From Mars to Model:
A Simulation of Mars Altitude Data Acquisition and Reconstruction
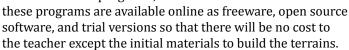
By David V. Black

Overview:

In this lesson, students will measure the altitude of a simulated Martian terrain using a grid pattern and will translate that data into both physical and virtual 3D models. This lesson will require quite a bit of preparation, but the end results in student learning make it well worth the time and effort.

After students collect the data, it will be built into three different models of the terrain. The first is a color topographic map keyed to altitude. The second model is made of cut pieces of drinking straws stuck into a layer of modeling clay to create a physical representation of the terrain. The third model is more involved: students will record the data as a number array in a word processing program, then convert it into a grayscale image based on the numeric values, then convert the image into a virtual model using 3D modeling software. It will take about three days to complete all three models. It also requires using several software programs; all of

First Color Image of Mars from Mariner 4:
Digital Data Colored by Hand

these programs are available online as freeware, open source software, and trial versions so that there will be no cost to the teacher except the initial materials to build the terrains.

The basic core of this lesson is a commonly used "mystery box" terrain activity. I have built on to this to add both physical modeling and technology components. The physical modeling activities were developed as a group of NASA/JPL Solar System Educators for our training workshop in 2001. I decided to adapt these activities for my multimedia and 3D modeling classes. I also demonstrated them for the 2002 through 2004 NASA Explorer Schools program at the Jet Propulsion Laboratory, for which I was an Educator Facilitator.

As both a multimedia and science teacher, I am always looking for good activities that integrate science with technology. This lesson began with a problem: how to locate actual Mars altitude data and then convert it into a format that could be read by the 3D software I was using. Over a period of several months, and with the advice of several people, I was able to find suitable free software that could convert numbers into images and images into 3D models. I also developed a process for downloading and using the actual 3D altitude data of Mars acquired by the Mars Orbiter Laser Altimeter instrument on the Mars Global Surveyor spacecraft.

This somewhat obsessive hobby eventually paid off: my students were selected for the 2003-2004 Mars Exploration Student Data Team (MESDT) program, where they were given access to actual Mars data (such as atmospheric dust

opacity) directly from Mars. My students used 3D modeling and data visualization skills to create images and animations of this data and of the Martian surface, then presented our techniques at an MESDT symposium at Arizona State University that spring. I had the good fortune of presenting our project at the 35th Annual Lunar and Planetary Sciences Conference in Houston, TX that same year. Over the years since, I've updated the lesson several times for new versions of the software. With the renewed interest in Mars exploration surrounding the launch and landing of the Mars Science Laboratory (Curiosity), it's time to update this lesson again and make it available for everyone.

I'd like to thank several people who have helped with this lesson. First, my thanks to Eric Brunsell and the other Solar System Educators that helped develop the physical model versions of this lesson. Eric spent quite a bit of time drilling holes in the lids of pencil boxes so we could create various versions of Mars terrains. Also, to Kees Veenenbos, who provided advice on where to find the Mars MOLA data and how to download and use it in 3D software, and to Jerry Farm and Richard Horne for developing the MacDEM and 3DEM software that can read and animate the data. Finally, to Dave Seidel, Art Hammon, Sheri Klug, and the many Education and Public Outreach coordinators at JPL with whom I've had the great privilege to work as an Educator Facilitator for the NASA Explorer Schools program.

Teacher Instructions

Objectives:

By the conclusion of this activity, students will be able to:
1 – Measure and record altitude data from a simulated Martian terrain,
2 – Create a color-coded altitude map of the terrain,
3 – Build an accurate physical model of the terrain,
4 – Convert numeric data of the terrain into a grayscale height map, then use 3D modeling software to build a virtual model of the data,
5 – Explain how actual altitude data of Mars was acquired and modeled,
6 – Utilize the same techniques to visualize other scientific data sets.

Science and Technology Standards Addressed:

This lesson is meant to integrate hands-on science (data collection and analysis) with technology (3D data visualization skills). The following national science standards are fulfilled

through this lesson:

Change, Constancy, and Measurement: (c) Measurement.
Science as Inquiry: (c) Use technology and mathematics to improve investigations and communications.
Understandings about Scientific Inquiry: (c) Scientists rely on technology to enhance the gathering and manipulation of data, and (d) Mathematics is essential in scientific inquiry (modeling).
Understandings about Science and Technology: (c) Creativity, imagination, and a good knowledge base are all required in the work of science and engineering.

Materials:

1 - Sturdy boxes or plastic containers with flat lids, approximately 15 x 20 cm and about 8 cm deep: one for each group of students.
2 - Modeling compound or clay, which can be modeled into simulated terrains and baked into a hard surface: enough for one model per box. Note: This cannot be Styrofoam or other porous material that can be easily poked.
3 - Lollipop sticks (3-4 per team).
4 - Metric ruler, one per team, preferably clear plastic.
5 - Colored markers, one set per team.
6 - An electric drill.
7 - Drinking straws: three boxes per team.
8 - Scissors.
9 - Thin cardboard sheet, same size as box, one per team.
10 - Modeling clay such as plasticene or other oil-based clay or Play-Doh ™, which can be rolled out onto the cardboard sheet.
11 – Rolling pin or some other smooth cylinder, used for rolling out the modeling clay.
12 – Grid paper, labeled to match the lids of the boxes.
13 – Permanent marker of a color that will show well on the box lid.
14 – Laser pointer and beach ball or globe (for the lead in demonstration).
15 - Each team also needs access to a computer with the following software installed: a word processing program such as MS Word, TextEdit, or Open Office that can save a text file in .txt format; ImageJ (a freeware image processing program created by the National Institutes of Health [NIH]); the GIMP (an open source image editing program) or Adobe Photoshop; and Blender (open source 3D modeler) or Daz3D Bryce 7 Personal Learning Edition (a free trial version). Here are the websites where these programs can be downloaded for free:

OpenOffice:
http://download.openoffice.org/other.html

ImageJ:
http://rsbweb.nih.gov/ij/download.html

The GIMP (Mac version):
http://gimp.lisanet.de/Website/Download.html

The GIMP (Windows version):
http://gimp-win.sourceforge.net/stable.html

Daz3D Bryce 7:
http://www.daz3d.com/i/software/bryce7/download
The serial number for the PLE is:
BDZPLED-070-0000000-NBA-001-HBUVMLF

Blender:
http://blender.en.softonic.com/

   The explanation in this lesson will use ImageJ, GIMP, and Bryce. The same results can be obtained using ImageJ, Adobe Photoshop, and Blender or other 3D program.

Preparation:

   This lesson takes quite a bit of time and effort to prepare, but you only have to do it once. The terrain boxes can be saved and reused for many years.

   Boxes: Your boxes should be rectangular, about 15 by 20 cm, and about 8 cm deep. Use a ruler and a fine point permanent marker to mark a grid of lines that intersect every centimeter but which don't come all the way to the edges of the box. Leave room on the edges for the labels, so that you have a final grid that has about 10 by 15 square centimeters. Mark each row with a letter and each column with a number. Then take an electric drill (make sure to wear goggles and other safety equipment) and drill holes in the middle of each

square that are slightly wider than the diameter of your lol-lipop sticks.

Terrains: Use a modeling compound which can be hardened by baking to create simulated terrains that will fit in each box, preferably snugly so the terrains won't move around during the activity. This compound can be found at most craft stores. The terrain should have a variety of landforms, or can be abstract. The maximum relief between the highest point and the lowest point on the terrain should be about 5-6 cm. For additional realism, you can look at photos or maps of Mars and duplicate areas of the Martian surface, such as Valles Marineris, Gusev Crater, Kasei Valles, etc. which have good relief (both low and high areas). If you want something that will be especially good, and if your school has a ceramics program, talk to the ceramics teacher about having some students create your landforms out of porcelain and fire them in a kiln. Whatever material you use, it needs to be hard enough that a lollipop stick can't be poked into it.

Grid Paper: Prepare a grid paper with lines identical to the lines and intersections on your box and labeled with numbers and letters in the same way. Make two copies for each group.

Measuring Sticks (to be done by the students): Lollipop sticks can be found at most craft stores as well. They are white and about 10 cm long, and work very well to simulate the laser in the Mars Orbiter Laser Altimeter on Mars Global Surveyor. Each student team should get 3-4 lollipop sticks. On the first stick, they will use a metric ruler to measure off every 7 mm or .7 cm, then use the colored markers to color in the areas between the marks. Start on the end with white, then yellow, orange, red, purple, blue, green, brown, and black (see the diagram). They may have to leave a few marks blank at the end, so that if the lid were on the box with the terrain inside, the stick would come to the yellow color when it hits the highest point of the terrain when stuck through the holes in the lid. When it hits the lowest point of the terrain, it should come to black.

On the second lollipop stick, use the metric ruler to carefully draw a line straight down the side of the stick and neatly mark off every millimeter along it, with larger marks every half centimeter, then carefully label every ten millimeters

starting with 80 (or whatever the depth of your box is) at the bottom end and counting up to zero (see the diagram). This way, when the terrain is measured, it will be the height of the terrain and not the depth of the valleys that is measured.

Clay Bed (to be done by the students): On the thin piece of cardboard, use your rolling pin or cylinder to roll out modeling clay (plasticene) into a thin, even layer about .5 cm thick that covers the cardboard and is the same size as the terrain. Use the metric ruler to measure off and mark each centimeter along each side, then take the ruler and press a crease into the clay to correspond with the layout of the box lid with the holes drilled in it.

Activity Lead-In:

Start by asking students if they know how the heights of mountains are measured for maps. Explain that before space travel, the U. S. Geological Survey (or the equivalent organization in whatever country you're in) had to send teams of surveyors out into the field, hiking through deserts and mountains, with surveying levels, sextants, chains, and other heavy equipment. Many errors occurred. Now, with space travel, we can use satellites to accurately measure the altitude of Earth's landforms. One recent mission was the Shuttle Radar Transponder Mission (SRTM), which used two radar transponders on the space shuttle, one in the main bay and one at the end of a long boom, to acquire stereoscopic measurements at the rate of one data point every three meters. It covered the Earth from 55° N to 55° S latitude (higher latitudes can't be reached by the space shuttle).
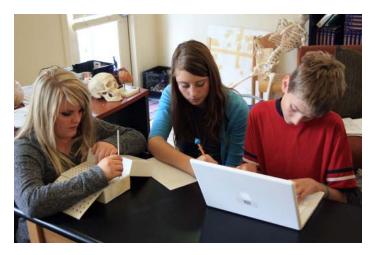
A similar device was deployed on the Mars Global Surveyor (MGS) probe, called the Mars Orbiter Laser Altimeter. It used a microwave laser, bouncing pulses off the surface of Mars which were captured by the instrument and timed. The longer the pulses took to return to the probe, the lower the altitude at that point. Since MGS was in an almost polar orbit, it was able to cover the whole surface of Mars from 88° N to 88°S. At first, the data was in low resolution (eight points per

degree), but over time and repeated orbits, the MOLA instrument built up more and more data points until it reached 128 points per degree. This data was radioed back to Earth and reassembled and is now archived at the NASA Planetary Data System node at the Washington University in St. Louis

(WUSTL). Similar instruments are used by the Magellan probe at Venus and the Lunar Reconnaissance Orbiter now orbiting the moon.

Demonstration: Have a student hold up the beach ball or globe and turn it slowly and evenly on its axis. You hold the laser pointer and push the on button repeatedly to create flashes of laser light as you also move the pointer in a polar orbit (looping over the north, then the south pole, then back to the north again). This will take a bit of practice, but it should show how eventually all the surface of Mars will have data collected from it. Safety note: be very careful as you rotate the pointer that you do not shine the laser in any student's eyes, or your own. If you shine it only at the ball or globe, you should be able to avoid this problem.

Procedure:

Divide students into equal teams, one team per terrain. Explain that they will be simulating how the Mars MOLA instrument collected the data from Mars by measuring a simulated terrain. They will then convert the data into color-coded maps, physical models, and virtual 3D models of the terrain. These same techniques can be used to analyze many types of data.

Provide each group with a terrain box and other materials. Have them begin by preparing their measuring sticks (lollipop sticks), both the color-coded stick and the millimeter stick. Also have them prepare the clay bed for the physical model and mark it off in the same grid pattern as the box lid.

Color-Coded Topographic Map:
Using the grid paper to record their measurements, the students use the color-coded stick to measure the height of the terrain at each hole in the box lid. At each hole, a student will insert the lollipop stick with the yellow end down, until it lightly touches the terrain inside. Don't press hard, or the stick may slide down a slope and give an inaccurate reading. Look at what color is seen at the level of the box lid, and use the color markers to make a mark in each square corresponding to the color seen on the stick. Once all the holes have been measured, color in the all squares on the paper. Then create a key showing what colors are high (yellow) and what colors are low (black). The team now has a topographic

map showing the high and low areas of the terrain model.

Physical Model:
Once the color map is complete, use the millimeter lollipop stick to record exact numeric heights on the second grid sheet. With the highest number down (80 mm), insert the stick at each hole until it lightly touches the terrain and record how far the stick goes in, even with the level of the lid. Write your numbers in the corresponding boxes on the grid sheet in millimeters. As the numbers are being recorded (one student can measure with the stick as another writes the numbers), another two students can create the physical model by measuring lengths of drinking straws with a metric ruler using the same numbers as the grid sheet, then cutting the straws and inserting them sticking up in the center of each square of the modeling clay on the cardboard sheet. Once it is done, they will have an exact replica of the terrain. Note: This will take some time and will be a bit tedious to do, as they will need to record, measure, and cut straws for 150 data points. Making the physical model will help keep the student's interest up and keep everyone working.
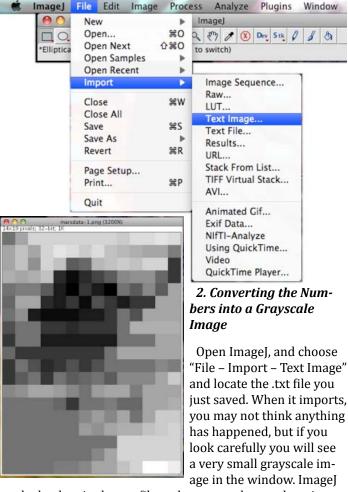
Virtual Model:
This is the most complex of the three models, and will take at least a day to complete. You will need a word processing program, ImageJ, the GIMP (or Adobe Photoshop or other image processing program), and Daz3D Bryce or Blender software installed on a computer for each team. This model will progress through four phases.

1. Typing the Number Array

Open a word processing program such as MS Word, TextEdit, or Open Office. Have the student team type in each row of numbers from the grid sheet, separating the numbers by a comma and a space and hitting "return/enter" at the end of each row. There should be ten numbers per row and 15 rows. Then type a zero at the start and at the end of each row, also separated by commas. This will prevent a problem later on in the 3D program. Then save the file as a simple text (.txt) file, not as an MS Word file.

from the menus and typing in 300 for the X and Y resolutions and 6 inches for the width.

D – Make the image square by changing the canvas size. Choose "Image – Canvas Size" from the menus and choose "Inches" for the units. Then click on the chain link icon next to the Canvas Size (width and height) selectors. Raise the Width and Height to the next highest unit. For example, if the Width is 2.76 inches, then change the Width to 3.0 inches and make the Height the same amount so that the final image will be square. Then click the Center button. This will prevent a problem in the 3D software later on (where height maps must be square). If we don't do this, your terrain will be distorted. Deselect by choosing "Select – None".

E – Blur the image to eliminate any artifacts around the pixels. Choose "Filter – Blur – Gaussian Blur" and choose one pixel for the blur amount.

E – Fill in black around the grayscale area by selecting the grayscale area only with the Rectangular Selection tool, then inversing the selection with "Select – Invert". The selection "marching ants" should be around the outside now. Flatten

the image by choosing "Image – Flatten Image". Choose black for your foreground color, then fill black into the selected area by choosing "Edit – Fill with FG Color" from the menus.

2. Converting the Numbers into a Grayscale Image

Open ImageJ, and choose "File – Import – Text Image" and locate the .txt file you just saved. When it imports, you may not think anything has happened, but if you look carefully you will see a very small grayscale image in the window. ImageJ reads the data in the .txt file and converts the numbers into gray pixels, with white being assigned to the pixel with the highest numeric value and black to the lowest (the zeros on the outside of each row). You should see a thin black line on each side of the image. Now zoom in on the image as far as possible by choosing "Image – Zoom – In" or "Command +". Keep doing this until you have zoomed in as far as it will let you. To save the file, you won't use the save command as that would only give you the tiny pixel image. You need to save the zoomed in version. To do this, take a screen capture of the window by holding down "Shift-Command-3" on a Macintosh or by hitting "PrntScrn" on Windows. On Macs, this will save a .png image on your desktop. In Windows, it will copy the screen image to the clipboard.

3. Editing the Screen Image

A - Open up GIMP. If you are on a Mac, choose "File – Open" and choose the .png file that was just saved on your desktop, which should be named Picture1.png. If you are on a Windows machine, choose "File – Create from Clipboard" and it will automatically paste in the clipboard and make a file that has the same dimensions.
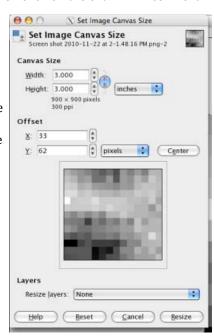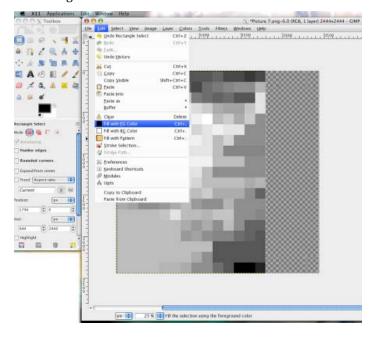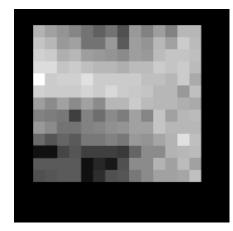
B – Crop the image by choosing the Rectangle Select Tool in the Toolbox, then selecting only the height map part of the screen capture. Then choose "Image – Crop to Selection" to crop it (Mac only).

C – Resize the image by choosing "Image – Scale Image"

F – Save the file by choosing "File – Save As" and naming it something appropriate. Choose .jpg from the pull-down list and choose 100% for the quality setting. Good! Now you're almost there.

4. Creating the Virtual 3D Model

This last step will involve opening a 3D modeling program, creating a landform or terrain, then applying your image as a height map, where the light colors become mountains and the dark colors become valleys. Most 3D modeling programs can do this, and the one we'll use here is Bryce by Daz3D. Version 7 is available on the Daz3D site as a Personal Learning Edition, or free trial. As far as 3D software goes, Bryce is about the easiest to learn (versus Blender, which, althoug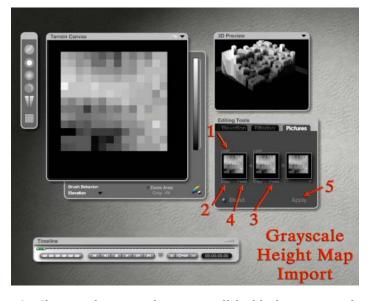h free, has a very steep learning curve). Bryce is actually a lot of fun to learn and has powerful resources for creating natural landscapes, or, in our case, artificial terrains.

A – Create a mountain in Bryce by opening the program, then clicking on the Terrain primitive (third icon from the left in the Create menu). A red wireframe version of a random fractal mountain will appear in the scene window.
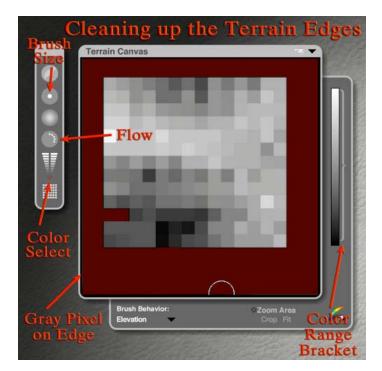

B – Map our data onto the mountain by clicking on the small "E" square next to the mountain wireframe (see image). This opens the Terrain Editor. To load in our terrain image, click on the "Pictures" tab in the Editing Tools window. Then click

the "Load" text above the left square in the window (Step 1). Navigate to find the .jpg image you just saved from GIMP. There is a slight glitch in Bryce that requires a couple of quick extra steps to work around. Once the image loads in, it will look somewhat mirrored in the small window. To fix this, click on the "Copy" button under the left window (Step 2), then click on the "Paste" button under the middle window (Step 3), and click back on the "Paste" button under the left window (Step 4). This will now show the same image in all three windows. Then click the "Apply" button at bottom right (Step 5).

C – Clean up the terrain by cutting off the black area around the original terrain grayscale image. This is done by clicking on the small icon next to the arrow at the top right of the Terrain Canvas. This will open up some options, including a bracket down the right side of the Terrain Canvas. If you drag up the very bottom of this white color range bracket slightly, you will see the black areas of the terrain go a deep red color. This turns those areas transparent in the model.

Sun Control

Texture Selection

Camera Controls

Trackball

Render Button

Rendering the Terrain

D – Make the terrain solid by turning on the "Solid" toggle choice under the small black arrow at the top right of the Terrain Canvas. Exit the Terrain Editor by clicking on the Check Mark circle at the bottom of the screen.

E – Apply a texture to the model by clicking on the small arrow to the right of the Edit menu at the top of the screen (see the image). This gets you into the preset materials window. Choose "Terrains" from the selection pop up at the bottom left of the window and choose a material of your liking. Click the Check Mark to apply.

F – Fix any artifacts or weird edges by going back into the Terrain Editor (click the little E) and using the tools to reset the brush size, flow, and color. The color is selected by dragging the small red dot all the way down to the bottom of the inverted pyramid, which is black. Then paint around the edges to remove any unwanted gray pixels that may have crept in.

G – Adjust the camera's viewing angle and position using the Camera Controls and the Trackball.

H – Adjust the sun's position by entering the "Sky and Fog" menu and using the Sky Control trackball to move the sun to a good position.

I – Render the scene by clicking on the large Render ball at the bottom left of the control icons. If the model has poor lighting or still has artifacts, fix them. Get out of the rendering by hitting your escape key twice. Try different sun angles, different camera angles, and different materials. You can also select the ground plain and put a better texture on it than the default gray, such as a water texture.

J – Once the scene is looking good, render it out all the way (it will make several passes ending with Antialiasing), then export the image with "File – Export Image" and save it as a .psd or .jpg. Congrats! You've done it! You've just turned raw numbers into a sophisticated 3D model to visualize the data.

Follow Up and Application:

You can use this same process to visualize almost any type of numeric data, especially if it can be written as a data matrix or array. For example, my students received dust opacity data during the Mars Exploration Student Data Team program which was acquired as a global map of numbers (tau readings). These numbers were converted into a gray-scale image for each day, and we turned those images into an animation showing how a dust storm began on Dec. 10, 2003 north of the Valles Marineris then spread globally and threatened the Mars Exploration Rover missions. Seeing the dust storm as a 3D animation allows patterns and trends to be observed that can't be seen by merely looking at the raw numbers. You could just as easily create a 3D chart showing the production of various types of cheeses in Utah over the last decade (we've done this one, too) or any other type of numeric data. Once you have a model in 3D, you can texture it, render it, animate it, and visualize it in many useful ways. The ability to take raw data and turn it into an appealing visual image or animation is a very marketable skill, one that many companies and scientific organizations are in need of.

All models have limitations. The ones we've made here have the problem of low resolution: not enough data points to portray the actual terrain in detail. Fine points of the terrain may be missed. To improve the resolution of our models, the students could set up the box lid so that it can be moved by .5 cm either right, down, or diagonally (or all three) to measure data points between the points we already have, much as the MOLA instrument did to increase the resolution of the data. Missing data can also be extrapolated by averaging the data points on each side.