MARS EXPLORATION: A COMPLETE TUTORIAL for the STAR PROJECT

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INTRODUCTION

Hello! I am Joe Kolecki, and I will be your scientific consultant for the Science Through ARts (STAR) project. I am a physicist and Learning Technologies Project mentor at the NASA Glenn Research Center (GRC) in Cleveland, Ohio, U.S., where I have pursued my lifelong interest in Mars through research into Earth orbital science and spacecraft-environment interactions. I have been interested in astronomy since I was seven years old. Quite possibly like you, I built imaginary scenarios that involved interplanetary flight and exploration.

NASA's work with environment interactions began 30 years ago. The Earth's ***ionosphere*** is an electrically active environment in Earth's atmosphere that interacts in a variety of ways with electrically active satellites. Other planets besides Earth show evidence of electrical activity. For example, Jupiter has extensive auroras and atmospheric lightning, as do the other gas giant worlds to different degrees. When the Apollo astronauts went to the Moon, they acquired evidence that Moon dust became charged photo electrically from solar ultraviolet light. Charged dust was levitated on local electric fields to 10's of km above the lunar surface; the dust clouds were most prominent at the ***morning terminator*** (the sun rise line between night and day).

I began to wonder if similar phenomena might not occur on Mars. For the next 20 years, I became actively involved with Mars research and learned and tried new ideas with other members of the Mars community in the U.S. and abroad. When the idea of sending humans to Mars became serious within NASA in the late 1980's, I convened and ran a three-day workshop for Mars, Moon, and rocket science experts from across the country to identify issues associated with a potentially chemically and electrically active Martian environment. The published results of that workshop are still being referenced by scientists around the world.

In the early 1990's, I was approached by the Pathfinder team at the Jet Propulsion Laboratory (JPL) in Pasadena, California, with questions about rover electrostatic charging during operations on Mars. The primary question was, "Will the rover acquire electrical charge as it moves over the Martian surface and, if so, how much?" My answer was "Yes," and I was able to back my answers and give actual estimates with calculations and laboratory results.

In the laboratory, I also discovered a ***mechanism*** (physical process) that would enable lightning to occur on Mars during Martian dust storms. Charging in Martian dust varies by ***sign*** (+ or -) with the physical size of the dust grains. A similar process occurs in terrestrial thunderstorms where water, not dust, is the charge carrier. The mechanism has only been seen in the laboratory so far; it has not been verified yet on Mars. But experiments to verify my laboratory findings will be sent on future missions, possibly within the next 10 years. My observations of the Pathfinder rover on the Martian surface confirmed my expectations about rover charging on Mars. Those results have now become one little brick in the structure of modern day Mars science that has been rapidly developing since the Pathfinder mission.

In STAR, you will learn and write about Mars exploration. This document covers many of the more important aspects of your STAR activity:

- Part I presents facts about Mars that represent our current state of knowledge as obtained from NASA's various robotic spacecraft. Use these facts as a springboard to learn even more via the World Wide Web and via direct videoconferencing interviews and e-mails with me. The section on Indigenous Water on Mars includes questions intertwined throughout the text to guide your thinking and to show you how to get the most out of your reading. In the remaining sections, I want YOU to generate the questions and relate your questions to me via e-mail or during one of our videoconferences!
- Part II presents a synopsis of the STAR program that describes how your newly acquired scientific knowledge can be used as a basis for producing stories and other works of art based on that knowledge. Please read it carefully and remember that learning science is the primary objective of STAR.
- Part III presents a sample story, a Fantasy in the spirit of P. Lowell, to demonstrate how scientific concepts can be placed into phrases, or even single words or images. It is probably more a prose poem than an actual story, and I wrote it largely for my own amusement. The time was high summer, and I wanted to express a summer-evening type of mood. Pull out as much science as you are able from the story and prepare to discuss your findings with me during one of our videoconferences.

When you have completed the tutorial and are ready to begin, I hope that you will enjoy your STAR experience and learn a great deal. Remember, as with all learning, to have fun. You are looking into a new and unknown realm. The process is not unlike what we do at NASA—experience the excitement of discovery and self-expression as you learn.

Best wishes! I'll be talking to you soon!!!

Joseph C. Kolecki
NASA/GRC/LTP/STAR

PART I:

Section A - HIGHLIGHTS of MARS

Your STAR activity will most likely reflect the current interest in sending humans to Mars. However, before we begin, I will briefly summarize our existing knowledge of the Red Planet. Remember, this is ONLY a brief summary. To relay everything known about Mars would fill a book of several thousand pages. Such books have already been written, and I do not intend to repeat their words. I will discuss just two topics of vital interest:

- ***Indigenous*** (native) water on Mars, and
- Life on Mars.

After you read about these topics, consult the World Wide Web or an astronomy text to learn even more about Mars, its history, its topology, its weather, its two moons, and so on.

Indigenous Water on Mars

Mars shows ample evidence of having been very Earth-like in its remote past. It was both warmer and wetter and had a magnetic field, with traces surviving today. The importance of planetary magnetism cannot be ignored. The magnetic field acts as a natural defense that protects the surface from high energy charged particles streaming from the sun as solar wind or as ***coronal mass ejections*** (violent solar events spewing large amounts of high energy particles with radiation that roar through the solar system, disrupting everything in their paths). Life, as we know it, cannot survive direct bombardment with these particles. We exist here because the Earth has a magnetic field to capture and hold them.

There is evidence that liquid water flowed over the Martian surface early in Mars' planetary history. From orbit (Voyager, Viking, Global Surveyor) we have seen ***arroyos*** (dry river beds) and dry lake beds, particularly in tropical and semi-tropical latitudes. These features indicate that water must have flowed for long periods of time in the Martian past.

- Try to find some pictures of Martian arroyos. Why do you think that they indicate a wet past? How do they compare with large river systems on Earth?

Most arroyos show ***dendritic*** (branching) ***drainage patterns*** (river channels with extensive tributary systems) extending from source regions in the Martian highlands to drainage basins in the lowlands. These lowland basins may have once been fresh water lakes or small salt seas. Source regions often contain dry highland lake beds, some with well formed outlets but no inlets. It seems most likely that the "lakes" were replenished by an ***atmospheric water cycle*** (rain) in the distant Martian past.

- Since Mars is a frozen world today, what does the presence of rain on Mars suggest about Mars ancient climate? What does this, in turn, suggest about the ancient Martian atmosphere? How might that atmosphere have changed over time? What might have happened to cause the change?

The depth and extent of the river channels and the alluvial fans at their outlets are evidence that large amounts of water flowed when the river channels were active. ***Alluvial fans*** are deposits of water-borne materials, collected during periods of rapid, heavy flow, then deposited again when the flow slows upon entering a larger body of water. Alluvial fans exist at the mouths of all major river systems on Earth.

- How does water transport material? Do you think rapidly flowing or slowly flowing water moves more material?

Splash craters, which provide evidence of subsurface water or ice, have been found in various regions on Mars. These craters have distinctive crater walls, best explained by assuming that mud, rather than dry material, was disrupted upon impact and thrown outward. Bring a hammer sharply into mud and watch the results. The aftermath will appear similar to some of the Martian splash craters.

- Why did we find subsurface water or ice rather than surface water or ice? What do splash craters and arroyos suggest about the history of water on Mars?

There are regions on Mars that show evidence of having experienced devastating floods. Pathfinder landed at the outwash of one such region just northeast of the Mariner's Valley at the opening of the ***Ares Vallis in Chryse Planitia*** [Greek: Mars Valley (emptying into) the Golden Plain].

- It is a good idea to have a Dictionary handy when you study names in astronomy. You will learn much about Greek, Latin, and mythology! Find a map or globe of Mars and locate the Ares Vallis. You will find it at the extreme northeastern end of the Mariner's Valley.

On Earth, such features are associated with glacial recession at the end of the ***Pleistocene Epoch*** (Great Ice Age). Ice dams, which formed at the height of the Great Ice Age and held back vast quantities of liquid water, warmed, melted, and collapsed. The dammed up water was released in one huge surge that washed down slopes, taking out everything in its path and carving deep, semi-linear channels.

- What does "Pleistocene" mean? What was the Great Ice Age? What evidence do we have that it occurred? Who is Louis Aggasiz?

On Mars, the Ares Vallis is over a mile deep at some points, indicating that an immense surge of water must have been released at some time in Mars' remote past. Features such as these are distinctly different from the well formed branching arroyos, and are easily recognizable, even to an untrained eye.

The Martian surface has a thin crust that was observed at three landing sites—the two Viking sites and the Pathfinder site. The crust (called "duracrust") is believed to have formed as the result of water arising from the ***sublimation*** (direct transition from solid to gas) of ***permafrost*** (subsurface ice), which liquefied briefly at the surface and dissolved various clays that loosely cemented the surface dust together.

- Find a picture of the Sojourner rover at the rock Yogi Bear. Next to the rock you will see a beautiful piece of duracrust turned up by the rover wheel.

So where did all the water go? Well, for one thing, Mars' surface gravity is a mere 1/3 of Earth's surface gravity. Thus, Mars started out having less capacity to hold onto its early warm atmosphere than did the Earth. It is not unreasonable to assume, therefore, that some of the native water on Mars evaporated into space with the atmosphere over the long eons of Mars' gradual drying out. The remainder subsided into rocky layers and reservoirs under the Martian surface.

- Evaporation is a cooling process. How might the evaporation of part of Mars’ atmosphere have affected the entire atmosphere? How does an atmosphere store heat? You will need a physics book to answer this one!

As Mars lost its atmosphere, it also cooled down. An atmosphere acts much like a thermal blanket, enabling a planet to retain surface heat. As the atmosphere evaporates, the ability to retain heat diminishes, and the surface cools, or, as in the case of Mars, eventually freezes. The atmosphere that remains at this point is no longer able to evaporate because it is simply too cold.

- How does Mars’ thermal history differ from Earth’s? Will Earth ever undergo a drying out similar to Mars? Some scientists suggest that Mars is in a protracted ice age. What does this statement mean?

The water that remained on Mars must have ***subsided*** (moved underground) long ago and become frozen, becoming a permafrost layer under the surface. The permafrost layer is believed to exist several meters below the surface in the equatorial regions of Mars, but draws closer to the surface near Mars’ north and south poles. At the latitudes of the polar ice-cap edges, it breaks through the surface and joins with the Martian polar ice.

- Can you draw a cut-away view of Mars and sketch the permafrost layer?

Today Mars is thought to be locked in a permanent ice age. The Mars Global Surveyor recently discovered surface flow patterns on Mars, suggesting geologically recent ***liquid*** water (having flowed within, possibly, the last 10 to 100 thousand years!?). This discovery came as a genuine surprise to scientists who are still trying to understand exactly what is going on.

- You will certainly want to find out more about this!!!

If the interpretation of these most recently discovered patterns is correct, there must exist one or more thermal sources on Mars to provide for the melting and flowing of subsurface ice in sufficient quantities to break out above surface in the form of artesian wells. The quantity of water involved in these wells is not tremendous. But that something like this occurred at all in Mars' own recent history is nothing short of astounding!

- Mars has many volcanoes both great and small, such as the Tharsis volcanoes. But there are many others as well. Scientists had believed that the Martian volcanoes were all extinct. Does the discovery of the possibility of liquid water put a new twist on this idea?

Life On Mars

If there IS or WAS life on Mars, I believe that it is very primitive—as suggested by the possible fossils found in the two Mars' rocks presently stored at NASA Johnson Space Center (JSC). The search for life on Mars will take many years and involve many small steps, each turning up a little more new data than the previous.

The Viking landers carried biological experiments based on Earth life as a prototype. Their initial results were very exciting; it appeared that life had been found! But then complications began to set in. The final conclusion from Viking was indefinite about life. But we learned that

Martian surface chemistry is unexpectedly unstable, a fact neither known nor anticipated before Viking.

What can we know initially from life on Earth? We know of two classes of living organisms on Earth. By far, the largest, most abundant, and most familiar is the class made up of organisms that ***metabolize*** (live off of) carbon. Humans are one member of that class. Everything that we eat contains organic substances made up of types of molecules called hydrocarbons.

The other class has only recently been discovered. We know little about it yet, but we are slowly learning more. This class is made up of organisms that metabolize sulfur. Their representatives are found in deep regions of the ocean that are volcanically active. Specifically, they are found near deep oceanic vents called "smokers" because they vent hot materials into the surrounding water much as a chimney vents smoke into the air.

The mysterious creatures that live near these vents are varied in form. Some have legs and are mobile. Others appear to be rooted (like sea anemones) and are stationary. They are all, uniformly, sightless, colorless, and, as far as we know, soundless. Their life cycles are still virtually unknown. They live in deep watery regions of absolute darkness, horrendous pressures, and abysmal cold. Heat, apparently, is derived from the thermal energy associated with their local vent. They live on a rich diet of volcanically produced sulfur compounds that constantly spew from the vent, coming, in turn, from hotter, deeper magma-rich regions far below the ocean floor.

When a particular vent goes cold, as happens quite often in their world, we suspect that the little creatures die off or migrate somewhere, only to mysteriously reappear when another vent opens nearby. These creatures of the volcanic ocean deep provide biologists with an excellent example of "alien" life right here on Earth!

Given the extremely harsh conditions that prevail on Mars, microorganisms are the most probable sort of life that we can expect to find there. The rocks stored at JSC are believed to have come from Mars! They were all found at the Earth’s South Pole. How did they get here? We have found evidence that Mars underwent some devastating collisions in its past. Perhaps rocky or iron fragments from the asteroid belt impacted its surface. Perhaps some of these impacts threw material free of the planet. This material would have then settled into orbit around the sun. The orbits might not have been the near circular orbits of planets, but ***eccentric*** (elliptical, or shaped like a circle stretched out in one direction), carrying the Martian debris across the orbits of the inner planets, Mercury, Venus, and Earth. If so, then it would only be a matter of time before these inner planets collided with and collected some of the debris.

To date, we have less than 20 pieces of Martian rock on Earth. The origin is fairly certain based on chemical analysis compared to the Viking surface data. Two of these rocks have revealed what might be fossils of ***nano-bacteria*** (rod-shaped bacteria smaller than anything known today, but similar to the earliest terrestrial fossils found in ***pre-Cambrian*** rocks (one of the earliest geological periods on Earth, long before life had become firmly established). If these features are fossils, then humanity has already seen its first evidence of Martian life. As with all science, much work remains to be done.

Let’s assume a piloted mission to Mars. Let’s also assume that previous robotic missions have given positive indications of present day microbial life on Mars. Naturally, the crew would want to have a firsthand look at alien microbial colonies (a typical colony might be microscopic or no more than a few millimeters in diameter). The colonies would have to be well protected from the extremely harsh conditions on Mars, and might, in fact, live in the interiors of rocks, as do some organisms at the Earth's South Pole. So, while they might be fairly widely distributed, they might also be very difficult to find!

Let us suppose further that the astronauts succeed in actually finding such colonies and excitedly report their success back to Earth in their daily progress report. Mission control would carefully consider what they have said and instruct the astronauts to return a live sample to Earth. Such a sample would have to be handled in some very special ways.

First, there is the risk of killing the microbes in the process of transplanting them from their native habitat on Mars to an artificial environment suitable for storage and transport to Earth. There is also the risk of exposing them to lethal conditions while on board the spacecraft. (For example, the temperatures comfortable to the astronauts might be far too hot for Martian microbes to survive.)

Before any attempt is made at removal or transport of the microbes from Mars, their tolerance to a whole host of living conditions must be thoroughly tested and understood, unless preserving them alive is not a requirement. If the microbes were SO sensitive to being disturbed by humans that no other options were available, then we would bring back small samples of non-living material.

Second, there is the so-called "Andromeda Strain Syndrome." (The name "Andromeda Strain" is derived from the title of a science fiction novel written by Arthur C. Clark in 1969. Please get a copy and read it. It is a quickly moving story that I know you will enjoy!)

The Andromeda Strain scenario assumes a strain of alien organism that is lethal to humans. The likelihood of such a scenario is very remote, since most disease bacteria and viruses are highly specialized to their host organisms. But it cannot be entirely ruled out. For example, Ebola is painfully fatal to humans, but is carried without any effect at all to a species of African monkey. Monkeys are close to humans, genetically; and yet Ebola is so specific that it can tell the difference between a monkey host and a human host and will destructively invade only human tissue.

It is far more likely that indigenous Martian organisms will be specialized to consuming and/or invading other indigenous Martian species. Even if some type of bacteria represents the highest form of microbial life on Mars, there might still be species of ***bacteriophage*** (viral organisms that destroy bacteria) that prey on them. We know of such phage species living on Earth.

The Andromeda Strain Syndrome extends to the planet Earth itself as well as to the astronauts on Mars or in their spacecraft. If living organisms are transported to Earth, they will be shipped in complete isolation from the crew and delivered into isolation in a ***remote flyer*** (an unmanned Space Station module that orbits the Earth separately from the main Space Station). The living organisms will be remotely analyzed in automated laboratories using television cameras and elaborate robotic devices that can be controlled from a safe, isolated vantage point. Depending on the remote analysis, they may never actually be introduced into a laboratory with human presence. Even if the chances of unleashing a Martian plague on Earth are only a million to one, NO responsible scientist or political leader would ever endorse taking such a risk. The bacteria would, most likely, be destroyed after a thorough analysis and discarded into space, possibly to eventually fall into the sun.

Section B - ROBOTIC EXPLORATION

Exploration of a planet is not an easy task. Exploration must proceed in a step-by-step fashion, with thorough learning and thorough planning accomplished at every step.

The initial phases of Mars exploration will be accomplished using robotic exploration of specific areas of interest on Mars. This is the phase NASA is actively involved in today. The robotic exploration phase will probably take years or even decades to complete.

Three types of robots have been used on Mars in such missions as Viking, Pathfinder, and Mars Global Surveyor. The fourth type of robotic explorer, flyers, has not yet flown on Mars.

- Orbiters: Orbiters enable global planetary reconnaissance, the construction of maps, and the identification of peculiar and interesting surface formations. But orbiters often fail to give the required detail (resolution) for a thorough understanding of “minute” surface features – i.e., those features that are below the ***resolution limit*** (the smallest thing that an orbiter instrument can “see”) of the onboard instruments. Most orbiters can ***resolve*** (“see” or just make out) objects down to, say, about a km or so in size. A featureless plane in an orbiter camera might, in fact, be strewn with km-size and sub-km-size boulders that cannot be resolved at all from space.
- Landers: Landers actually leave orbit and descend to the surface, enabling a detailed reconnaissance to be made of their immediate surroundings, their landing site. They are also able to "touch" the surface with remote robotic arms, diggers, and so forth, to “sniff” the atmosphere with delicate chemical sniffers, and to perform in-situ chemical and physical analyses of local native materials. But because they are stationary, they cannot move around so as to see behind large obstacles; neither can they look beyond the local horizon. Their landing sites, therefore, must be carefully pre-selected based on the best data obtained from orbit.
- Rovers: Rovers are able to travel large distances across the planetary surface. This mobility is of tremendous advantage for exploring interesting regions remote from the landing site. The rover might be set down in the middle of a particular area of interest, then perform excursions throughout the area to collect data. Rovers cannot devote all their energy and mechanical space to exploration, however; they must also carry their own drive, guidance, navigation, and control mechanisms. Typically, a rover might gather rock samples from far ranging places; but it must then bring them back to a lander for analysis, or for being sent to an orbiter (via a surface-to-orbit type lander—a lander with the ability to launch part of itself back into orbit) for return to Earth. Images, weather, and other collected data are relayed back to the lander, if it is within view, or directly to orbit for transmission to Earth.
- Flyers: NASA is currently developing a Mars airplane that may be flown on Mars in the near future. The airplane will probably be solar powered, built of very light material, and have enormous wings to provide sufficient lifting surface in the sparse, cold Martian atmosphere. The plane will carry lightweight instruments to sample Martian air and local electric fields, and, perhaps, to obtain aerial image data. The Mars airplane might also be used to do quick reconnaissance prior to sending a rover into a particular area. Or it might

become an exploratory tool in its own right. Its real limitation is the small amount of instrumentation it can carry. But its benefits far outweigh any liabilities!

Section C - COMMUNICATION with EARTH

In order to successfully accomplish exploration of Mars, it is essential for controllers on Earth to be able to communicate with the robotic or human explorers placed on the planet's surface. But communication is tricky when astronomical distances are involved.

Mars travels once around the sun approximately every two Earth years; therefore, Earth and Mars are on the same side of the sun every other year. At closest approach, Mars and Earth are nominally separated by about 80,000,000 km (50,000,000 miles). Light, traveling at 3×10^8 m/s, takes about 4 minutes to make the trip one way, or 8 minutes round trip. When the Earth and Mars are on opposite sides of the sun, one way communication takes almost ½ hour!

Given these lapses in time, direct communication between Earth and Mars is not a viable option. In the Pathfinder mission, information was telemetered between Earth and Mars twice a day. Since a day on Mars (called a "***sol***," from the Greek name for our sun) is only about 35 minutes longer than a day on Earth, the timing worked well, both for mission control on Earth and for the lander/rover on Mars.

In the morning, instruction sets were ***uplinked*** ("radioed" up to Mars) to Pathfinder. The Pathfinder lander received the ***uplink*** ("radioed" information packet) via its main antenna, then used its onboard computers to run the days activities ***autonomously*** (on its own). It communicated with the rover via a smaller secondary antenna. Both lander and rover had onboard computers that were used to carry out tasks assigned via the transmitted instruction sets.

In the late afternoon, the Pathfinder lander ***downlinked*** ("radioed" back "down" to Earth) its own and the rover's accumulated data sets back to Earth. Mission control then had about 12 hours in which to review the data, decide on the next sol's activities, and prepare another uplink. This pattern was repeated over and over each day of the mission.

This type of operation is referred to as "***semi-autonomous***" (partially autonomous). All robotic missions to outer space must be semi to fully autonomous because of the delays caused by the speed of light and the immense distances involved.

Section D - A MARS MISSION SCENARIO

Having gained a foothold in present-day reality, let's develop a generic Earth to Mars scenario, starting with robotic exploration and ending with a manned landing on Mars.

Robotic Phase

The robotic phase is the initial phase of eventual manned Mars exploration and may take years to decades to complete. The robotic phase has already begun with Mars Pathfinder (landed July 4, 1997), has continued with the Mars Global Surveyor (arrived November 1997), and will continue with other planned missions.

Not only are we developing detailed maps of the planet as a whole and of all particularly interesting sites, we are also learning what indigenous environmental hazards we must design against in order to maintain crew health and safety. Remember: ***In a manned mission, the safety***

and well-being of the crew is absolutely the number one priority! At this point in time, we've only just begun.

Robotic Cargo Shipment to Mars

Let’s now leap ahead in time, and imagine that our robotic exploration of Mars has proceeded to the point of giving us sufficient information and confidence to attempt a manned landing (probably within the next 50 years).

In the first step, a specific mission and landing site must be decided. Will we land in a region rich in arroyos or one rich in ancient volcanoes? Will we use rovers to enable the astronauts to travel far and wide, or will we limit their activity to the landing site? How large a crew will we send[1]? What are the selection criteria? And so on…The decision is complex and not to be made lightly!

When a mission has been decided upon, a landing site has been selected, a crew has been named, and things are pretty much "GO," for a Mars mission, then everything that the crew will require on Mars will be sent ahead to await their arrival. The cargo mission will launch about a year before the piloted mission.

Cargo vehicle(s) will be sent along low-cost trajectories, coasting through the gravitational field of the sun. The Pathfinder followed just such a course to Mars. It was launched along an elliptical orbit (called a “Hohmann transfer ellipse,” named after German mathematician, Dr. Walter Hohmann, who first developed the concept around 1925) and traveled halfway around the sun to intercept the orbit of Mars.

Pathfinder’s journey required 7 months to complete. It traveled over 496,000,000 km (310,000,000 miles) at a nominal speed of 99,000 km/hr (62,000 miles/hour!). The Mars Global Surveyor, using a similar strategy, required over 10 months to travel to Mars. The difference in travel time depended on the initial location of the planets at time of launch and on all the complexities of orbital dynamics.

During the trip from Earth to Mars, regular "health-monitoring" of the spacecraft and its stowed materials is carried out by ground control. Health-monitoring involves automatic day-to-day sending and receiving of commands and data to and from active hardware on the spacecraft to assure mission controllers that everything is ***nominal*** (remaining within normal operating range).

Small course corrections are also routinely made. The spacecraft does not travel in a perfect ellipse because of the gravitational pulls of the gas giant planets, particularly Jupiter. Thus, occasional thruster firings are necessary to keep the craft on target. Mission controllers know where the spacecraft is at all times and how it is oriented via a complex network of ground tracking stations distributed throughout the world.

When the cargo vehicles DO finally arrive at Mars, their cargo will be deployed in orbit or on the surface as appropriate. Once this phase of the mission has been accomplished, and everything has been checked out by ground control and found to be nominal, the crew will prepare to depart from Earth and begin their journey.

Astronaut Training and Selection

[1] Present NASA thinking places crew size at around 8 or 10 individuals.

The individuals who will eventually fly to Mars are in school in the year of this writing, 2003. They range in age between 5 and 20 years old. Mars is a future that students interested in science and exploration can inherit if they put their minds and hearts into obtaining it. In some sense, the people who will finally go to Mars will be the ones who most want to go and who are most willing to seize the opportunity!

At present, NASA is learning about the human response to living in space through astronaut teams that fly on the shuttle and live on the Space Station. Research into human ***physiology*** (dealing with the body as a whole, especially the muscular-skeletal system), ***neurology*** (dealing with the mind and the nervous system), and ***cardiology*** (dealing with the heart and circulatory system) is being actively conducted. Countermeasures are being sought to offset the various adverse human responses to reduced gravity and long stays in space.

When a decision has been made to actually send humans to Mars, candidates will be sought from countries around the world. Candidates will initially be chosen based on factors involving physical fitness, academic standing, psychological fitness, and a whole host of others. All will be put through rigorous training. This training will not only serve to develop the future crew for the manned Mars mission, but also to screen out those who cannot make the cut.

Mars astronaut training will be very involved. Included in the training itinerary will be long stays in remote outposts on Earth (e.g., the South Pole), in space (e.g., on the Space Station), and even on the moon. Astronauts will repeatedly practice vehicle landings and lift-offs, ***trans-Mars vehicl***e (TMV) operations, ***extravehicular activities*** (EVAs), and all eventual Mars surface maneuvers.

Astronauts will also be thoroughly trained in a whole host of ***human factors*** (any and all factors that might affect the crew) including using low gravity countermeasures, maintaining physical and mental health, using countermeasures for the effects of extreme isolation, maintaining a proper diet based on the limited amount of consumables that they will be able to transport with them, and so on.

From several thousand possible initial candidates chosen from all over the world, eight or ten individuals will finally be chosen for the actual mission through an elaborate process of competition and elimination. In addition to technical competence, physical endurance, mental soundness, etc., the selection criteria will probably include internationality and multi-gender factors.

As with the Apollo Program, each astronaut in the final pick will have one or more backups, fully trained and ready to go if the astronaut becomes incapacitated. A typical crew might include a pilot, a communications specialist, a doctor, possibly a psychologist, and, of course, several mission specialists.

Artificial Gravity

Long periods of weightlessness[2] have adverse effects on human physiology, neurology, and psychology. Before a crew can be sent to Mars, NASA must develop countermeasures for these

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[2] Weightlessness occurs inside the spacecraft because of its motion through space. There is gravity is space. The astronauts are weightless just BECAUSE there is gravity in space!!! ***The state of being in orbit is equivalent to the state of being in freefall***. Because everything at a given location in space falls at the same rate, it is possible, in a closed environment such as a spacecraft, to experience weightlessness or “zero-g” during orbit. Because the TMV will thrust during large portions of its flight to Mars (this is what I mean when I say, “The piloted mission will

adverse effects, or learn how to supply the Mars crew with artificial gravity[3] while on board the spacecraft.

Let’s look at just one possibility: providing artificial gravity by rotating the spacecraft. An idea that I worked on in the 1980’s involved using a tether many km long. The spacecraft would be built in two halves that would be spun up then separated while connected with the tether. As the spacecraft halves moved apart, the rate of rotation would slow, much as ice skaters slow when extending their arms.

Could such a concept be made to work? A tethered spacecraft is certainly possible, although there are tremendous practical risks involved with the possibility of the tether being severed by a meteoritic or asteroidal fragment. But suppose that we found a way around such risks? How would the crew respond to a rotating environment? Let’s proceed step by step.

First of all, imagine that you are on a non-rotating platform, like a merry-go-round that has not begun running yet. The only force that you are aware of is Earth’s gravity acting on you—your own weight.

When the operator starts the merry-go-round, what happens? If you are near the edge of the platform as it begins to rotate, you find yourself reaching out to grab onto something to avoid being thrown off. There is now an outward directed acceleration that was not there before the platform began to move. And this ***acceleration increases in direct proportion to the rate of rotation*** (gets greater as the rotation increases).

You are experiencing what physicists call a “***centrifugal acceleration***.” The word “centrifugal” simply indicates something that points radially away from a center. This centrifugal acceleration is artificial gravity. It points radially outward from the center of rotation.

Since the centrifugal acceleration is artificial gravity, it follows that, on a rotating spacecraft, you would not stand in the position that you would on the merry-go-round. You would stand in the same position that you would be in if you were to *lie down on the merry-go-round with your head pointing toward the center and your feet pointing outward*. Thus your head would point "up" and your feet would point "down" in the centrifugal field.

"Up" and "down" are not absolute directions in space. They only exist relative to local gravity, whether natural or artificial. Remove the gravity, and "up" and "down" completely disappear—as our astronauts know only too well when they are in orbit! Imagine two people standing on opposite sides of the world. Which one is right side up? The answer is that each is right side up—in his/her own locality.

But the story does not end here. There is another part to it—a somewhat trickier part. The centrifugal acceleration is NOT the only acceleration present on the rotating platform (or in the rotating spacecraft). So long as you stand still, you feel no other acceleration. But as soon as you

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SPRINT to Mars.”), the astronauts will not experience zero-g the entire way. Only when the thrusters are turned off and the vehicle is allowed to coast in the sun’s gravitational field (as during the outward bound or inward bound portions of the mission), or in the Martian gravitational field (as during Mars’ orbit, when the crew is at Mars and some of the astronauts are on the surface) will the astronauts aboard the TMV experience zero-g. None-the-less, countermeasures are essential for use during these periods of time.

[3] One means would be to rotate the spacecraft while it is in flight. But while rotation produces artificial gravity, it also has other effects that can produce astronaut disorientation. The use of rotation is, therefore, of questionable value. The paragraphs that follow go into more detail.

try to take a step, you feel a new acceleration that wants to push you to the right or to the left. THIS acceleration is the Coriolis acceleration[4]. It gets larger the faster you try to move across the platform.

Watch the water flow down the drain in a bathtub or in a wash sink. The water flows toward the drain. But the motion takes place on Earth, which is a rotating platform of sorts[5]. (Do you see why? The Earth turns on its axis once every 24 hours!) So, the water starts out toward the drain. But as soon as it begins to move, it feels a sideways Coriolis acceleration. Now, a fight begins between the low pressure at the drain and this newly felt Coriolis acceleration, the result being that the water forms a little whirlpool and spins as it goes down the drain.

The Coriolis acceleration in a rotating spacecraft will very likely have a disorienting effect[6] on an astronaut who tries to move about the spacecraft. The occurrence of Coriolis acceleration on board the spacecraft is the effect that we must try to minimize if we are to use rotation to produce artificial gravity. If we do not rotate the spacecraft, we have neither artificial gravity nor Coriolis acceleration. If we DO rotate the spacecraft, we have both accelerations. They are intimately related.

The question becomes, can we find a rotational speed that produces sufficient artificial gravity without overdoing the Coriolis acceleration? In other words, can we find a level of artificial gravity that is comfortable and healthy and has an associated Coriolis acceleration that the astronauts can tolerate? So far the answer appears to be "No."[7]

Food, Fuel, and Water/Radiation Protection

The TMV will be stocked with consumables for the astronauts to use throughout the mission. The amount of stored consumables will have to be limited since it is not possible to carry enough food for a crew of 8 or 10 people living day-to-day for up to two years. Spoilage is certainly an issue here. So is cost. Delivering any payload from Earth to orbit costs, on the average, $10,000 to $20,000 per pound!

Innovative ***bio-technology*** (technology based on the laws of biology rather than on the laws of engineering) must come into play. Perhaps some sort of ***hydroponic gardens*** (gardens that can be grown, watered, and maintained without the use of heavy soil beds) will be used to provide continually fresh astronaut diets over the duration of the mission. Such gardens will also help to recycle oxygen. Water will also have to be recycled during flight. On the Martian surface, water found on Mars will supplement supplies brought from Earth.

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[4] First identified by Gaspard Gustave de Coriolis (France, 1792-1843), this acceleration occurs in any rotating frame of reference and is dependent on the subject's velocity in that frame.

[5] Actually, the rotation of interest here is the vector component of the Earth's rotation perpendicular to the Earth's surface. This component varies with the sine of the latitude and is zero at the equator. The effect described with the water in the sink works everywhere on the surface of the Earth except at the equator. It becomes more and more pronounced as you increase in latitude North or South, and is a maximum at either of the two poles.

[6] In the human body, balance is maintained by fluid in the inner ear. In a Coriolis field, this fluid will behave somewhat like the water in the sink. If it begins to rotate, the astronaut will experience moderate to severe dizziness and will be unable to function.

[7] I have included this argument for two reasons. Many people ask about using rotation to produce artificial gravity; Werner von Braun used it in his original design of a space station more than 50 years ago. The development of gravity countermeasures is still a very open question. The problems that arise with rotation in this example give some idea of how difficult it can be to produce and/or counteract an effect without introducing other complications.

We call materials mined at the exploration site "***in-situ resources,***" (Latin: "situated at"). Just as the settlers of the Old West in the U.S. used in-situ resources as the wagons traveled along, so will our Mars astronauts. The settlers found water, hunted buffalo, and so on. The astronauts will have to rely, in part, on Martian reserves of water and CO_2 (Martian atmosphere) to supply part of their needs.

Stored water and liquid fuel will have a dual use on board the TMV. The water and fuel tanks will double as radiation shields in the event of a ***solar flare*** (a violent, eruptive event on the sun that spews high energy particles outward into space) or other energetic solar event such as a ***coronal mass ejection*** (another type of violent solar event spewing large amounts of high energy particles with radiation that roars through the solar system, disrupting everything in its path). The radiation from solar flares and coronal mass ejections is deadly to living tissue.

Water and some liquid fuels are excellent ***mitigators*** of high energy particle radiation—they absorb high energy particles and rob them of their thunder, so to speak. Thus, a "***fall-out shelter***" (a safe zone, perhaps a lead box?) will be placed in the midst of the onboard fuel and water tanks of the TMV for the astronauts' retreat in the case of a dangerous solar event.

How will the astronauts know to take cover? The ***optical signature*** (light) of a flare or mass ejection will be received at Earth around 8 minutes after the event. The particles themselves, traveling at speeds much slower than light, will arrive at Earth a couple of days later. Either the astronauts will have detected the optical signature themselves, or mission control will send them a stern warning. Either way, the astronauts will have plenty of time to take cover and wait until the danger has passed.

Even on the Martian surface, radiation protection will still be necessary, probably with underground shelters. Most likely, the astronauts will have to dig out and set up the shelters after they arrive. A lot of this detail has not yet been worked out in final form.

Pre-Flight

Departure time is defined by the relative positions of Earth and Mars in their respective orbits around the sun. The two planets must be in such a position initially that their motions will bring them into optimal alignment for arrival several months later. There is only a period of a few weeks during which such positions become available. The positions change at different rates due to the different motions of the planets around the sun.

When the positions of the planets are right for a launch, we say that a ***launch window*** (a time suitable for making a successful launch) has opened. When the planets move out of position again, we say that the launch window has closed. If a launch window is missed, the launch must be postponed until the next window opens. In the case of the Earth and Mars, this usually takes around 2 years.

In preparation for departure to Mars, the crew will launch from Earth in a Space Shuttle, and rendezvous with an orbiting Space Station. The TMV, which has been assembled in space and is now parked in orbit waiting to go, will co-orbit with the Space Station. After a brief stay on board the Space Station, during which the crew will undergo final briefings, the crew will enter an ***orbit transfer vehicle*** (OTV) and taxi over to the TMV.

The TMV will be fully equipped with everything not already sent ahead in the cargo phase of the mission. The OTV will dock with the TMV and the astronauts will don their portable space gear and transfer over. They will spend their initial hours on board making final checks on all aspects of TMV readiness for operation. The entire time that these activities are going on is called "*c**ountdown.***"[8] The activities follow a rigid schedule that is ticked off by a clock in launch control. If a delay is incurred, the clock stops. Once the cause of the delay is cleared up, the clock resumes. It is hoped, of course, that the delays are short lived so that the launch window is not missed!

The Outward Journey and Arrival at Mars

Unlike the cargo vehicles, the TMV will not solely use the sun's gravity to travel to Mars. It will use advanced propulsion, which will enable the astronauts to ***sprint*** (get there in minimum time!) along a high energy trajectory requiring continuous or near continuous thruster firing. The time in flight must be minimized in order to reduce the astronauts' exposure to in-space hazards that include:

- lethal particle radiation from the sun and galaxy (galactic cosmic rays or GCRs).
- small solid rocky or metallic objects (***micrometeoroids***) left over from the earliest periods of solar system history and orbiting the sun in various orbits.
- larger solid objects that are too small to be tracked from Earth but which, nevertheless, could impact the TMV with devastating results.

The hazards will be mitigated by using advanced technologies (some of which are still to be developed) that will maintain risks at a minimum. *No risk can ever be completely eliminated; risks can only be minimized*. The astronauts will all know and understand the risks before they ever fly. All will have signed statements acknowledging this understanding.

Remember: *The crew of a piloted mission is absolutely the number one concern of the entire mission.* EVERYTHING shall be done to ensure crew safety and, once they arrive at their destination, ease of access to their strange, new environment. NOTHING shall be left to chance if at all possible.

Initially, the crew will begin their journey by clearing the Space Station using small orbit maneuvering thrusters. Once clear, they will fire the main thrusters to accelerate and leave Earth orbit, and will immediately place the TMV onto a pre-determined ***trans-Mars trajectory*** (a pre-selected path through space that leads from Earth to Mars and is in complete accord with orbital dynamics).

Life will then settle into a routine for the astronauts. Each will have pre-assigned duties to perform to maintain spacecraft operations. Their days will keep to a fixed schedule involving periods of work, exercise, meals, rest, recreation, entertainment, and so on. They will also maintain communications with Earth, although the time between sending and receiving transmissions will gradually lengthen as they move farther from Earth and closer to Mars.

There will also be routine checks of those pieces of onboard equipment that have been stowed for arrival at Mars. Health checks will be performed by the astronauts themselves. All data will be relayed to Earth on a regular schedule and reviewed by mission control. Any glitches will be handled by the astronauts relying on any and all necessary consultation with Earth.

[8] Actually, countdown goes on for months or even years before a launch. We only hear of the last few hours in the countdown when we tune in our televisions to watch the event. At the Pathfinder control center, a large, digital clock mounted on the wall ticked off the months, days, minutes, and seconds to launch.

Boredom during a long mission can lead to disastrous results. Therefore, the interior of the spacecraft will be carefully designed to maximize astronaut comfort and alertness and minimize boredom. Colors, pictures, photographs, and so on will used to maintain the psychological well-being of the crew. Entertainment will also be provided to give as diverse an array of off-hour activities as possible. The crew will arrive at Mars in 2-3 months after departing from Earth. When the TMV arrives at Mars, it will have to dump excess energy and momentum in order to achieve a stable orbit around the Red Planet. One technique will be to fire ***retro-thrusters*** (rockets that fire in the reverse direction to the motion and remove energy from the spacecraft), which act as brakes and slow the vehicle. Another approach is to deploy ***aero shields,*** possibly large, inflatable balloons, and skim through the Martian upper atmosphere using atmospheric friction to slow the vehicle. This latter operation is called "***aero braking.***"[9]

Once in orbit around Mars, the TMV will be secured and will become an orbiting Mars space station. Those crew members who are slated to go to the surface will don their space suits and enter a smaller Mars ***orbit-to-surface transfer vehicle*** (OTS) that has been stowed on the TMV. They will undock the OTS, fire retro-thrusters, and begin their descent to the surface. The remaining personnel will stay behind on the TMV to "keep house."

Once they have landed and secured the vehicle, the surface crew will immediately set to work establishing a base camp. Meanwhile, the TMV will relay information to Earth on the status of the orbital and surface portions of the mission. It is quite likely that, as the surface crewsteps onto the Martian surface, each crew member will give a prepared statement representing his/her country as first words from Mars to Earth.[10]

Afterwards they will set to work. The cargo that has been sent ahead and is now waiting for them nearby will be put to immediate use. Of course, hazard mitigation remains a top priority, even on the Martian surface. Easily deployable systems will be provided to ensure astronaut safety from the very start of their surface stay. Mars surface hazards include:

- solar ultraviolet light (because of an almost negligibly thin ozone layer).
- meteoroids (that can easily penetrate the thin, cold atmosphere).
- high energy particle radiation (that also can easily penetrate the atmosphere).

Establishing electrical power will be a priority. Solar cell blankets will be deployed as an initial step. Whether other, more elaborate, power generating systems will be deployed later in the mission has still not been determined. Solar power should suffice for all of the astronaut needs, so larger systems may not be required.

Drinkable water and breathable air will be immediately available for the astronauts. As part of the cargo phase, a special system will have been landed and placed on the surface to mine and purify indigenous Martian water. It will be an automated system that will have deployed itself

[9] Aero shields are essential for high speed entry into an atmosphere. The Shuttle uses an elaborate system of thermal tiles to keep from burning up when it re-enters Earth's atmosphere. In aerobraking, the spacecraft skims through the outer atmosphere, using the atmosphere to produce drag in order to slow the vehicle. But the ***kinetic energy*** (energy of motion) lost by the vehicle becomes heat in the local atmosphere, with temperatures of possibly several thousand degrees in the immediate vicinity of the spacecraft!

[10] Remember Neil Armstrong's first words as he stepped onto the Moon: "That's one small step for man, one giant leap for mankind."

and begun working for all the months between the arrival of the cargo and the crew, drilling into the Martian surface and mining sub-surface ice.

Another automated system will ***electrolyze*** (chemically change) some of the Martian water into hydrogen and oxygen gases. Hydrogen plus oxygen equals rocket fuel—all that is needed is an ***igniter*** (a spark source). Watch the main engines light the next time you watch a Shuttle launch on television! The Shuttle's main engines burn hydrogen and oxygen, which is stored in separate tanks inside the big external tank. You will see an external igniter. The main engines burn hydrogen and oxygen to produce an exhaust of water vapor or steam!

The Martian derived hydrogen and oxygen will be used to fuel small surface to orbit cargo vehicles that will deliver collected Mars surface samples to the TMV for stowage and eventual return to Earth. The Martian derived oxygen will also be used to provide a breathable atmosphere for the astronauts.

Mars Surface Exploration

The crew's first days at Mars will be spent setting up house, so to speak. Afterward, they will embark on a pre-determined plan of exploration.

Their daily work will follow a schedule that has been carefully worked out to include periods of exploration, sample collecting, base camp maintenance, exercise, meals, rest, recreation, entertainment, and so on—similar to the schedule that was followed during the outward leg of the voyage to Mars.

As before, all communications will be relayed to Earth at the beginning and end of each Martian day (or "sol"). Remember, there is now a minimum 4 minute delay for communications one way—8 minutes total for round-trip communication. And this interval is likely to grow longer as the two planets move along their respective orbits around the sun over the weeks and months that the crew will spend on Mars.

Almost certainly, new discoveries will be made that might necessitate changes to the original plan. These changes will have to be carefully discussed with mission controllers on Earth, and all alterations to the original mission plan will have to be thoroughly agreed upon before the astronauts attempt to carry them out. This procedure might introduce delays into the exploration activity, but it is the only way to ensure the safety of the astronauts.

Some typical surface activities might include:

- monitoring the physical and mental health of the astronauts.
- recording astronaut responses to the new, unknown environment.
- maintaining careful logs of all experiments and surface excursions.
- maintaining logs of vehicle operations.
- monitoring communications from Earth.
- monitoring space weather reports (on solar activity).
- conducting biological experiments with living plants brought from Earth.
- planning and executing excursions to sites remote from the base camp.
- gathering rocks for return to Earth.

- storing and labeling samples.
- conducting chemical analyses of Martian rocks, dust, and volcanic residues.
- analyzing appropriate rock samples for evidence of present or past life.
- conducting meteorological experiments.
- monitoring electrostatic discharge activity associated with dust storms and dust devils.
- searching for subsurface thermal sources and reservoirs of liquid water.
- conducting seismic experiments.
- investigating residual planetary magnetism.
- launching and controlling remote flyers.
- data analysis and reduction.
- extensive site photography and mapping (cartography).
- observing the Martian moons (more likely to be done from the orbiting TMV).

Departure from Mars

At the end of their stay on Mars, from several months to possibly a year or more after their arrival, the astronauts will lift off from the Martian surface in a surface-to-orbit vehicle, dock with and re-enter the TMV, and prepare to depart for home. Earth and Mars will have progressed on their respective orbits around the sun and will now enter relative positions that will enable successful flight from Mars to Earth. A new launch window will have opened for the return trip.

Rocks and other inert specimens will probably be sent back in separate vehicles, possibly the original cargo vehicles themselves, refueled using hydrogen and oxygen distilled from Martian water-ice. The trip back will be much the same as the trip out, except that the communication delay between the Earth and the TMV, which has now become a ***trans-Earth vehicle***, TEV, will now grow shorter and shorter rather than longer and longer.

The crew will use the TEV's onboard advanced propulsion system in much the same way that they did on the outward leg of the journey to sprint back to Earth. Upon arriving at Earth, they will perform an Earth-orbit insertion, dumping excess energy and momentum as they did when they arrived at Mars, probably using retro-thrusters. They will put the TEV into Earth orbit and bring it into alignment with the orbiting Space Station.

After an initial period of isolation aboard the TEV, during which the astronauts will undergo various tests and possible decontamination, they will enter an OTV and transfer to the Space Station, where they will be reunited with their fellow humans. All collected samples will remain in isolation. The astronauts might then spend several weeks on board the Space Station, undergoing further tests and de-briefings before returning to the Earth's surface.

All collected samples and specimens will be thoroughly screened against any possibilities of contamination before being introduced into an inhabited laboratory environment. Hazards would include chemical toxicity, flammability, even biological contamination. In the case of biological hazards, it must be a standard part of any planetary mission to ensure against the Andromeda Strain syndrome!

Conclusion

This mission scenario is based on my own experiences with the Mars program at NASA. It is brief, providing only the most significant elements of designing and executing a planetary mission. Hopefully, after you've read this section over several times, you will understand a little more about planetary missions and will have developed questions that you can use to extend your knowledge. Many key words have been presented and highlighted in the text. Some of these words are explained in parentheses, others in footnotes. Use these words as search words on the web to gain a deeper understanding of the concepts involved. Do not be discouraged if your progress is not as fast as you would like. Remember, Rome wasn't built in a day. The effort you put into researching these questions will help you understand NASA's role in space exploration. And more importantly, your research will help you understand the universe in which we live. Exploration of our universe has just begun—for the first time ever in all of human history! Join our STAR team and we'll explore together!

PART II:

<u>S</u>CIENCE <u>T</u>HROUGH <u>AR</u>TS (<u>STAR</u>)

By Joe Kolecki, Ruth Petersen, and Lawrence Williams

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In general, secondary schools today teach a variety of subjects, each to the relative exclusion of the others. For example, classes in history are taught with little or no reference to the sciences, mathematics, or the arts. Classes in mathematics and/or physics are taught *sans* history. Similar statements hold true for most subject areas.

The traditional or standard method of teaching and learning might be thought of as being *vertically aligned*. Thus, if the titles of the individual subject areas were written across the top of a page, their corresponding activities would fill the respective narrow subject columns below with little or no overlap. This practice involves serious omissions. <u>Example</u>: The equation $E = mc^2$ is taught as *Einstein's equation* in physics classes. The word "*Einstein's*" is an adjective modifying the word "*equation.*" The *equation* is taught merely as an algebraic structure, with minimal reference to the individual (*Einstein*), and no reference to the historical context in which the equation was developed. And yet, the individual and the context are both essential to understanding the true meaning and impact of this important equation.

When education is vertically aligned, important connections between individual subject areas are lost. Since the world at large is an integrated system with minimal partitioning between individual disciplinary areas:

- Relevance of the individual subjects to the world at large is lost; and
- Students advance through school with their knowledge highly partitioned, rather than integrated into a single world picture.

Science Through Arts (STAR)* is a new educational initiative that will horizontally integrate a set of student science activities in a given topic area across the vertically aligned subjects taught in schools. Not only will it provide a multidisciplinary environment, it will be a multilingual, technology-rich learning experience in which students can integrate their creative arts skills with current space science exploration.

Selection of a Topic Area

The initial step in STAR is to select a topic area. In the pilot project, STAR will use Mars exploration as the topic to be integrated. From the Internet, students will be exposed to current knowledge of Mars and its exploration, then will be challenged to develop everything from real-life mission scenarios to stories, plays, pictures, music, etc.

Mars exploration is a worthwhile area because:

- It is current. – *Mars missions are being planned and launched by the National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA).*
- It is historically relevant. – *Mars has been a subject of human interest from the Ancient Roman Empire to the present century*.

- It provides extant prototypes for STAR-type activities. – *There is a wide range of human artifacts including myths, stories, novels, radio broadcasts, television and movie casts on the topic.*

Mars exploration will involve many people in many disciplines in the future. Astronauts will travel to Mars for scientific research and exploration, map-making, picture-taking, and so on. Mars exploration will also involve activities on Earth, ranging from mission support to written and oral broadcasts and updates, from assembling historical records to writing popular books and building public expositions. In short, Mars exploration provides the perfect context for trial and development of new ideas in and for the STAR concept.

A Body of Known Facts

In order to initiate student activity in Mars exploration, a variety of extant facts must be provided. The students will discover these facts for themselves via web-based materials (especially from NASA's Jet Propulsion Laboratory, which currently runs the Mars missions), published materials, and live videoconferencing interaction with a NASA Mars-Pathfinder scientist, Joe Kolecki. Kolecki will provide guidance for the students in accumulating pertinent information. Actual lecturing will be held to an absolute minimum.

The Formulation of a Question or Questions

The quintessential step now follows: The students will evaluate the information they have gathered, and attempt to formulate *pertinent questions*. The basis of all good science is the formulation of questions. If someone were to say, "You're scientists, you ought to know," their answer would be, "We're scientists because we don't know…but we know how to find out."

A *pertinent* or *well-formed question* is a question that contains enough information to imply some means for obtaining its own answer. With well-formed questions, scientists are prepared to develop theoretical and/or experimental scenarios to obtain new information. It is anticipated that the formulation of a question will be one of the most challenging and rewarding exercises of the STAR activity.

Mission Scenario

Part of the formulation process will be to develop a Mars mission scenario to answer the students' questions. The mission scenario must be as realistic as possible, and must have a sound basis in science, mathematics, and engineering.

Interdisciplinary Extension

The extension from the mission scenario to an interdisciplinary, horizontal activity may now begin. In the pilot project, a method adapted from the theory of science fiction by British author, H. G. Wells, is suggested.

Wells wrote science fiction by postulating an extraordinary "what if" element, and then recording people's responses. The extraordinary element could be anything the author pleased; it did not have to be explained or justified on any grounds. Once introduced, however, it was to be pretty much left alone. The writer's focus had to be directed to how people responded, and the responses had to be as realistic as possible. As an example: "Suppose pigs could suddenly fly," Wells wrote in the introduction to his ***Seven Famous Novels*** [Knopf Publishing, 1934], "and one suddenly came hurtling over a hedge and into a group of people?"

The students, accordingly, will be asked to introduce an extraordinary element into the Mars scenario they have developed. The extraordinary element will be something that the students invent, something that must be realistically dealt with in some way. Mathematics students might try to develop models or logic chains for dealing with the extraordinary element. Authors and playwrights might develop descriptive scenarios to be read or acted out on stage. Music students might provide music for plays or original compositions akin to Gustav Holst's ***Mars*** from the orchestral suite ***The Planets***, and so on.

This activity is the heart of STAR. From a scientific point of view, it is not unlike the scenarios made up for mission practices at NASA. In a practice session conducted prior to the Pathfinder landing, a group was given the challenge of working out what to do if a rose bush were found growing on Mars near the landing site!

Finale

When everything has been completed, the students will be given the opportunity to revise their original works in appropriate formats. They will use PowerPoint to present their work in simple language for younger readers, using lively graphics, animation, and music files (perhaps created by the original school, or sent to a partner school for development). The PowerPoint presentation will then be translated into a second language (by the originating school or a partner). Art work, mathematical calculations, posters, pamphlets, travel brochures, leaflets on health issues in space—these are all possible creative outcomes, provided that they are securely based on accurate scientific data from NASA web sites. It is hoped that the schools will work collaboratively through email or videoconferencing connections to accomplish some of these tasks.

The pilot project will include schools in the UK, Japan, and the U.S; completion is planned for April 2003. All pilot project schools have IP H.323 or ISDN H.320 videoconferencing equipment. The schools will be provided with Guidelines, and each school will be asked to submit one winning work to be posted from a NASA website created for the STAR Project (http://www.grc.nasa.gov/WWW/K-12/STAR/index.html).

The work created during the STAR pilot project will provide a model, or point of reference, for other schools to use when offering further contributions to the global, multilingual website showcasing the students' winning creations. By the start of the 2003-2004 school year, the STAR project will be available for participation by schools worldwide. The directors of the project believe that through the horizontal integration of science with the arts in this new educational initiative and others like this, students will begin to see the relevance of science to the world at large and knowledge will be integrated into a single universal picture.

**The STAR Project, which targets middle grades students, is co-directed by Joe Kolecki, Pathfinder scientist (Joseph.C.Kolecki@grc.nasa.gov) and Ruth Petersen, Educational Coordinator, Learning Technologies Project, NASA Glenn Research Center, Cleveland, Ohio, USA, (Ruth.Petersen@grc.nasa.gov), and Lawrence Williams, the Holy Cross School, Surrey, UK (LawrenceHX@aol.com). The idea was developed by Williams following the successful completion of an on-line collaboration during the "Japan 2001 Science, Creativity and the Young Mind Workshop" held at Bristol University, July 2001, and sponsored by Eric Albone, Clifton Scientific Trust, UK. Highlights of that collaboration and its outcomes are available online at www.grc.nasa.gov/WWW/K-12/MarsV/index.htm.*

PART III:

A SAMPLE STORY

The Once And Noble Race

By Joseph C. Kolecki

They were a proud and ancient race, standing tall in flowing white robes and delicate sandals. They contemplated their world with soft eyes, full of empathy for the myriad wonderful things with which Nature had endowed them.

They were builders of lacework monuments and glittering crystal cities that blended so well into the landscape that, everywhere they occurred, they looked more like natural extensions of the hills and valleys than ever did the harsh, world-consuming structures of our own modern world.

They made soft, molten music, with bells and voices, gentle sounds that were set adrift on chill evening breezes to mingle with the shrill waking cries of nocturnal desert creatures, and meant to enhance the deep evening meditation of which they were so fond. They were creators of a gentle art in canvas and stone that bespoke in other ways that same high esteem with which they regarded their world and all its varieties of indigenous flora and fauna. They were finely attuned to the daily and seasonal rhythms of their world. They rose with the light, chill morning winds of the high desert, they worked and played in the sharp, crisp sunlight of red-violet day, they retreated to their meditations with the swift descent of the sunset afterglow, and slept deeply during the icy cold of star-imminent night.

Things had not always been so placid for them, however. They recalled (in collective memories that extended back in time to their very origins as a people) the world shattering violence of an age of immense volcanic eruptions, and the terrible jarring and rending of the planetary crust during a devastating epoch when almost nothing survived, not even the planet itself. Their numbers were very sparse in those days, and they were small and weak in the face of gigantic forces. They were given to long and continuous migrations in an endless quest for mere safety. Indeed, they were tried to the very limits of their endurance.

They survived…

Long afterward, even until their final days as a race together aeons later, they told of these ancient experiences in their myths and legends. They sang of them in their crystalline songs.

They also recalled a later age of darkness, which followed the time of cataclysms. In these days, they grew stronger, their numbers increased. They became fierce and belligerent, competing between themselves, sometimes engaging in wars of terrifying proportions. They also recalled their first priests and philosophers, and the dawn of a brighter, saner time in which their planet settled at last into a long period of stability, and gentleness began to replace violence as their way of life. They learned to cope with the relatively more moderate problems of occasional ice ages and a slow but inexorable planetary desiccation.

They came to embrace a worldwide tradition. Yearly, after the season of storms and dust (which served as a reminder of the violent ages past), they all held pilgrimage to the site of one of the greatest upheavals of all, a volcanic mountain that could be seen looming from almost unimaginable distances across the plains. From every corner of the planet, they came, and gathered together as a global race, and shared everything they had. They gave freely of both substance and spirit. They listened to the orations of their greatest priests and philosophers, who held forth, especially during this time of celebration, on all the elements of their history and belief. They prayed prayers of belonging, of unity, of life…

Beyond the mountain, on the edge of the great canyon, which gaped toward the rising sun and opened a heart-rending gash in the horizon as it wrapped a sixth of the way around the planetary equator, they held ritual celebrations, lasting many sols, and reminded themselves of the priceless gift of enduring life. Special temples stood throughout the area, places of rock and crystal, of towers and bells and wind chimes, places to offer gifts and bring the sacred ritual artifacts.

In this way, they learned to participate in *Mystery* without demanding an answer for their existence. They also learned to care not to rip apart the delicate fractal fabric of their world, or of their own minds…

And war became a thing unknown to them…

Near their end, they learned to leave their world, and decided that the time had come for them to spread their seed into the surrounding system of planets, and ultimately into the cosmos. They seem to have left *en masse.* Their bells went silent, their music faded, and the temple towers gradually grew brittle with the passage of time, wind, and dust, and began to crumble and fall back to the soil of the world whence they had originated.

In the system of the yellow star they left behind, a star, you might guess, that saw the rise of more than a single race of beings on more than a single world, their memory is, today, all but vanished. If once these other races knew, the knowledge seems to have been long forgotten, or misplaced in the mists of endless time...except…

Except for the inhabitants of a small, blue world, luminous, richly hydrated, mottled with ever changing cloud motifs. Sometimes, glimpses, fragments, transient glints of memory (like light reflected from a shard tumbling through time) furtively recurred in their dreams or appeared in idle ruminations...such as the tale that lies open before you... By and large, such glimpses were ignored, written off as simple aberrations of the mind, or as pleasant fictions, entertaining, yet without any real substance or meaning. But for just a select few, perhaps the most fortunate of all, these memories endured in a different way, still remote, but more persistent, and suggested the almost impossible idea that they had actually shared in the ancient lives of those slender, delicate beings who marched each year with coming of the southern Spring to celebrate life, and had actually stood with them amidst the glistening temple terraces, raising their voices and their own sacred artifacts against a thin dust-red sky…