to **implement** refinements to a procedure
3.2: to implement
Cc: knowledge of criteria for determining when to use appropriate procedures

LO1d: to **explain** criteria and constraints of a successful solution
2.7: to explain
Cc: knowledge of criteria for determining when to use appropriate procedures

LO1e: to **differentiate** between the visual characteristics of volcanic and sedimentary rocks and their scientific significance
4.1: to differentiate
Ba: Knowledge of classifications and categories