# Rover Races

**Grades: 5-9 Prep Time: ~45 Minutes Lesson Time: ~105 minutes**


## WHAT STUDENTS DO: Establishing Communication Procedures

Following Curiosity on Mars often means roving to places with interesting materials to study, places away from the initial landing site. In this lesson, students experience the processes involved in engineering a communication protocol. To reach their goal, students must create a calibrated solution within constraints and parameters of communicating with a rover on Mars. In this collection, this activity continues to build students' understanding of engineering design in pursuit of scientific objectives.

| NRC CORE & COMPONENT QUESTIONS | INSTRUCTIONAL OBJECTIVES |
|---|---|
| **HOW DO ENGINEERS SOLVE PROBLEMS?**<br>*NRC Core Question: ETS1: Engineering Design* | *Students will be able* |
| **What is a design for? What are the criteria and constraints of a successful solution?**<br>*NRC ETS1.A: Defining & Delimiting an Engineering Problem* | **IO1: to produce** an engineering design that meets goals within constraints<br>. |

## 1.0 About This Activity

This activity is part of the Imagine Mars Project, co-sponsored by NASA and the National Endowment for the Arts (NEA). The Imagine Mars Project is a hands-on, STEM-based project that asks students to work with NASA scientists and engineers to imagine and to design a community on Mars using science and technology, then express their ideas through the arts and humanities, integrating 21st Century skills. The Imagine Mars Project enables students to explore their own community and decide which arts-related, scientific, technological, and cultural elements will be important on Mars. Then, they develop their concepts relating to a future Mars community from an interdisciplinary perspective of the arts, sciences, and technology. imaginemars.jpl.nasa.gov

The Imagine Mars lessons leverage *A Taxonomy for Learning, Teaching, and Assessing* by Anderson and Krathwohl (2001). 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 Imagine Mars instructional series. The 5E stages can be cyclical and iterative.

## 2.0 Materials

### Required Materials

**Please supply:**

- 3 blindfolds per team of 6 students (if worried about sanitary conditions, simply ask students to close their eyes while being a rover)
- 2 clipboards and pencils per team - 1 for each team driver and official
- Flat obstacles to represent surface rocks (See Teacher Tip in Section 5.0 Procedure: Preparation")
    - Laminated construction paper works well
- Objects to represent rock samples
    - Small Traffic cones work well
- 1 stopwatch per team (for use by the team timer)
- 1 set of job cards per team (see *Section 5.0 Procedure: Preparation, Step A)*
    - 30 3x5 index cards
- 1 set of 3 plastic sports cones per team
- LCD projector and computer with internet connection to show videos
    - *Free Spirit - Plotting an Escape: http://www.jpl.nasa.gov/video/index.cfm?id=877*
    - *Curiosity Rover Rocks Rocker Bogie: http://mars.jpl.nasa.gov/msl/multimedia/videos/movies/msl20100916/msl20100916-640.mov*

**Facility**

- Large flat area to set up obstacle course (classroom, gym, or outside area)

**Please Print:**

**From Student Guide**

| | | |
|---|---|---|
| (A) | Rover Driver Command & Information | – 2 per 6-student team |
| (B) | Official's Record | – 1 per student team |
| (C) | Rover Team Evaluation – First Race | – 1 per student |
| (D) | Rover Team Evaluation – Second Race | – 1 per student |
| (E) | Iterative Process of Engineering | – 1 per student |
| (F) | Final Evaluation | – 1 per student |

## Optional Materials

### From Teacher Guide

- (G) Course Set-up Example
- (H) Iterative Process of Engineering Key
- (I) "Rover Races" Assessment Rubrics
- (J) Alignment of Instructional Objective(s) and Learning Outcome(s) with Knowledge and Cognitive Process Types

## 3.0 Vocabulary

| | |
|---|---|
| **Analyze** | consider data and results to look for patterns and to compare possible solutions |
| **Calibration** | the act of checking or adjusting (by comparison with a standard) the accuracy of a measuring instrument |
| **Constraints** | limitations or restrictions |
| **Design Criteria** | the standards that are used to judge a proposal |
| **Explanations** | logical descriptions applying scientific information |
| **Evaluate** | check the scientific validity or soundness |
| **Hypothesis** | a suggested explanation that predicts a particular outcome based on a model or theory, to be shown true or false |
| **Investigation** | an exploration of a topic or question to gain information |
| **Mission** | an operation designed to carry out the goals of the space program |
| **Models** | a simulation that helps explain natural and human-made systems and shows possible flaws |
| **Prediction** | the use of knowledge to identify and explain observations or changes in advance (NSES, 1996) |
| **Processor** | onboard computer that performs calculations |
| **Prototype** | the entire system of models put together and tested to see if they coordinate (compare to **test model**) |
| **Protocol** | procedures or commands to be followed by a robotic mission |
| **Robotics** | the use of machines to perform manual tasks |
| **Rover** | a small remote-controlled vehicle that roams over terrain, taking photographs and gathering data about the surface |
| **Solutions** | the best choice given the criteria and constraints of the problem |
| **Traverse** | to move across |

| | |
|---|---|
| **Tele-operate** | to operate remotely (e.g., operating a Mars rover from Earth) |
| **Test Model** | a small component of the system that is tested (compare to **prototype**) |
| **Uplink Command** | directions sent through antennas on Earth (Deep Space Network) and received by antennas on a spacecraft or rover |

## 4.0 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*

| **Instructional Objective**<br>*Students will be able* | **Learning Outcomes**<br>*Students will demonstrate the measurable abilities* | **Standards**<br>*Students will address* | |
|---|---|---|---|
| **IO1:**<br><br>**to produce** an engineering design that meets goals within constraints | **LO1a: to identify** limitations in an engineering design<br>**LO1b: to generate** solutions by setting new requirements to improve engineering design<br>**LO1c: to test** an engineering design<br>**LO1d: to evaluate** an engineering design | **NSES (E): SCIENCE AS INQUIRY:**<br>**Abilities of Technological Design**<br><br>**Grades 5-8:** E1b, E1c, E1d<br><br>**Understandings about Science & Technology**<br><br>**Grades 5-8:** E2e | ***Rubrics in Teacher Guide*** |

This activity also aligns with:

**NRC SCIENCE & ENGINEERING PRACTICES**

2) Developing and using models
3) Planning & carrying out investigations
4) Analyzing and interpreting data
5) Using mathematics and computational thinking
6) Constructing explanations and designing solutions

**NRC SCIENCE & ENGINEERING CROSSCUTTING CONCEPTS**

2) Cause and effect
3) Scale, proportion, and quantity
4) Systems and system models
6) Structure and function

**21ST CENTURY SKILLS**

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

- Flexibility and Adaptability
- Initiative and Self-Direction
- Productivity and Accountability
- Leadership and Responsibility

## 5.0 Procedure

## PREPARATION (~45 minutes)

### Constructing the Job Cards and Obstacle Course

**A.** Prepare a set of *Rover Races job cards* for each rover team. Use 3" by 5" index cards and write the job titles on them:

1 "Rover Driver" card

3 "Rover Student" cards

1 "Timer" card

1 "Official" card

**B.** Use pieces of laminated construction paper (or similar) to create the obstacle course for the rovers. The course design can be anything. *See (G) Course Setup Example*.

**C.** Use small traffic cones (or any appropriate item) to represent rock samples

**Teacher Tips:**

- Laminated construction paper works well for multiple uses and easy storage.
- Because some participants are blindfolded, do not use any items that could cause students to trip or fall (e.g.; desks or chairs).
- Since Mars is the Red Planet, red construction paper in 12" X 12" sizes works really well, but any paper can work.
- If doing this activity outdoors, you might use tape to fasten the tiles down to prevent them from blowing away or disturbing the course design.

## STEP 1: ENGAGE (~15 minutes)
### Rover Driver's License

**A.** Start the activity by having the students brainstorm about how a robotic vehicle on another planet (e.g., Mars) might be driven. Create a list of ideas.

**B.** Independently or together, read the following story about how the main driver of the Sojourner Rover earned a "Rover Driver's license."

http://tes.asu.edu/TESNEWS/6_VOL/2NO/brian.html

**C.** To make a connection the Mars Science Laboratory mission, view an animation and read about how the rover, Curiosity, will make use of advances in autonomous navigation:
http://mars.jpl.nasa.gov/msl/mission/technology/insituexploration/planetarymobility/

## STEP 2: EXPLORE (~20 minutes)
### Rover Course

**A.** Explain to students that rover drivers do not actually use a joystick to direct the rovers. It takes between 8-20 minutes for our data signal to reach Mars. So instead, the mission team creates a series of commands to direct the rover and sends them to the rover. This activity will demonstrate some of the complications humans (engineers) must overcome to allow for accurate communication to rovers on another planet.

**B.** Choose, ask for volunteers, or draw names of students to form rover teams. Six students are needed for each team:

- 1 Rover Driver
- 3 Rover Students
- 1 Timer
- 1 Official

**Teacher Tips:**

- Use *Rover Races job cards* to recruit your first set of Rover Races participants. After making assignments, collect the cards and pass them out to the next Rover Races participants. These students can watch the first rendition of Rover Races knowing what their role will be in the next rendition.
- Pair students of different heights as the Rover Driver and the Rover Student. Due to their vastly different stride lengths, this selection will help to add to the complexity of the calibration that will emerge as a challenge during the first simulation.
- You can adjust the difficulty of the course by adding or minimizing the number of turns for the rover to make.

**C.** The *Rover Driver* will walk through the course first, counting the number of steps and listing the turns needed to guide the rover through the course (e.g.; 3 steps forward. Stop. 1 step left. Stop. etc.). The driver will use the *(A) Rover Driver Command and Information Sheet* to build the list of commands.

**Teacher Tip:** Have the *Rover Drivers* start to walk through the course and build the command list while the class is performing the initial brainstorming. This action will save time in starting the simulation with the entire class.

**D.** Once the *Rover Drivers* have recorded their uplink sequences on their *(A) Rover Driver Command and Information Sheets*, the rover races can begin. The rover teams are lined up at the starting line. Blindfold the three *Rover Students* to prevent the rovers from aiding the *Rover Driver* during the command execution. The 3 *Rover Students* represent the six wheels of the rover and are sequentially in a line (front to back). The blindfolded *Rover Students* have their hands placed on the student's shoulders in front of them for stability.

**Teacher Tip:** This simulation is fun and the students can get quite engaged. To add to the simulation, have at least two teams going simultaneously (more is fine, just expand the course).

**E.** Once the *Rover Drivers* have recorded their uplink sequences on their *(A) Rover Driver Command and Information Sheets*, the *Rover Students* will proceed along the course by following the *Rover Drivers*' verbal commands. The commands cannot be changed from the original commands that the *Rover Driver* wrote down. They must be followed exactly. During robotic missions, usually the commands are sent up all at once. Any changes have to be made in another uplink of commands later.

**Teacher Tip:** To prevent any road rage, give the *Rover Drivers* ground rules for driving their rover:

1. No yelling at the rover!
2. No touching the rover!

**F.** The *Timers* will start their stopwatch as soon as the teacher says "start" and will time until their rover team crosses the finish line. Their time will be recorded on the *(B) Official's Record*.

**G.** The *Official* will use their *(B) Official's Record* to record any time either foot of the first *Rover Student* touches a Tile on the course (foot faults). The *Official* will keep a tally of the number of foot faults that their rover team makes.

**Teacher Tip:** Remind the students that accuracy, not speed is most important in operating a planetary rover. No one will be on Mars to help the rover if it gets struck.

**H.** The cones on the course are rock samples that can be collected if the Rover Driver has included it on their *(A) Command and Information Sheet*. The command would be "Rock Retrieval Right" or "Rock Retrieval Left" At that command, the third *Rover Student* bends down, and, still blindfolded, sweeps with his or her hand to feel the cone. The student picks the cone up and hands the cone to the second (middle) *Rover Student* to carry. The second *Rover Student* then has only one hand on the shoulder of the first *Rover Student*. The retrieved rock samples give the team extra points upon completing the course.

## STEP 3: EXPLAIN (~10 minutes)

### Identify constraints.

**A.** Allow time for all the teams to complete the course. Each *Rover Team* will get together to debrief how the driving went and complete the *(C) Rover Team Evaluation Sheet*. This information will include the challenges they faced or observed and their ideas about what might have caused those challenges. They will make a list of the challenges along with the suggested changes for the next drive.

**Teacher Tips:**

- After the first race, take time to debrief with the students. Have them describe some of the challenges and successes they found during their first race. What would they do differently?
- The students might observe that the size of the *Rover Driver's* steps and those of the *Rover Student's* steps are different sizes. The usual conclusion is that some type of control or calibration needs to be done to make the size of the steps uniform. This could be in the command change of "take baby steps" or take "giant steps". Turns might be more accurate by saying, "turn 45 degrees" or "turn 90 degrees" right or left. Driving a rover with 3 axles is also different than walking the course as a single person.

## STEP 4: ELABORATE (~30 minutes)
### Revise race based on calibration.

**A.** When teams are finished, have students tally the counts on the *(B) Official's Record Sheet*. The team that has successfully completed the course, with the least foot faults, most rock samples returned and best time is declared to have "mission success."

**B.** Repeat the activity as time permits with the second group of students, allowing for the changes the students brainstormed to be included. This iteration will also allow for more students to participate directly. Students will complete a second version of their *(C) Rover Team Evaluation Sheet*.

**C.** At the conclusion of the activity, read the following to explain and tie up all of the Engineering concepts introduced and experienced in this activity:

*What you have just experienced is a lesson on engineering and how we communicate with a rover on another planet. Engineering allows us to solve human problems using science and technology. In this case, you found quite a few problems on your first round. Give me a couple of examples.*

Examples students might note:
- Our steps were not the same, so we had to adjust.
- Moving three people is harder than moving one.

*These are examples of calibration. Calibration means that you need to make adjustments to create a standard. For example, you adjusted the length of your step to a standard length for everyone in your group.*

*So, the engineering design cycle includes identifying a problem, specifying constraints (limitations) and criteria for the desired solution, developing a design plan, producing and testing models (physical and/or computer generated), selecting the best option among alternative design features, and redefining the design ideas based on the performance of a prototype or simulation.*

*Here are two videos of real engineers working with a physical rover model and one with a computerized rover model to solve real problems that the rovers encounter on Mars.*

*Free Spirit - Plotting an Escape:*
*http://www.jpl.nasa.gov/video/index.cfm?id=877*

*Curiosity Rover Rocks Rocker Bogie:*
*http://mars.jpl.nasa.gov/msl/multimedia/videos/movies/msl20100916/msl20100916-640.mov*

## STEP 5: EVALUATE (~60 minutes)

### Evaluate proposed solutions.

**A.** Students will complete the *(D) Iterative Process of Engineering Practices Sheet*, filling in examples they experienced during Rover Races and possibly even drawing arrows when the cycle was interrupted and needed a revision. This cycle reflects the language in the NRC Framework and *(E) Final Evaluation Sheet*. The students have been provided kid-friendly terminology in their version of the *(D) Iterative Process of Engineering Practices Sheet*. An adult version and teacher sample of possible student results can be found in *(G) Iterative Process of Engineering Practices*. These *(D)/(G) Iterative Process* sheets can be utilized in the future as a formative assessment for all engineering lessons used in class.

**B.** It is important to define the difference between test models and prototypes for students. They can sound very similar; however, there is a distinct difference. A test model would be testing a small component of the system. For example, calibrating the length between steps would be a test model. A prototype includes the entire system of test models put together to see if they coordinate. If the students calibrated the step length and the number of commands, it is possible that, when those two test models are put together, the number of commands is too many for the Rover Students to keep track of.

**C.** Have the class discuss the results of the simulation. Were there advantages to taking the course slower and being more accurate (more careful moves, less foot faults) or perhaps taking advantage of the speed and getting as much done in a shorter period of time? Real planetary rovers have to coordinate utilizing available power and getting as much done as possible, but have to ensure that the risk to the rover is not too great.

## 6.0 Extensions

**Rover Races Variations and Discussion Points:**

1. To simulate remote sensing and a time delay, a video camera and monitor can be set up so that the *Rover Driver* is in another room and has to command the *Rover Students* via a runner going back and forth. Touch tablet or Smartphone technology could be used in coordination with *CU-SeeMe* applications instead of a video camera and monitor.
2. Have the students design their own rovers. Have them annotate what type of instrumentation they think would be necessary to learn about Mars. What would the scientific data their rover would collect reveal about Mars and why do they think this would be important?

## 7.0 Evaluation/Assessment

Use the *(F) Final Evaluation Sheet* to confirm student understanding of the iterative design process and the use of criteria based on constraints in a mission.

## 8.0 References

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