Lunar Reconnaissance Orbiter: (LOLA)

Audience
Grades 5-8

Time Recommended
2 hours

AAAS STANDARDS
3A/M2: Technology is essential to science for such purposes as access to outer space and other remote locations, sample collection and treatment, measurement, data collection and storage, computation, and communication of information.

3B/M4b: The most common ways to prevent failure are pretesting of parts and procedures, overdesign, and redundancy.

12C/M5: Analyze simple mechanical devices and describe what the various parts are for; estimate what the effect of making a change in one part of a device would have on the device as a whole.

12C/M7: Select the proper tool for completing a particular task.

12C/M8: Maintain tools and simple devices so they are in good working order.

NSES STANDARDS
Content Standard A (5-8): Abilities necessary to do scientific inquiry
- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard E (5-8): Science and technology
- Abilities of technological desgin
- Understandings about science and technology

Content Standard G (5-8): History and nature of science
- Science as a human endeavor

NRC Framework
Dimension 1: Scientific and engineering practices
1. Asking questions (for science) and defining problems (for engineering)
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations and designing solutions
7. Engaging in argument from evidence

Dimension 2: Crosscutting concepts
PS4.C: Information technologies and instrumentation

Dimension 3: Disciplinary core ideas
ETS1.A: Defining and delimiting an engineering problem
ETS1.B: Developing possible solutions
ETS1.C: Optimizing the design solution
ETS2.A: Interdependence of science, engineering, and technology

MATERIALS
- See supply list on p. 10

LRO Communication Design Challenge

Learning Objectives:

- Students will learn how scientists and engineers design and build spacecraft like the Lunar Reconnaissance Orbiter (LRO) to collect, store, and transmit data to scientists on Earth
- Using readily accessible materials, teams of students will design a system to store and transmit topographic data of the Moon collected by the Lunar Reconnaissance Orbiter
- Students will analyze lunar topographic data

Data Overview:

Explain to the students how the Lunar Orbiter Laser Altimeter (LOLA) collects topographic data, as described in the **Background** handout (p. 6). You may give them the handout, if desired. Use **Figure 1** to explain the steps in the flow of data from initial collection at the Moon to final analysis on the Earth.

Each team should get a copy of **Figure 3**. It shows a sample of the four colors at the top and a sample dataset on the bottom. Four different colors represent the topography, or height of the lunar surface. Purple is low, light blue is medium low, green is medium high, and orange is high.

The original, high-resolution data from LRO are shown in **Figure 4**. The students should NOT see this image until the end of the activity. The image shows Einstein and Einstein A craters: a newer crater within an older crater. **Figure 5** shows a lower resolution version of **Figure 4**. The students will collect the data from **Figure 5** in sets of 2x2 pixels. They will not know what the image is until the end of the analysis phase.

For the sake of this activity, we pretend that LRO flies over the crater from north to south (top to bottom). During each pass, it collects a series of six 2-pixel by 2-pixel snapshots. This series forms a strip of data that is 2 pixels wide and 12 pixels long. On the first pass, it flies over the area represented by the first two columns. On the second pass, the process repeats itself but is shifted to the east (right). The second strip of data covers the third and fourth columns, and so on.

The entire image is 12 pixels by 12 pixels. Since each dataset is 2x2, the image is 6 columns (or strips) of 6 datasets each. There are two pages of datasets (**Figures 6a** and **6b**). You will need to cut out the datasets along the dashed lines.

Here are some rules for how to split up the datasets depending on the number of teams. Note that teams may receive the some of the same datasets as other teams.

- *Two teams*: Team 1 receives datasets 1-18. Team 2 receives datasets 19-36.
- *Three teams*: Team 1 receives datasets 1-18, Team 2 receives 7-24, and Team 3 receives 19-36.
- *Four teams*: Team 1 receives datasets 1-18, Team 2 receives 7-24, Team 3 receives

13-30, and Team 4 receives 19-36.

- *Five or more teams*: The entire image will be analyzed twice. For example, for five teams, use the two-team rules for two of the teams and the three-team rules for the others.

Team Member Roles:

Divide the class into teams. Each team should have at least three members, each of whom performs a task with the data: a Collector, a Transmitter, and a Receiver. If a team has four members, one should be an Analyst. The Collector and Transmitter will be on one side of the room, and the Receiver and Analyst on the other. Distribute the **Student's Sheet** (p. 7) to each student.

Each team will operate as follows (give a copy of **Figure 2** to each team to help them understand):

1. The Collector will observe and encode the data using a method determined by the team. The Collector will place the encoded data into Data Storage.
2. The Transmitter will use a device designed and built by the team to send the stored data to the Receiver.
3. The Receiver will record the transmitted data by encoding and placing them into Data Storage.
4. The Analyst, if present, will decode the data and record them on the strips in **Figure 7**. If there is no Analyst, a team member will decode the data after all the data have been collected and transmitted.

Cut out and the **Team Member Instructions** (p. 8) and distribute them to the appropriate students. Here are the rules for each team member:

Collector: You are the scientific instrument on LRO that collects topographic data of the Moon.

1. Look at the topographic data on each card.
2. Transfer those data to data storage using the code.
3. Do not show the card to the Transmitter.
4. You may not speak or use a writing utensil while collecting data.

Transmitter: You are the antenna that sends the data from LRO to the Earth.

1. Sit or stand with your back to the Receiver.
2. Do not look at the data cards.
3. Take each piece of coded data out of data storage and transmit them using the transmission device.
4. You may not speak or use a writing utensil while transmitting data.

Receiver: You are the radio antenna that receives data from LRO.

1. When the Transmitter sends you data, transfer them to data storage using the code.
2. You may not speak or use a writing utensil while receiving data.

Analyst: You are the scientist who converts the encoded data into a format that is easy to use.

1. Take each piece of coded data out of data storage.
2. Record it on a sheet of paper in a strip your teacher will give you (**Figure 7**).
3. You can finish data analysis even after the transmission time is over.
4. You may not speak during the transmission time.

Activity Instructions:

Tell the students that the activity occurs in the following four phases (suggested times are only approximate):

1. **Design and Build** (40 minutes): Teams design the code to use for data storage and build the transmission device.
2. **Test** (40 minutes): Teams test every step of collecting, storing, transmitting, receiving, and analyzing data, and they make necessary changes to their equipment.
3. **Operation** (30 minutes): Teams collect, transmit, receive, and analyze data.
4. **Analysis** (30 minutes): Teams finish analyzing their data, and then all teams synthesize all the data into a single image.

Design and Build Phase (40 minutes):

Five years before LRO launched, scientists and engineers met to decide how to design and build the spacecraft. They worked out how it would collect, store, and transmit data to Earth. They also decided how the scientists would analyze the data.

During this phase, students will design the code for data storage and build the transmission device. Give each student a **Design and Build Phase Student Sheet** (top half of p. 9). The students must meet the following requirements in their designs.

Criteria for the data storage code:

1. The coded data must be stored in the data storage box (a shoebox).
2. The code cannot use a writing utensil.
3. The codes for the spacecraft and the codes for the ground do not have to be identical.

Criteria for the transmission device:

1. It must be self-contained, that is, all the pieces must be attached to the device.
2. It must be manually operated.
3. It must be operated while sitting on a table or desk.
4. It must be no more than 30 cm x 30 cm x 30 cm.
5. It must have at least one moving part, such as a hinge or an axle.
6. It must transmit information visually. In other words, it cannot send an object to the Receiver.
7. It cannot use any electronic equipment, such as smart phones or cameras.

Test Phase (40 minutes):

Before they launched LRO, scientists and engineers made sure it worked in the laboratory by using simulated, or pretend, data.

During this phase, students will practice collecting, coding, transmitting, receiving, and decoding simulated data. They will also make necessary changes to their equipment. Give each student a **Test Phase Student Sheet** (bottom half of p. 9).

Each team should:

1. Create a set of 18 simulated data cards based on the sample dataset in **Figure 3**.
2. Collect, code, transmit, receive, and decode their simulated data.
3. Use the rules for the team members written above (p. 2).

Once students finish testing their designs, they should discuss these questions with their teams:

1. Were you able to transmit all the data? If not, why? What changes do you need to make?
2. Are there things you can improve? Think about all the steps.

If students need to make changes, they should do so at this time. Once you are satisfied that all the transmission devices meet the above criteria, the teams may start the next phase.

Operation Phase (30 minutes):

LRO has launched and is now orbiting the Moon! The instrument is collecting data and sending them to the scientists back on Earth.

During this phase, students will do everything they did in the Test Phase, but with real data. They do not need new student sheets.

The Operation Phase will last for 15 minutes. You will notify the teams when they may start collecting data and sending them to Earth. You will also tell them when the time has finished.

Analysis Phase (30 minutes):

As scientists receive lunar data from LRO, they must convert those data into a useful format. Scientists also cooperate to learn even more about the Moon.

Analysts will use the data sheets in **Figure 7** to record the data. They can use colored pencils or crayons to color in each square using the topographic colors in **Figure 7**. (If you want to make a three-dimensional model of the data, see **Optional Idea 1**.)

After the Analysts have finished their work, have all the teams combine their data into the image shown in **Figure 5**. Here are some rules for how to combine the data sheets depending on the number of teams:

- *Two teams*: Combine both teams' strips of data into a single image (**Figure 5**).
- *Three teams*: Combine the first two strips from Team 1, the second and third from Team 2, and the second and third from Team 3.
- *Four teams*: Combine the first two strips from Team 1, the second from Team 2, the second from Team 3, and the second and third from Team 4.
- *Five or more teams*: Combine the strips to create two full images. For five teams, combine the above rules for two and three teams. For six, use the rules for three teams twice over.

Ask the students what they think they see. Show them the high-resolution image (**Figure 4**), and explain that the image they created shows two lunar craters, one inside the other. Tell them that every instrument on LRO does what the students just did. LRO, however, does it many, many more times, which is why the high-resolution image is more detailed than the one they made. Every instrument, computer, transmitter, and reciever must work in order for scientists to analyze the data. Finally, the students should explain their codes and transmitters to the rest of the class.

Optional Ideas:

1. Students make a strip of a topographic map using materials given by teacher. Then all strips are put together, so they can see the two craters. Assign a height value (0-3) to each topographic color. Use toy connecting blocks or other stackable square objects to create a three-dimensional map using the height values. You will need at least 260 objects.
2. Give the teams a budget they cannot exceed. Use the supply prices below shown in parentheses. OR see which team can spend the least amount of money while still meeting mission requirements.
3. Scientists and engineers must make sure their instruments do not exceed mass limits. Add a mass limit (perhaps 500 grams) to the transmission device.
4. Midway through the project, tell the students there has been a budget cut or a volume cut of the transmission device. They will have to redesign the device to meet the new requirements.
5. Include loss-of-signal (LOS) and acquisition-of-signal (AOS). See the Background section for what LOS and AOS are. Use the following instructions to modify the associated phases:
    - DESIGN AND BUILD PHASE: Remind the students that the transmission device should be able to transmit data more quickly than the data are collected. During LOS ("loss of signal"—see instructions below for the Operation Phase), the Collectors will be storing data, even though the Transmitters will be doing nothing. This simulates either the Moon or the Earth blocking the line of sight between the spacecraft and the ground-based radio antenna. The transmission device must operate quickly

enough to keep the Transmitters from falling behind the Collectors.

- TEST PHASE: Tell the students also to follow the rules for LOS and AOS that you will give them (see instructions for the Operation Phase).
- OPERATION PHASE: After the 4th and 9th minutes, you will count down from 5 and then call out, "LOS!" During LOS, Collectors will continue to put data into data storage, but the Transmitters will not be able to transmit. After 1 minute of LOS, count down from 5 and then say, "AOS!" At this point, the Transmitter can restart transmitting data.

Background:

NASA's Lunar Reconnaissance Orbiter (LRO), like all spacecraft, is an intricate machine. It carries scientific instruments that collect data and store them as digital information on LRO's computer. The spacecraft's antenna (it looks like a small satellite dish) transmits the data back to Earth. On Earth, a radio telescope (it looks like a large satellite dish) receives the data and sends it to scientists' computers. The scientists then convert the data into useful information (**Figure A**).

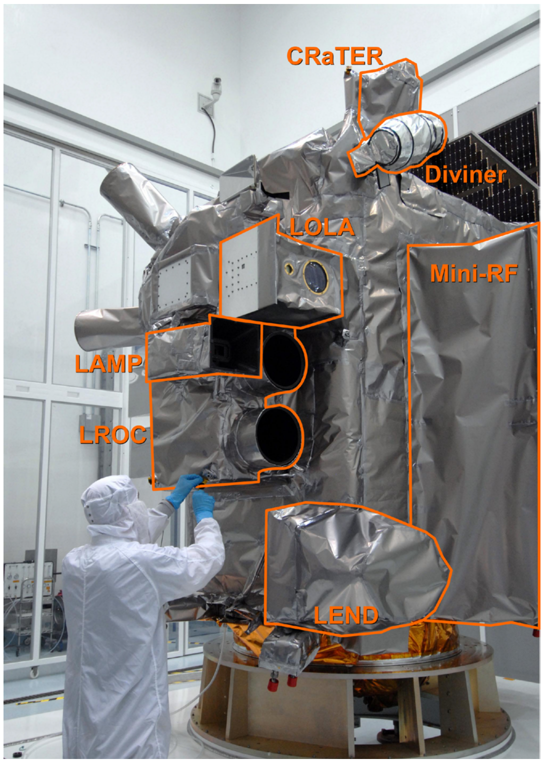


Figure A: A technician works on a completed LRO. All instruments, incluiding LOLA, are labeled.

The scientists and engineers who designed LRO's instruments had questions about the Moon. They knew what types of lunar data would answer those questions. They didn't know, though, what those data would tell them.

For example, some scientists wanted to measure the Moon's topography. They worked with engineers to build a camera system that would collect topographic data. A laser shoots light from LRO to the surface of the Moon. Some of that light reflects back to LRO, where a camera detects it. The time from the laser pulse to the detection by the camera tells scientists how far away the surface is from LRO. Mountains will give a shorter time, while valleys and craters will give a longer time.

The LOLA scientists knew what type of data they were collecting, but they didn't know the heights of mountains or depths of craters. They found out only when LRO sent data from the Moon to the Earth.

For LRO to send the data to scientists on Earth, LRO's antenna and the radio telescope on Earth need to have a clear line of sight between them. A clear line of sight is not always possible, however. The Earth rotates, so sometimes the radio telescope is on the other side of the Earth. In this case, the Earth blocks the line of sight. LRO also orbits the Moon. Sometimes it is on the other side of the Moon, so the Moon can block the line of sight, too.

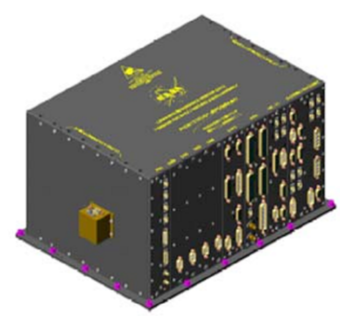


Figure B: LRO's main computer, called the Command & DataHandling Subsystem.

When the line of sight becomes blocked, the ground telvescope can no longer receive LRO's signal. This is called loss-of-signal, or LOS. Acquisition-of-signal (AOS) happens when the line of sight becomes clear again.

LOS and AOS are important to scientists and engineers. The scientific instruments on LRO continue collecting data, even when LRO cannot transmit the data to the Earth during LOS. Thus LRO needs a hard drive to store the data until it can transmit them to Earth after AOS. LRO's computer (see **Figure B**) can store over 900 gigabytes of information. It has a mass of 25 kg and is 41x30x29 cm (about the size of a shoebox).

Lunar Reconnaissance Orbiter Communication Design Challenge

Student's Sheet

Goal:

Your team will design, build, and use a system to collect, store, and transmit real scientific data across the room.

Team Rules:

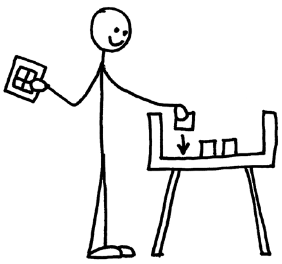
Each team will have three to four members: a Collector, a Transmitter, a Receiver, and possibly an Analyst. The Collector and Transmitter will be on one side of the room, and the Receiver and Scientist on the other. Here are the rules for the team and each team member. Use **Figure 2** to help you understand how your team will work.

1. The Collector will observe and encode the data using a method determined by the team. The Collector will place the encoded data into Data Storage.
2. The Transmitter will use a device designed and built by the team to send the stored data to the Receiver.
3. The Receiver will record the transmitted data by encoding and placing them into Data Storage.
4. The Analyst, if present, will decode the data and record them on the strips in **Figure 7**. If there is no Analyst, a team member will decode the data after all the data have been collected and transmitted.

Team Member Instructions:

Cut out these instructions for each team member.

--- Cut here ---

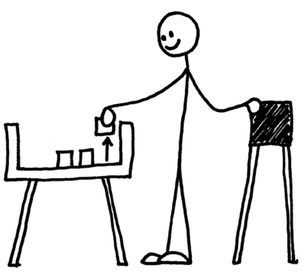


Collector:

You are the scientific instrument on LRO that collects topographic data of the Moon.

1. Look at the topographic data on each card.
2. Transfer those data to data storage using the code.
3. Do not show the card to the Transmitter.
4. You may not speak or use a writing utensil while collecting data.

--- Cut here ---

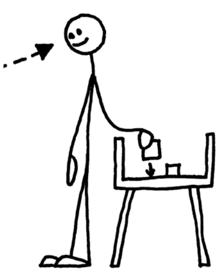


Transmitter:

You are the antenna that sends the data from LRO to the Earth.

1. Sit or stand with your back to the Receiver.
2. Do not look at the data cards.
3. Take each piece of coded data out of data storage and transmit them using the transmission device.
4. You may not use voice or hand signals or use a writing utensil while transmitting data.

--- Cut here ---

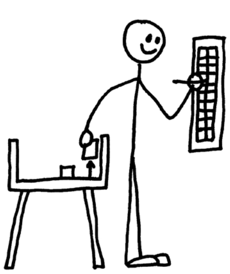


Receiver:

You are the radio antenna that receives data from LRO.

1. When the Transmitter sends you data, transfer them to data storage using the code.
2. You may not speak or use a writing utensil while receiving data.

--- Cut here ---



Analyst:

You are the scientist who converts the encoded data into a format that is easy to use.

1. Take each piece of coded data out of data storage.
2. Record it on a sheet of paper in a strip your teacher will show you (**Figure 7**).
3. You can finish data analysis, even after the transmission time is over.
4. You may not speak during the transmission time.

Design and Build Phase (Student Sheet):

LRO scientists and engineers met to decide how to design and build the spacecraft. They worked out how it would collect, store, and transmit data to Earth. They also decided how the scientists would analyze the data.

During this phase, you will design the code for data storage and build the transmission device. Both must meet the following requirements:

Criteria for the data storage code:

1. The coded data must be stored in the data storage box (a shoebox).
2. The code cannot use a writing utensil.
3. The codes for the spacecraft and the codes for the ground do not have to be identical.

Criteria for the transmission device:

1. It must be self-contained, that is, all the pieces must be attached to the device.
2. It must be manually operated.
3. It must be operated while sitting on a table or desk.
4. It must be no more than 30 cm x 30 cm x 30 cm.
5. It must have at least one moving part, such as a hinge or an axle.
6. It must transmit information visually. In other words, it cannot send an object to the Receiver.
7. It cannot use any electronic equipment, such as smart phones or cameras.

-- Cut here --

Test Phase (Student Sheet):

Before they launched LRO, scientists and engineers made sure it worked on the ground using simulated, or pretend, data.

During this phase, you will practice collecting, coding, transmitting, receiving, and decoding simulated data.

1. Create a set of 18 simulated data cards based on the sample dataset in **Figure 3**.
2. Collect, code, transmit, receive, and decode their simulated data.
3. Use the rules for the team members.

Once you finish testing, discuss these questions with your team:

1. Were you able to transmit all the data? If not, why? What changes do you need to make?
2. Are there things you can improve? Think about all the steps.

If you need to make changes, do so at this time.

Spacecraft and Ground Station Supplies:

General supplies for each team

- Watch (stopwatch is preferable)
- Two data storage boxes (shoeboxes)
- Colored pencils, crayons, or markers
- Scissors
- Glue
- Hand-held hole punch

Supplies for transmission device (prices are in parentheses—see Optional Ideas section)

- Paper cups ($2 each)
- Paper ($2)
- Cardboard ($4)
- 3x5 notecards ($3)
- String ($5)
- Masking tape ($1)
- Duct tape ($1)
- Plastic straws ($7 each)
- Brass fasteners ($6 each)
- Spools or wheel-like objects ($6 each)
- Pipe cleaners ($10 each)
- Craft sticks or chopsticks ($8 each)
- Toothpicks ($2)
- Beads ($1)
- Flashlight ($10 each)
- Ruler ($8 each)
- Mirror ($4 each)
- Toilet paper tube or paper towel tube ($6 each)
- Pennies ($1)
- Paper clip ($2 each)
- Binder clip ($3 each)
- Clothespin ($4 each)
- Aluminum foil ($2)

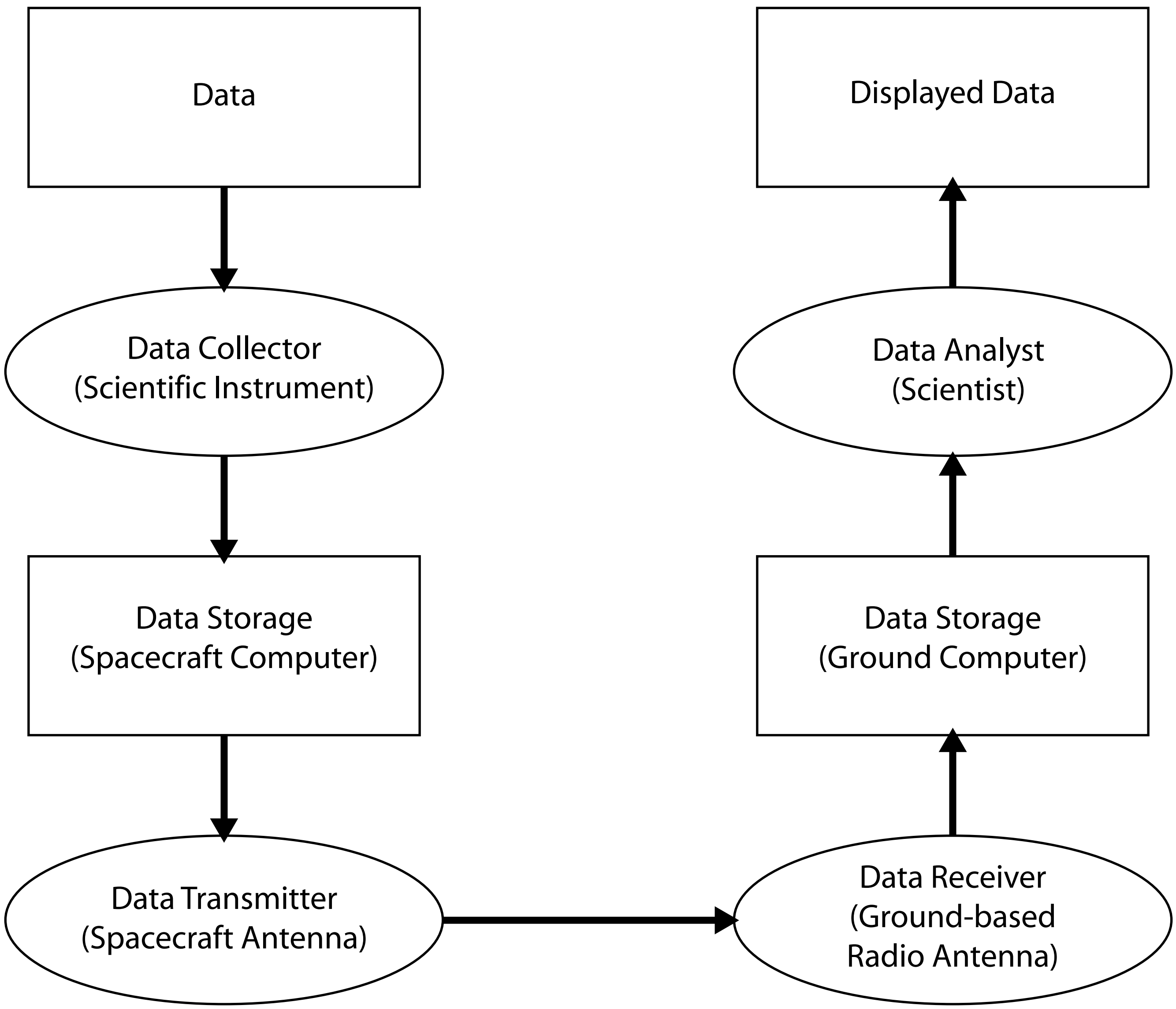


Figure 1. How scientific data get from the Moon to the Earth.

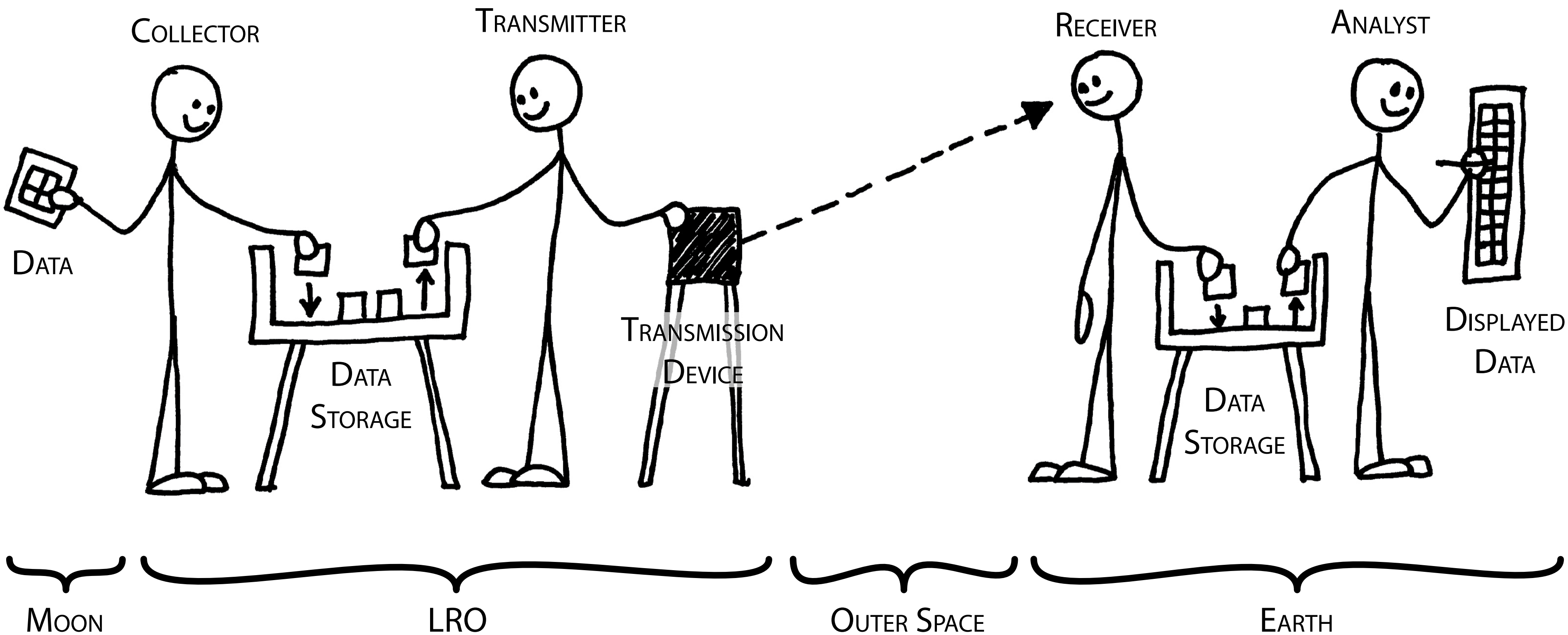
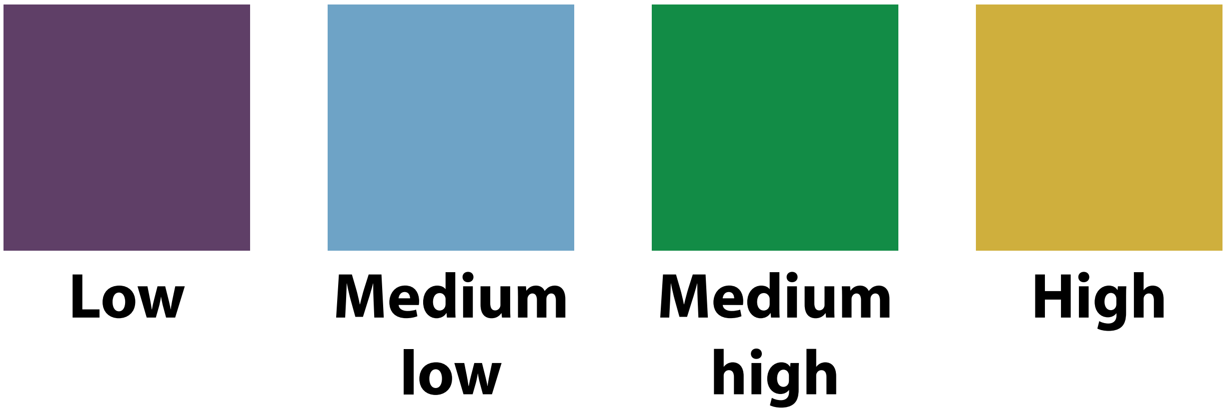


Figure 2. Diagram showing how the team operates.

Topographic Colors



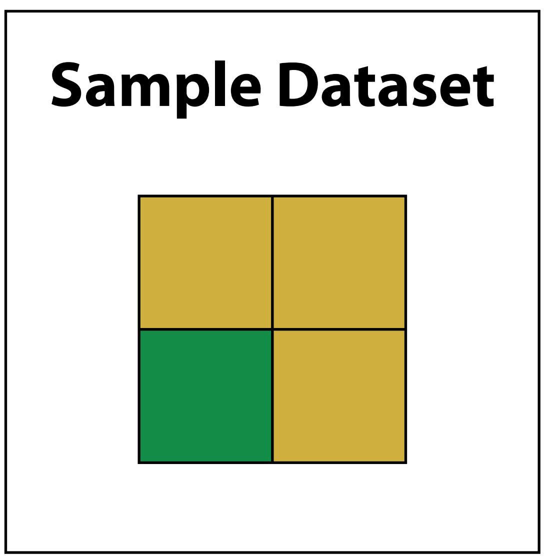


Figure 3. Data description for students.

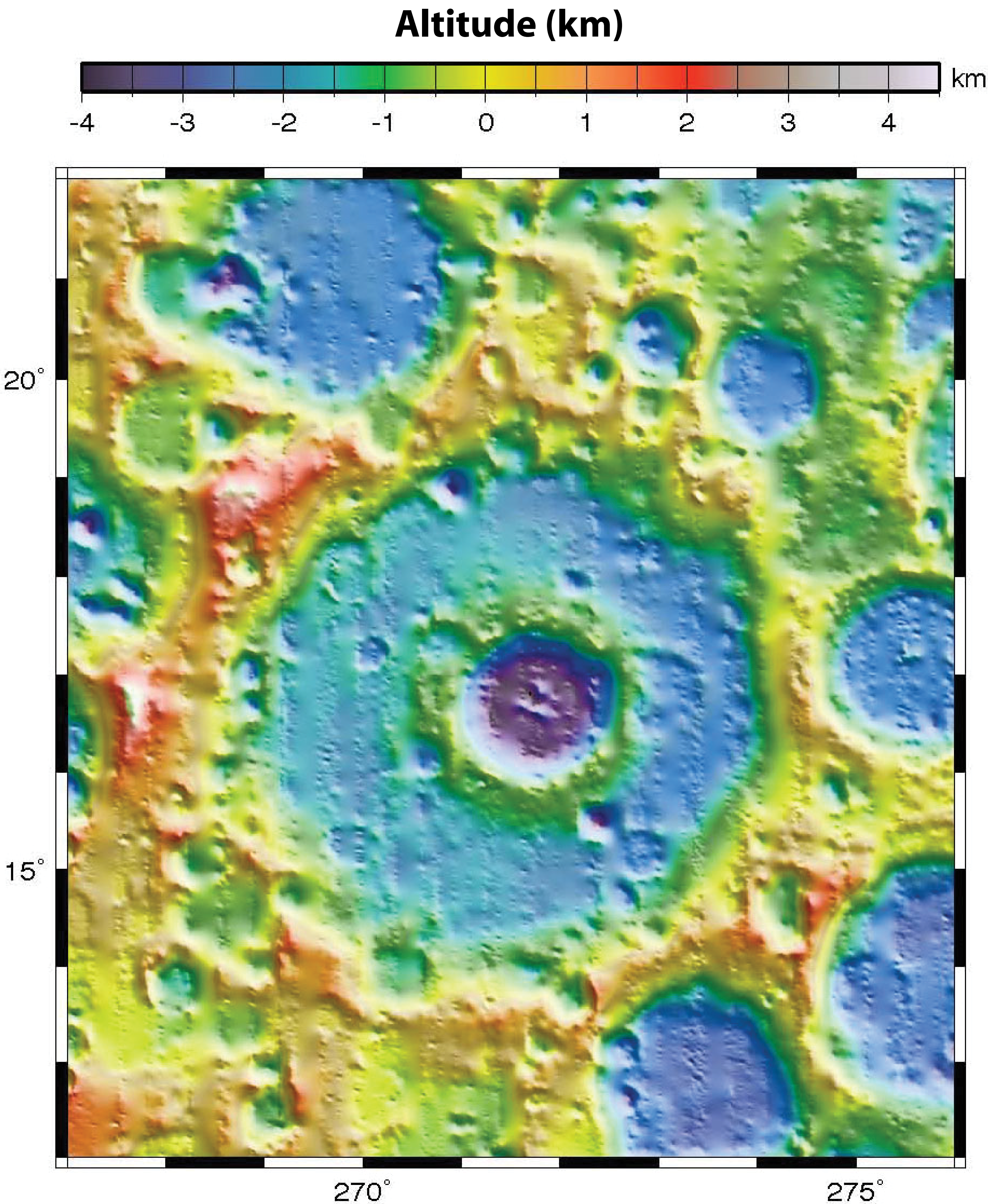


Figure 4. Topographic map showing Einstein and Einstein A craters on the Moon. Einstein A (the purple crater at center) formed in the middle of the older and larger Einstein crater (the light blue crater). The data are from LRO's LOLA. (NASA)

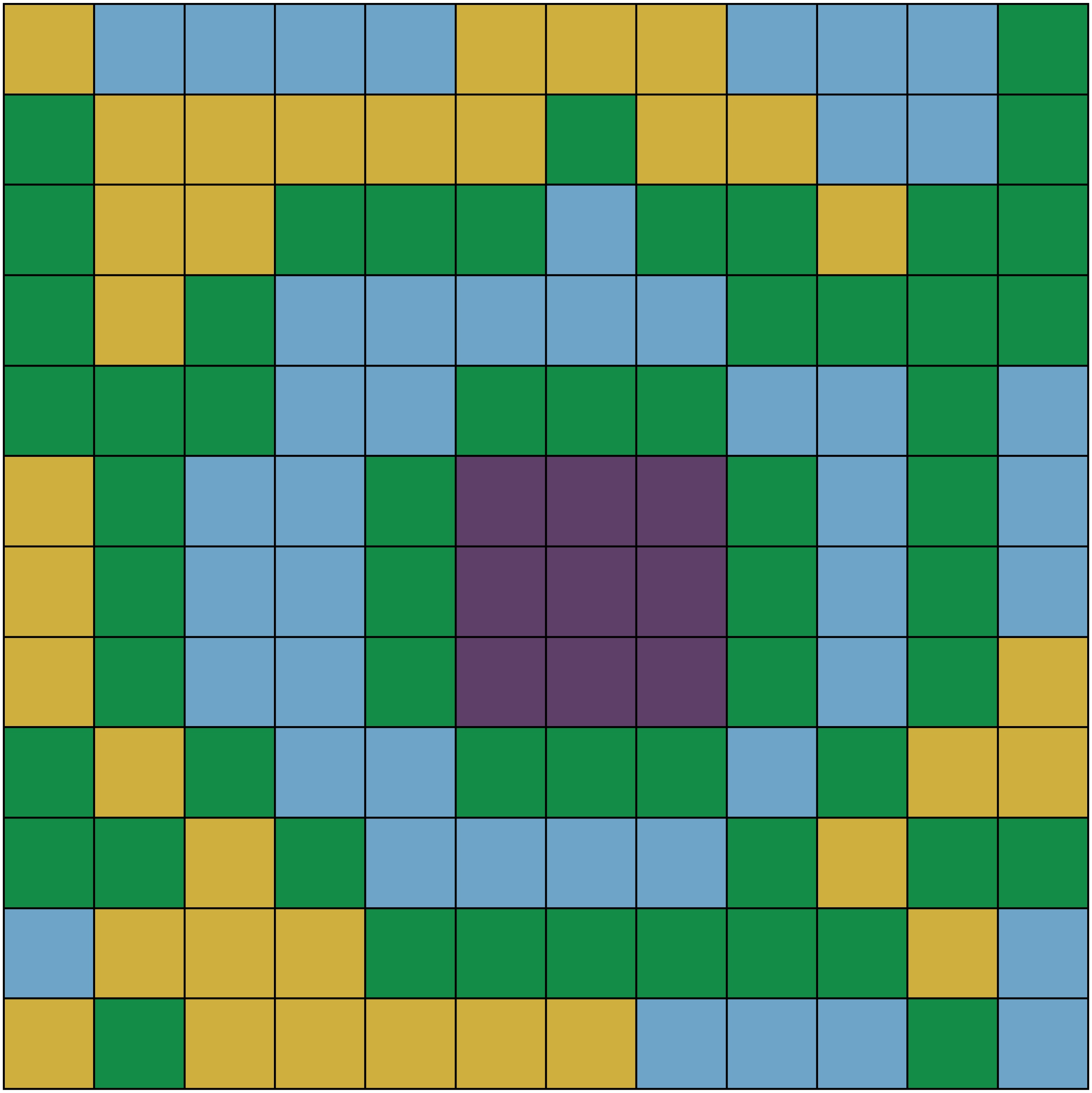


Figure 5. Low resolution topographic version of Figure 4. This is what the students will make.

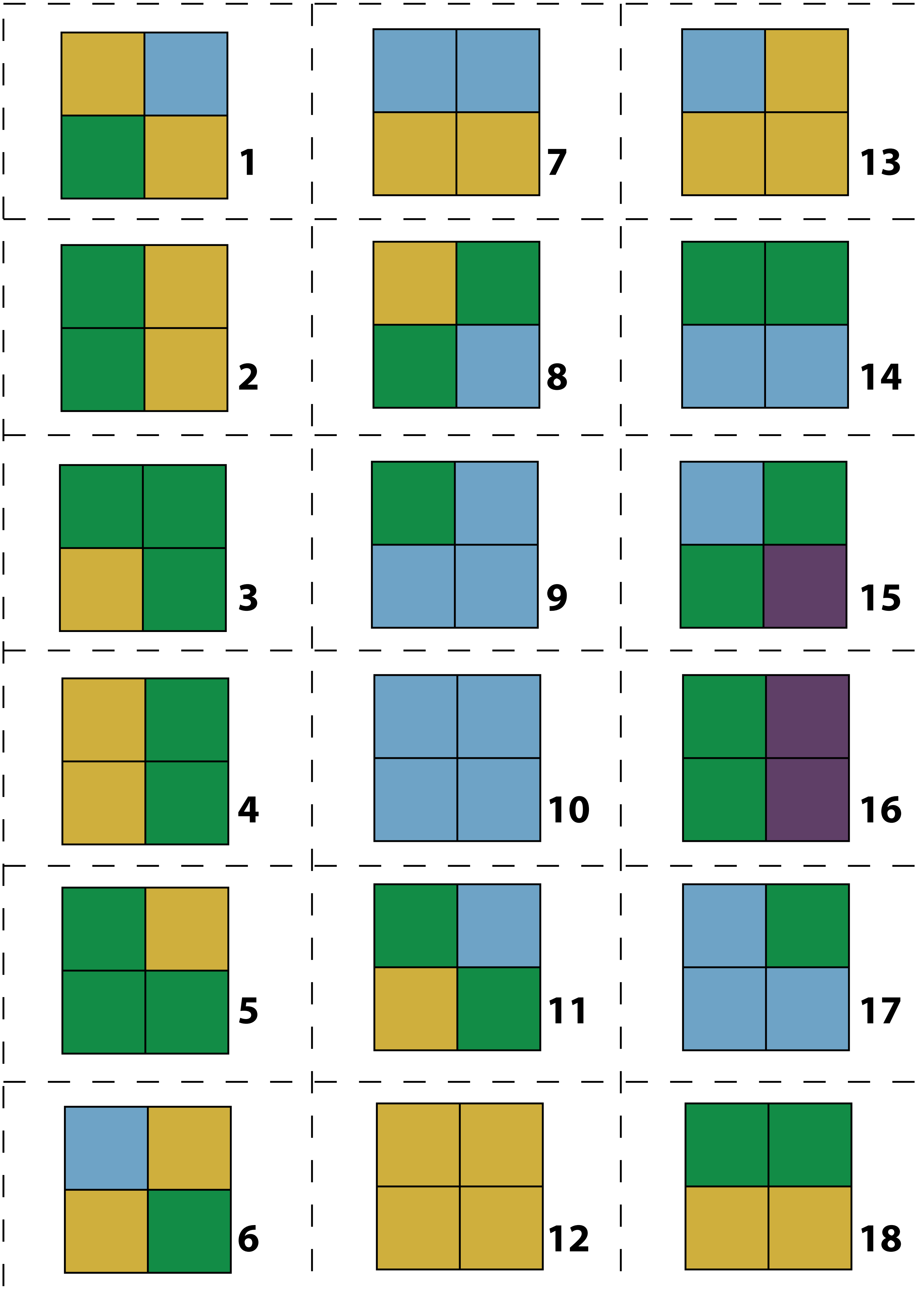


Figure 6a. Datasets 19-36. Cut along dashed lines

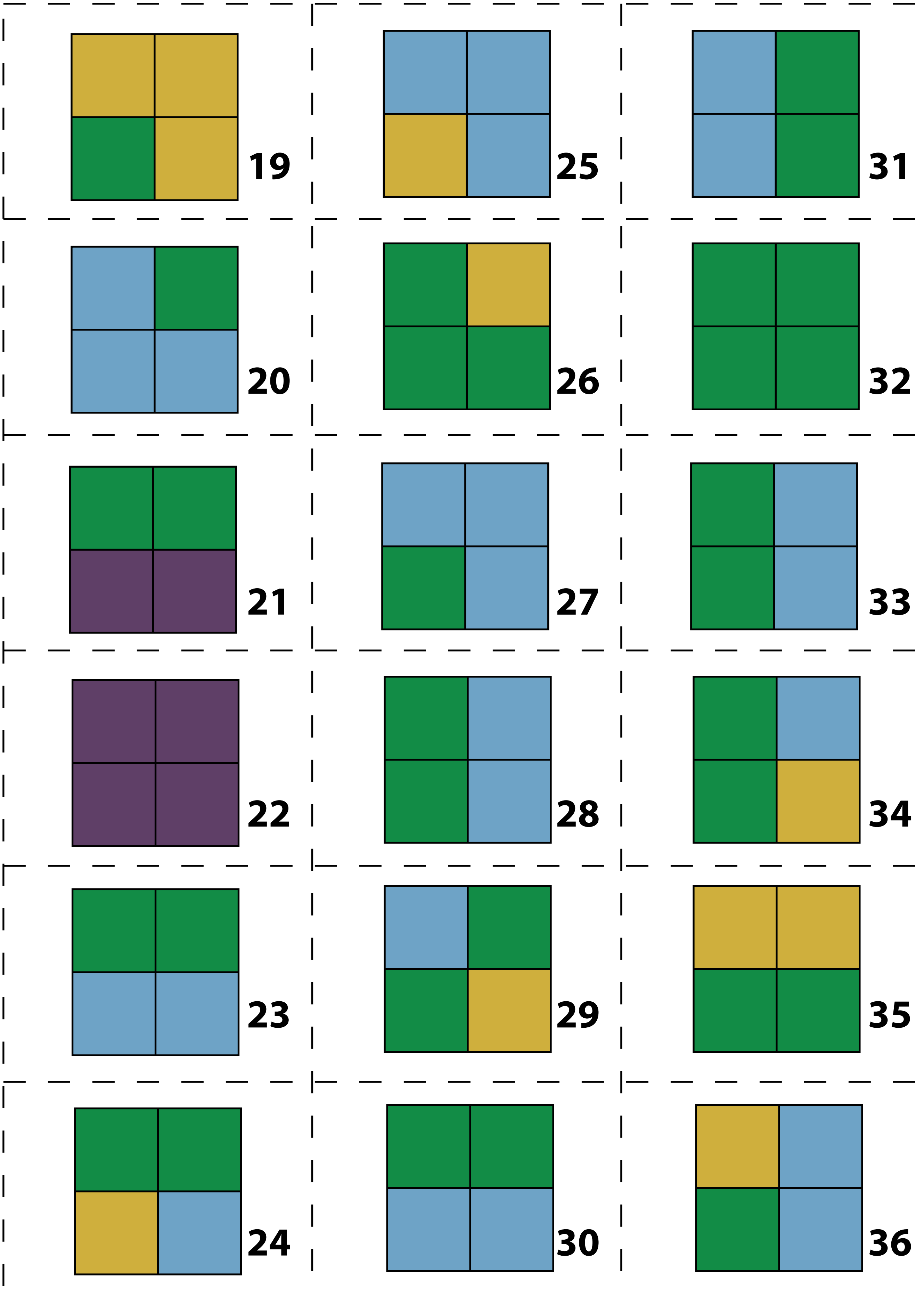


Figure 6b. Datasets 19-36. Cut along dashed lines

Figure 7. Data record sheets for the Analyst.