# Principles of Remote ExPloration (PREP) for the Moon

## *Lunar Rover Sample Return Mission*

### TEACHER VERSION

### *Introduction:*

***You are a team of NASA scientists and engineers. Your mission is to deploy a remotely operated rover to retrieve a sample of terrain from the Moon. You will be competing against other teams to be the first to successfully retrieve a sample from the Moon. Before launching your rover to the Moon, you must first conduct tests in the Arizona desert. Each team is divided into four smaller teams to accomplish specific goals to complete the mission. The roles of each team are:***

1. **Rover (ROV)** - 1 student or adult volunteer.
   - Objective: Navigate the *Moon* terrain while blindfolded. The rover receives command sequences from COM.
   - Materials: blindfold
2. **Mapping (MAP)** - 1 or 2 students.
   - Objective: Produces scale maps of the terrain using graph paper. The team must first map *Arizona*. The *Arizona* map is then compared to the satellite imagery of the *Moon* terrain when the rover is launched.
   - Materials: large graphing paper, pencils, rulers
3. **Communication (COM)** - 2 students.
   - Objective: Develops the communications strategy and delivers the commands to the rover. Command sequences are tested on the rover while in Arizona. MAP suggests to COM the best route the rover can use on the *Moon* terrain.
   - Materials: index cards, pencils, data table (p.7)
4. **Calibration (CAL)** - 1 or 2 students.
   - Objective: Works with ROV to measure step size while in *Arizona*. Makes recommendations to COM on rover's step capabilities. Monitors the rover's progress, reporting to MAP to update the rover's position on the map.
   - Materials: rulers, pencils, data table (p.10), calculators (optional)

## *Additional Materials and Set-up*

***Lunar terrain:*** Create an obstacle course in a classroom, cafeteria or gymnasium. Use chairs, desks, mats or any other moveable item to design the *Moon* terrain. This is the area that the students will map.

***Satellite imagery:*** This activity requires the use of a network camera and computer(s) to emulate “satellite imagery”. The network camera allows students to see the lunar terrain “remotely” by viewing the camera images on a computer in another room. When setting up the *Moon* terrain, place the network camera at a position above the *lunar* surface for a complete view. To do this, you will need:

1. Network camera and software
2. Ethernet cable
3. Open Ethernet port with **known IP address** for network camera.
4. Extension cord

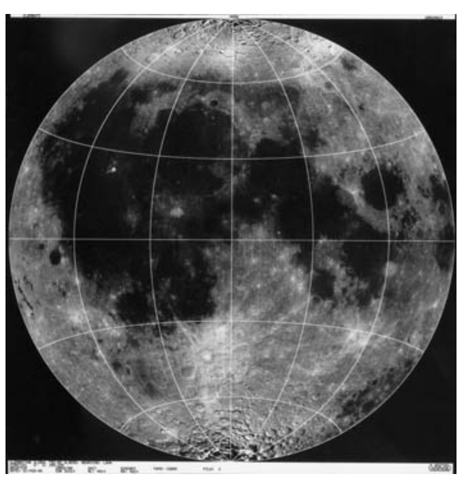
***Mission Control:*** Use another classroom to establish “Mission Control”. Connect one computer to an LCD projector and project on a screen for all students to see. If you can access a computer lab, each team should be assigned one computer instead. Note: All computers used in this activity must be connected to the internet and have the network camera software loaded onto it. Follow the directions for use of the network camera software to view your lunar terrain. **YOU MUST KNOW THE IP ADDRESS** of the port that the camera is connected through.

## Mapping Team

***Your Mission:***

**Arizona phase:** Scientists can't actually travel to other planets or the Moon before sending a rover. If they could, what would be the point of using a rover? Instead, scientists use satellite images to create maps. Your team must create a scale map of your "lunar terrain". Be sure to include any obstacles the rover may encounter. You will not have time to carefully map each feature, so make estimations. Once your map is complete, return to *Arizona* and work with COM and CAL to calibrate the rover's movements and compare them to the scale of your map. **Do not show the map of the Moon to the Rover** at any time.

**Moon phase:** Mission Control has launched the Rover. View the lunar surface from a remote location. Compare the image you see on the screen with your map. Your teacher will show you the sample site on the *Moon*. Plot it on your map. Once your Rover has landed, plot the path on your map the Rover will take to reach the sample site. While CAL and COM assemble the command sequence, mark the path on your map. Once the Rover begins to move, you will need to make sure it is staying on track. **MAP team must never leave their post at Mission Control.** Remember, the clock is ticking! Every moment counts! You want to be the first team to reach the sample.



# Mapping Team

## *Goal: Produce to-scale map of terrain.*

Use large graph paper and rulers to map out the *Arizona* terrain. REMEMBER you only have enough time to estimate your measurements!

## *Discussion Questions:*

- *What is your measurement strategy? (Hint: are there floor tiles or other ways to extrapolate one measurement to a larger distance?)*
- *What units are you using for measurement?*
- *How accurate are your measurements?*
- *How precise do you think they need to be? (Talk to your Calibration Team!)*
- *Look at your map. What is the scale of your map?*
- *Can you identify regions that might be difficult for your rover to navigate through?*
- *What are the most important features in your map for the rover?*

# Teacher's Notes - Mapping Team

## *Instructional Objective*

Produce a scale map of an environment. The units, techniques and spatial relations involved are concrete applications of concepts governed by Measurement.

### *NCTM Mathematics Standards (6 – 8 Targets)*

<u>**Measurement**</u>

**Understand measurable attributes of objects and the units, systems, and processes of measurement.**

⇒ Understand, select, and use units of appropriate size and type to measure angles, perimeter, area, surface area, and volume.

**Apply appropriate techniques, tools and formulas [sic] to determine measurements.**

⇒ Select and apply techniques and tools to accurately find length, area, value and angle measures to appropriate levels of precision.

⇒ Solve problems involving scale factors, using ratio and proportion.

### *Things to keep an eye out for...*

- Students trying to measure more precisely than necessary.
- NASA missions are always limited by time. The students should be careful not to measure so meticulously that they run out of time before a basic map is produced.

# Communication Team

***Your Mission:***

**Arizona phase:** While in the desert, you must determine how many commands the rover can reliably execute in each command sequence. There are a set number of commands that the rover can remember. You will write a set of commands on index cards and put them in the order you want them executed for each sequence. If the rover fails to remember a set of commands, it will shut down until a new command sequence is received. This can cost your team valuable time. Complete the chart on page 7 to show each command sequence, whether or not it was successful, and the time it took to execute the commands.

**Moon phase:** Mission Control has launched the Rover. Consult with MAP and CAL to determine how to reach the sample site. Write your first command sequence on an index card. Send a “signal” to the *Moon* (one student walks to the *Moon* terrain with the index card). Read out the command sequence to your rover. After you say goodbye, you must return to Mission Control before another sequence can be sent. Review the movements of the rover on the satellite image. Write another command sequence. Deliver the signal to the rover. Repeat the procedure until the rover reaches the sample site. Remember, the clock is ticking! Every moment counts! You want to be the first team to reach the sample.

# Communication Team

***Goal: Develop a communications strategy with the rover.***

Determine the appropriate length for a command sequence. Determine how long it takes to perform a command sequence, and which sequences are more efficient.

**Arizona phase:** Use this list of commands to test on your rover.

**Turn** (right or left, number of degrees)
**Forward** (number of steps)
**Backward** (number of steps)
**Bend** (at waist)
**Unbend** (at waist)
**Extend** (right or left) Arm (angle)
**Retract** (extended arm)
**Grasp** (with hand)
**Lift** (sample)

One set of commands must be written on one index card per "signal" sent to the rover. The command sequence★ is delivered as follows:

1. **COM touches rovers shoulder and says *HELLO* <rover name>.**
2. **ROV says *HELLO.***
3. **COM reads the command sequence★ from the index card.**
4. **ROV repeats the sequence. If sequence is repeated incorrectly, COM repeats the sequence until the rover gets it right.**
5. **COM says *CORRECT* <rover name>. *EXECUTE.***
6. **ROV says *GOODBYE.***

★ An example command sequence is:

a. **COM: Hello, "Rover Marty".**
b. **ROV: Hello.**
c. **COM: Go forward 5 steps, turn 90 degrees left, forward 3 steps.**
d. **ROV: Forward 5 steps. Turn 90 degrees left. Forward 3 steps.**
e. **COM: Correct, Rover Marty. Execute.**
f. **ROV: Goodbye.**

# Communication Team

***Discussion Questions:***

- *How many commands can your rover remember?*
- *Does it make a difference if you try to do it fast? Why?*
- *Does telling your rover to move FORWARD 10 get the same results as FORWARD 5 twice? How close are the results, in both time and distance? (Talk to the Communications Team!)*
- *How long does it take you to move the rover across the room?*
- *Now put a chair in the path of the rover so you have to move around it.  Now how long does it take you to move across the room?*

# Communication Team

What units are you using to measure time? ________

| Command Sequence | Successful? | Time |
|---|---|---|
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |

# Teacher's Notes - Communication Team

## *Instructional Objective*

Organize, interpret and use relevant information to devise an effective strategy for communicating with the rover. This activity simulates the two-way communication between ground-based scientists and engineers and the remotely operated rover.

### *ITEA Standards for Technological Literacy*

### Nature of Technology

**Students will develop an understanding of the core concepts of technology.**

⇒ Technological systems include input, process, output and, at times, feedback.

***Things to keep an eye out for...***

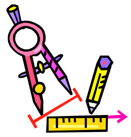
- It takes some students a while to understand that <u>all actions</u> taken by the rover must be dictated by the commands because the rovers have no on-board intelligence.
- Rovers tend to try to execute the commands before repeating the command sequence back to COM.
- The goal is to find the optimal length for the command sequence. Short sequences cost the team time in the uplink phase. Long sequences cost the team time if the rover makes mistakes and is shut down. Maneuvering around objects is time consuming.

# Calibration Team

***YOUR MISSION:***

**Arizona phase:** Engineers must always test the performance of a rover. How it performs in the lab may not be the same way it performs on the lunar surface. In the desert, you are responsible for measuring the performance of the rover as COM delivers commands. Listen as COM gives commands and measure the distance traveled by the rover. Record the measurements of the rover's movements in the data table on page 10. Once you have made all your measurements, make a **graph**, comparing the number of steps to the distance traveled. Now try blindfolding your rover. Does the rover travel the same distance as before?

**Moon phase:** Mission Control has launched the Rover. Work with MAP to compare the map with the remote view of the terrain. Calibrate the size of the Rover's steps and directions of its movements with the map For example, how many Rover steps equals 1 square on the graph paper? Once the Rover has landed, work with MAP to determine the best possible path to the lunar sample. Then work with COM to create a command sequence. Use what you learned during the Arizona phase to help you make wise decisions about how many steps or changes of direction the Rover should execute at one time. **The CAL team must never leave their post at Mission Control.** Remember, the clock is ticking! Every moment counts! You want to be the first team to reach the sample.



# Calibration Team

### *Goal:  Calibrate the rover's movements.*

Listen as COM give commands, then measure the distance traveled by the rover. Repeat several times and get an average value.  Plot the results.  Extrapolate.

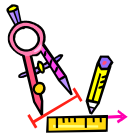
### *Discussion Questions:*

- *What is your measurement strategy? (from the toe, left foot, right foot, etc)*

- *How accurate are your measurements?*

- *How precise do you think they need to be? (Talk to your Mapping Team!)*

- *Look at your graph.  What is the relationship between number of steps and distance traveled? Estimate how far the rover will go in 10 steps:*



# Calibration Team

**What units are you using? ________________**

| | Trial 1 | Trial 2 | Trial 3 | Trial 4 | Average |
|---|---|---|---|---|---|
| 1 Step | | | | | |
| 2 Steps | | | | | |
| 3 Steps | | | | | |
| 4 Steps | | | | | |
| 5 Steps | | | | | |

## Graph Your Results

**What should the y-axis label be?**

**# of steps**

# Teacher's Notes - Calibration Team

## *Instructional Objective*

Discover and describe a mathematical relationship between the commands given to the rover and the response of the rover through measurement of time and distance.

### *NCTM Mathematics Standards (6 – 8 Targets)*

#### Algebra

**Represent and analyze mathematical solutions and structures using algebraic symbols**

⇒ Explore relationships between symbolic expressions and graphs of lines, paying particular attention to the meaning of intercept and slope.

**Use mathematical models to represent and understand quantitative relationships**

⇒ Model and solve contextualized problems using various representations, such as graphs, tables and equations.

**Analyze change in various contexts**

⇒ Use graphs to analyze the nature of changes in quantities in linear relationships.

#### Measurement

**Apply appropriate techniques, tools and formulas [sic] to determine measurements**

⇒ Select and apply techniques and tools to accurately find length, area, value and angle measures to appropriate levels of precision.

### *Things to keep an eye out for...*

- Students trying to measure more precisely than necessary
- Potential non-linearity of rover's movements, especially for a large number of steps

# Teacher's Notes - Calibration Team

## Technology Insertion Point

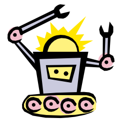
1. Graphing calculators can be used to make a plot of Number of Steps versus Distance Traveled.
2. Spreadsheet can be used to enter the data, and a graph can be produced using the spreadsheet software.
3. Item 2 can be done using a desktop, laptop or hand-held device. The Calibration Team can print their results to share with the rest of the team.
4. In a wireless environment, these data can be uploaded to the server so that the rest of the team can see the results.

# Rover

### *YOUR MISSION:*

**Arizona phase:** As the Rover, you must follow the command sequences given to you as precisely as possible. While you are blindfolded, you will need to trust your team members and follow their commands. Remember, you are a robot, and you don't have any "on-board intelligence". Do not make any moves unless a command is given in the correct manner. Do not make any adjustments on your own. You cannot communicate with your team members, except when repeating back a command sequence to COM.

**Moon phase:** While you are on your way to the *Moon*, your team members will compare the map of the *Moon* with the remote view. During this time, you will be sent to a holding station close to the *Moon*, where you will review the Rules on the *Moon*. Once you are blindfolded and have landed on the *Moon*, signal Mission Control that you have landed by waving your arms in the air. This is the start of the competition. You must correctly repeat a command sequence to COM before making any moves. If you make a mistake while executing the command sequence you will be ordered to shut down. You must then go into "safe hold" (you do not move), until a new command sequence is delivered. You will continue to execute command sequences until you, or another rover, reach the sample site. Remember, the clock is ticking! Every moment counts! You want to be the first team to reach the sample.



# Rover

### ***Goal: Retrieve the sample from the Moon.***

Listen as COM give commands, repeat to COM, then execute each command.

### ***Discussion Questions:***

*What was the most difficult part of being a Rover? Why was this part difficult?*

### ***Rules while on the Moon:***

1. Rover must remain blindfolded at all times.
2. If the rover makes a mistake, the monitor places the rover into SAFE-HOLD. The rover must stop immediately and wait until the next set of commands is delivered.
3. If a rover runs into another rover, the monitor places the rover in SAFE-HOLD. The other rover gets to go first, even if it takes that team longer to get the commands to their rover.
4. A rover may not move parts of the terrain; it must go around. If a rover runs into an obstacle, the monitor places the rover into SAFE-HOLD.
5. If a rover is driven out of the view, the monitor returns the rover to the edge of the field of view (facing out) and places the rover in SAFE-HOLD.
6. The rover that picks up the sample first and "lifts arms overhead" is the winner.

# ARIZONA TEST PHASE

### *Goal: Plan and execute a test run.*

Pick a START and FINSH in the area mapped by the Mapping team. Give yourself a challenge! Using the information gathered by Calibration team, all teams must plan a route on the map. Execute the plan and keep notes on how well the plan works.

### *Suggested Procedure:*

- Plan a route using your map.
- Put together a series of command sequences that will send your rover on the planned route.
- Blindfold the rover and lead the rover to the START.
- CAL writes the 1st set of commands on an index card.
- COM delivers the commands as they practiced.
- The rover executes the commands.
- CAL work with MAP to update the rover's position on the map.
- These steps are repeated until the rover gets to the FINSH.

### *Discussion Questions:*

- *How far is the planned route?*
- *Are you able to follow your plan? If not, where is the difficulty arising?*
- *How long does it take to get the rover from the START to the FINISH?*

## ARIZONA TEST PHASE

- *Does the rover get better at remembering commands with practice?*
- *Does the rover remember some commands or command sequences better than others?*
- *What is a reliable number of commands to use to ensure that the rover won't make a mistake?*
- *Is the shortest distance always the fastest route? Why or why not?*
- *What features of a map make it easier to use?*
- *What is the hardest part of getting the rover to go where you want it to go?*
- *What important reminders should be written down to make sure the run on the Moon goes smoothly?*

# Teacher’s Notes - Arizona Test Phase

### *Instructional Objectives*

Apply the information gathered by the Mapping, Communication and Calibration Teams to plan and execute a test run of the rover.

- Analyze multi-step problem solving situations.
- Solve a problem from a visual perspective (using maps and graphs).
- Organize, interpret and use relevant information.
- Communicate conclusions with appropriate mathematical justification.
- Identify alternate ways to find a solution when the original plan fails.
- Develop collaborative team skills.

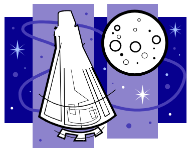
### *NCTM Mathematics Standards (K-12 Targets)*

#### Problem Solving

**Solve problems that arise in mathematics and other contexts. Apply and adapt a variety of appropriate strategies to solve problems.**

#### Connections

**Recognize and apply mathematics in contexts outside of mathematics.**



# Sample Return Mission

***Goal: Plan and execute a remotely operated Sample Return Mission.***

1. Map the *Moon* terrain (Mapping Team)
2. Launch the rover. (Rover leaves for the *Moon*.)
3. Identify the "sample" from the Web Cam view and on your Map.
4. Land the rover on *Moon* and ensure it is viewable on the WebCam.
5. Plan the mission.
6. Assemble command sequences by placing index cards in proper order.
7. Execute each command sequence in turn. Make adjustments as necessary.

Repeat steps 6 and 7 until the rover retrieves the sample. ☺

## *Sending a Signal to the Moon: How long does it take?*

The distance between Earth and the Moon varies as the Moon travels in an elliptical orbit around Earth. At perigee (closest), the distance is 336,000 km. At apogee (farthest) the distance is 405,500 km. Command and controls signals are sent to the lunar rovers using radio signals, which travel at the speed of light, $3 \times 10^5$ km/sec. The relationship between speed, time traveled and distance traveled is:

***speed = distance traveled / time traveled***

*How long does it take a signal to get to a rover when the Moon is at perigee? At apogee?*

Find more fun facts about our Solar System on the NASA portal:
*http://solarsystem.nasa.gov/planets/index.cfm*

*(Hint for remembering the relationship between speed, distance and time: what are the units of speed on highway signs?)*

# Sample Return Mission

***Discussion Questions:***

- *How did viewing the activity via WebCam change the way you had to work?*

- *What was the hardest part of remote operations?*

- *What part of your work in Arizona did you use during the Sample Return Mission?*

- *What would you do differently next time?*

- *What tools would make the job easier?*

# Teacher’s Notes - Sample Return Mission

## *Instructional Objectives*

Apply the information learned during the test run in *Arizona* to plan and execute a remote deployment of the rover. Apply what was learned to a more complex problem: the rover is now only visible via the WebCam, which introduces issues of perspective and foreshortening.

### *ITEA Standards for Technological Literacy*

#### Nature of Technology

**Students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study.**

⇒ A product, system or environment developed for one setting may be applied to another setting.

### *NCTM Mathematics Standards (K-12 Targets)*

#### Problem Solving

⇒ Solve problems that arise in mathematics and other contexts. Apply and adapt a variety of appropriate strategies to solve problems.

#### Connections

⇒ Recognize and apply mathematics in contexts outside of mathematics.

### Technology EXTRACTION Point

For teachers who do not have a Web Cam: we have made this work fairly well by removing the students from the direct vicinity of the rover where they can still see the rover. Examples:

- 2-story atrium: rover on ground floor, students above looking down on the rover.
- Room with interior or exterior windows: rover is in one area, students watch through the window.