In S. Turkle (Ed.), *Simulation and Its Discontents*. Cambridge, MA: MIT Press, pp. 107-127.
Please consult print edition before quoting.

Becoming a Rover

William J. Clancey

It is 3:13 AM at Gusev Crater on Mars, and the Mars Exploration Rover (MER) called *Spirit* is powered down for the night.[1] The team of scientists "working Gusev" lives on Mars time, but, with some luck, they are fast sleep in California. The MER is a remotely operated vehicle and it is not the only one exploring Mars at this time. On nearly the opposite side of the planet at Meridiani Planum, another MER called *Opportunity* photographs the Martian surface and undertakes the analysis of minerals. The thirty-seven scientists "working Meridiani" are ensconced in a fifth floor meeting room at the Jet Propulsion Laboratory in Pasadena. With my background in robotics and artificial intelligence, I am living as if on Mars with this team as I attempt to document its mission. It is a bright February afternoon, but we sit in a room darkened by heavy black shades. We are with our rover. We count time by the number of sols, Mars rotations, since our rover landed. Today is sol 25, M25.[2]

The first meeting of sol 25 includes short lectures by a half-dozen scientists. Speaking with wireless microphones, they display scores of colorful photographs and charts with titles like "Locations and things to do for Mineralogy." The MER scientists sit in clusters, organized into four Science Theme Groups and a Long-Term Planning Group. Later in the sol, the Science Operations Working Group polls the thematic groups for what they want the rover to do, what commands they want to give to the robotic vehicle. These commands will be converted into eight-hour-long software instructions that will program the rover's actions. Before the end of the

day, the scientists will settle on one set of instructions, known as a sequence. This sequence will be communicated to an engineering team who will prepare computer code for the rover's next-day exploration of Mars. An end-of-sol meeting will review daily progress, next-day plans, and the group's long-term goals.

Today, on sol 25, a month into the *Opportunity*'s mission, the Chair of the Science Operations Working Group gives a short lecture about the Rock Abrasion Tool, the RAT, which serves as a geologist's hammer, scraping a circle into a hard surface. The speaker warns the group against indiscriminate data gathering with the RAT, letting their curiosity bypass the discipline of scientific hypothesis testing. "As we think about how we are going to approach this outcrop, our thinking and our discussion should be very much based on hypothesis testing…. Don't say 'let's RAT here' to reveal this, and 'let's RAT here' to reveal that, let's talk it through in terms of the specific scientific hypotheses that we're trying to test."

Why is it necessary to lecture these scientists – experienced in field exploration, competitively selected to be members of the MER Science Team, many of them having worked on multiple missions before this one — on how to do science? Working with the remote-controlled rover changes the practice of field science in ways that make such lectures necessary, reshaping intellectual practices and professional identities.

An Explorer's Identity: Becoming a Rover

I chose six MER scientists to interview, representing different generations within the space program, spanning from those who have made NASA a lifetime career to the young scientists for

whom the MER project is their first mission. Getting a place on a mission team at NASA is a highly competitive enterprise. Regardless of their age, the MER scientists view their work on the project as the culmination of their careers, a scientific identity. Ed Dolan[3], 67, waited almost twenty years for this opportunity, a period during which he was "quite discouraged of the possibility of ever seeing another Mars mission." For Ned Rainer, 56, the project "represents a consummation of a career at NASA.… It provides a degree of closure in many things I felt I was preparing for, on behalf of NASA, some twenty years before they happened." Nolan Baxter, 34, describes it as a "dream come true…. This has been a calling for me in the same way some people are called to be a preacher or something like that. And I am really, really blessed to be doing this." Oscar Biltmore, 44, also feels comforted and fulfilled to be part of the MER team, the benefit of "just not giving up, having people help you along the way, believing in yourself." Bettye Woodruff, 40, sees MER, as one that will forever mark her career. "For anybody to receive that phone call . . . That is definitely a defining moment in somebody's career, somebody's life." She explains how the group consists of the most noteworthy people in the field: "I have to say when I saw the roster on that team I was a little bit scared . . It was an honor of course to be with those people."

The three younger scientists on the MER team, Woodruff, Baxter, and Biltmore, grew up in the era of planetary science, always knowing that they wanted to work in the space program; the older three, Dolan, Rainer, and Karl Trainor, came to it after doing other things – geophysics, chemistry, and artificial intelligence. Remarkably, given this diversity, all but two of the scientists have a degree related to geology – and refer back to this academic experience as a significant source of common understanding.

Working with the rover changes the scientists' sense of their professional identities. It calls on them to be more collaborative. No scientist gets unique "credit" for work; individual contributions are subsumed to serving the needs of the rover. Furthermore, disciplinary boundaries are erased in ways that make it hard to get a sense of making traditional "advances in ones field." Dolan describes how the focus on the MER blurs the lines between disciplines:

> Most scientists work, you know, in their office, with their heads down and their communication with other scientists is limited. But when you're on these missions, you've got to work with everybody else. You've got to put your heads together. You've all got to come to agreement…and you get to know everybody. Not only the scientists, but the engineers, the whole thing.

Woodruff is conscious of this blending and shifting of roles and ways of working. Like Biltmore, she did her graduate work in the 1980s, focused on planetary science. But whereas a few years ago she was confirmed in her identity as a planetary geologist, now she thinks of herself as "an explorer." Geology is part of that identity but it has led her to learn more biology to follow her interest in "figuring out Mars," the MER mission objective. It channels the scientists' energy into what Woodruff identifies as the "explorer's spirit." Biltmore expresses the same explorer's identity: "If I had lived 500 years ago I would have been on the ships of Columbus or Magellan. Exploration is in my bones."

Baxter, the youngest member of the MER science team, did her graduate work in the 1990s, sees herself as an explorer with the "mission bug."

> I knew I had the bug, the mission bug, a long time ago. I have not taken the traditional path of getting a tenure position and then moving on into research…. I have always wanted to do space science…. The reason I wanted to do that is the exploratory aspect of studying other planets, doing space science. I've often said that I do space science because I couldn't join Star Fleet. [Two] hundred years ago, I might have been on the Lewis and Clark expedition. I really, really enjoy the discovery and exploratory aspect of this. And to me missions are kind of the pinnacle of that.

Trainor, 54, a computer scientist, one of two engineers on the MER science team, sees his role as making other people's jobs easier and accepts that "sometimes that looks like sweeping the floors." He has redefined his sense of professional self worth in terms of working with the rover. Sometimes the code he writes for MER shows him at his best ("Sometimes it looks like I actually get to do … what I was educated to do, what I know how to do") and even when this is not the case, Trainor is sustained by his identification with mission objectives: "I'm all about exploration of space, and this is doing everything I can to make it work. So that's where I come from."

When they joined the project, the MER scientists could not know in advance how their expertise would fit into the mission of getting the rover to explore the surface of Mars. It was not

helpful to think in terms of one's narrow specialty. More useful was a pragmatic dedication to the rover. For Trainor, it was easy to position himself in this way, as serving the rover, "simply trying to make myself useful." Other scientists found the transition more difficult. It entails coming to a new view of one's professional training in which it becomes a "back story," something that brought you a ticket onto the mission, but is no longer central. One scientist said that, after a point, the repeated daily scientific work of cataloging data "figuring out … well, this rock has more olivine than that one… kind of gets boring." What stays compelling is being an explorer, a virtual explorer on Mars. As Biltmore puts it, "We've seen things that no one in human history has ever seen, and I've seen them first! … That's what gets me going."

Woodruff recalls wanting to be present for the downloading of data from the rover and coming to work hours before her shift was to begin: "I remember…the engineers running down to the science room and saying, 'Hey, Bettye, the data is coming down, do you want to come and see that?' and being there and just looking at something for the first time that nobody on the entire planet has seen before you—this is really exploration. And so, this is why this cannot become at any time routine, this is why I want to stay involved."

Each person I interviewed, from the youngest to the oldest, across all fields of specialization, talked about the importance of finding a niche on the rover team, of finding a way to be useful to the rover's voyage. The skills that they brought to the project did not always serve as their best guide for how they would find this niche. They had to embark on a self-directed, matching exercise, reflexive and ongoing: What can I do here? What are my capabilities? Where can I make a contribution? [4] The scientists developed an understanding of productivity that is not

relative to the standard metrics of assessing scientific contributions but to a sense of how well they have served the rover. When the niche is found, each scientist reports a sense of pleasure, even of relief. Biltmore describes the anguish of one scientist who confided in him. "He said, 'Why did I get picked for this team because I'm not going to be of any use.' And then lo and behold! Three weeks later we land in Meridiani and some of his experience and expertise is immediately valuable.'" Otherwise put, each participant gets a sense of identity from being part of something historical and important. Each feels compelled to make and remake his or her sense of professional self to feel individually relevant, even as individual contributions are hidden in the culture of how the system operates.

Balancing the desire to "fit in" to this new scientific culture, each person I interviewed pursues a personal scientific project in addition to his or her work on the mission. These personal projects provide a sense of individual accomplishment in a setting that minimizes any individual sense of "credit." But also, the scientists are continuing normal professional lives as researchers, in which a career is a kind of enterprise with multiple projects and interests. Facets of personal professional work are interwoven in both small group and large communal projects inside and outside of NASA.

Baxter teaches at a small university and has the satisfaction of bringing her unique expertise to bear. Woodruff and Rainer are dedicated to personal inquiries that integrate the MER data with that of other space missions. Biltmore brings fieldwork from terrestrial geology into his planetary interests. Trainor surprises me when he mentions, "I spend lots of long weekend nights doing…software modeling of physics. I'm interested in the process of model

discovery and refinement." Trainor, who feels he has given up his professional identity as a computer scientist in the MER mission, uses personal projects as a way to alleviate anxiety about his identity as a researcher. "Because those [personal projects] are part of my life, I'm much less concerned about actually proving in MER that I'm doing things that people would consider researchy."

An Explorer's Surrogate: Becoming The Rover

Dolan has participated in every Mars mission, but feels a sense of disorientation now when he works with MER. The rover demands a new perspective: "I spent my whole career looking down from above. And now we're down on the ground. It's a very different experience from what I had before…" The technology gives scientists the feeling that they are personally on Mars. Biltmore saw obvious things to do at Meridiani "because *everything was so laid out in front of me*." At Gusev, wondering where the lakebeds might be, "People started saying, *it's below our feet*." Asked how did he visualize his work, Biltmore says, "I put myself out there in the scene, the rover, with two boots on the ground, trying to figure out where to go and what to do… It was always the perspective of being on the surface." Yet the new perspective can bring its own disorientations. For Dolan, who was accustomed to the "big picture" he got from an orbital vision, "when we got down on the ground (this is me personally now) I'm a little uncomfortable at the narrow focus of the science." For Dolan, putting the MER output into a larger context takes work.

Working with a MER rover requires tending it day after day for years, planning its actions and interpreting the material it transmits back to earth as it moves a few meters a day or

remains nearly stationary for months as it studies a few rocks. The MER scientists become solicitous, devoted to this daily effort, the effort of nurturing the MER. But with the nurturance of inanimate things, comes attachment to them.[5]

Steve Squyres' 2005 study of the rover experience – Squyres is principal investigator of the MER work and a documenter of the experience – has many references to the MER scientists speaking of the rover in the first person and to the physical sensation of "being there" that working with the MER instills. ("As we work our way across the plains [of Mars] . . . We've arrived at Endurance Crater. . .Where we're standing now."[6]) I think of this as I speak with Baxter who sums up the decision that the group faces at the end of each day in Pasadena: "Well, are *we* going to go or are *we* going to stay here…?"

The rovers were designed to be the scientists' surrogates on Mars. Referring to the RAT, Squyres says: "Our rover was supposed to be a robot field geologist. When you see field geologists on Earth, they've got their boots, they've got their backpacks, and always, they've got big rock hammers."[7] The microimager on the rover is analogous to the geologist's hand lens, the Rover's wheels can be programmed to dig trenches (like scraping your boot in the dirt), a camera (pancam) is mounted on the rover at about the height of a man, a brush on the RAT can sweep away dust. The RAT, brush, and microimager are mounted on an arm that has a robotic elbow. It can reach and bend.

In fantasy, the rover becomes the body of each scientist who works with it. Their sense of connection to the device is visceral. Beyond this, the rover functions as the body of the science

team as a whole. Each day, when the scientists decide on the sequence of actions to translate into computer code, they are instantiating their intentions in the MER.[8] The sequence details what instruments the MER will use, what "observations" it will make, and where and for how long. It determines when and where the rover will drive or be idle (to recharge its solar batteries, referred to as a "siesta").

Mission practice requires the scientists to articulate the hypotheses that each observation is designed to test. Articulating these hypotheses forces scientists to negotiate disciplinary interests as they share a limited resource and prioritize research questions when daily confronted with the reality that the mission could end at any time. Yet scientific purposes are sometimes dictated by the technology that makes hypothesis testing possible. The historical importance of the stream of data that the rover generates can be so consuming that it diverts time and attention away from analysis of the data itself. Being involved in "operations," in daily systematic data collection, is compelling, for one is, after all, exploring Mars. Biltmore's conversation about "operations" is infused with this sense of thrill:

> I'm still heavily involved in operations, and I'm geology lead for a week out of every month…. Even when you're not the lead…I do it anyway because of the interest and honor of being here, to keep up with it and look at these pictures that are coming down every day. I mean, hell, we're on the surface of Mars!

Baxter says:

> You're not only using a very expensive machine, you're using a very limited resource and you're also *doing geology for the ages*.… This is the only data that we're going to get from Gusev or Meridiani probably for a very, very long time.… We have a big responsibility to make sure that data set is as complete but also as compelling as possible.

Early in the mission, the scientists couldn't be sure if Spirit would survive the 1.5 mile journey to the Columbia Hills. As a compromise, the team developed a plan to acquire systematic data (called "ground truth") that would be useful for calibrating orbital observations. This plan addressed the legitimate concerns of the scientists and instrument teams that the "forced march" might prevent Spirit from acquiring very much science data before she died. This "moving survey," with key observations repeated every fourth sol, was coined by Rainer "the sol quartet."

Any individual who wants to argue for a special observation is expected to articulate a scientific reason, ideally to present a hypothesis to be tested. In practice, especially when arriving at a new site, such investigations may be simply efforts to characterize materials. *They are not hypotheses to be tested, but like the strike of a hammer to open a rock, the gestures of explorers to find out what is there.* And thus, in the rover that instantiates the scientists' bodies and intellectual curiosity, one sees the natural extension of their explorers' enthusiasms – enthusiasms that do not wait for well-crafted scientific formulations, but enable them to revel in the fact of "being there."

Asked what working with a rover is like, Biltmore first describes his sense of "frustration" with the rover's body. He compares what his body could do on the surface of Mars compared to that of the rover surrogates, "They're so slow and plodding." But on reflection, he says that such comparisons are "unfair," for over time human and robot have merged into one explorer:

> These things have been our eyeballs out there and our legs and our arms… These rovers? It's been some kind of weird, man-machine bond (laughs). It's become an extension of each one of us, our eyes or our hands, our feet… I guess in a way, it's through them that we are tasting, tasting the rock. It's... kind of, it has morphed into us, or we've morphed into it.

Biltmore and Woodruff confirm this sense of having become "at one" with the machine. For Biltmore: "You want to just hop over those rocks or hop over that ridge over there and climb it, bang on it, do things." And Woodruff describes a similar experience. When she is asked to describe her relation to the MER, she offers, "What about symbiosis? You have to imagine yourself in the field, what would you do if you were there? . . ." Baxter explains:

> Sometimes you'll see people talking about, you know, 'get a picture behind us' and you'll see them turn their heads. Again, totally unconsciously, because they're thinking of themselves, if they were in the field, what they would try to be, what they would be attempting to look at.

When Rainer describes the process of "becoming the rover" he does so through a concrete scenario: The scientists will see a geological sample of interest and try to move the rover's body to reach it. They began by using engineering diagrams to mentally inhabit the rover's space, but as Rainer says, "Over time we stopped doing it so much because we began to gain a sense of the [rover's] body. That's definitely projecting yourself into the rover. It's just an amazing capability of the human mind… That you can do that, that you can sort of retool yourself."

These projections, "inhabiting the rover," occur especially as the scientists formalize and visualize plans for the next day in computer simulations.* The "science activity planner" program enables commanding the rover by pointing to and labeling images previously taken by the rover, such that chosen targets are automatically registered in precise three-dimensional Mars terrain coordinates. Other programs then convert these instrument and target sequences into specific movements and orientations of the arm and instruments. Through this tight coupling of image, targeting, and feedback, plans are transparently enacted into exploration paths, such that the scientists move over several days from broad panoramas to outcrops to particular rocks and then

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* Simulation plays a central role in the space program, ranging from computer models of spacecraft trajectories to full-scale physical mockups of cabins and modules to chambers and devices that replicate the radiation, cold, microgravity, and near vacuum of space. Simulation for the MER scientists included multiple-day simulated missions for training and refining operations, as well as rover "test beds" for practicing and testing MER behaviors. In focusing on the scientists' personal experience, this chapter considers just one small part of the nature and importance of simulation throughout the MER mission's planning and operations.

a handful of sharply resolved grains. As the rover moves forward, the returned images are ever more detailed; the retargeted cameras enable the scientists to make distinctions that interest them (Is that rock face other there layered? Oh, indeed, it is layered—are these wind deposits or layers in a stream bed?) and to move forward in their understanding of how the rocks and terrain formed over the millennia. Indeed, the use of simulation is so prevalent in the MER mission, it appears as Rainer says even in taken-for-granted informal ways, in their gesture and imagination: "There's something over there of interest to us… [I] thought about yesterday. Can we still see it? What can you see if you looked over there?" Working also with a duplicate rover in a simulated Mars terrain at JPL, the scientists further simulate how the rover will behave—compensating for the impossibility of directly touching, seeing, or manipulating the stuff of Mars itself. In coordinating the rover's work across a variety of physical and computational models, the projection of the self as being the rover is an embodied way of synthesizing these disparate sources of information.[9]

So coupled to the rover's sensing and moving, the scientists report the rover's motions as that of an entity with intention. "*Spirit* drove…" or "*Opportunity* investigated…" As if shackled at the ankles, the team moves together across the plains of Mars, looking and probing the rocks as one body. (Or course, there is some tension. Sometimes they speak as though they are at one with the rovers' bodies, sometimes as if the relationship were parental, as in this remark by Squyres: "*Spirit* and *Opportunity* have been timid, easily frightened into immobility by small rocks… But the new software should make them smarter and more courageous.…[9,,10])

Rainer refers to "retooling" himself, Biltmore to "morphing" and Woodruff to a "symbiosis" but they are all referring to the same thing—in a manner of speaking, they have

become the rover. Although a craft that lands on a planet's surface, such as the Viking in 1976, establishes a presence, a rover is different, says Biltmore, "[It's] like the next best thing to being there." Working from orbit, "You're more removed and remote."

The rover can only be in one place at a time. When the scientists have multiple agendas, difficult decisions must be made. The mind of the rover emerges as the scientists negotiate their differences. Every debate about the rover's actions has to end in consensus. Every debate has to end in a decision about a concrete sequence of computer code that will guide the rover's actions. Each step must be articulated. Biltmore gives this account of the debate about whether to move *Spirit* clockwise or counterclockwise around a small rock formation:

> We had one of these telecons, an end-of-sol presentation…a big discussion.… I was pretty vocal about going counter-clockwise around Home Plate.… It was probably the most wrenching and detailed discussion in Gusev the whole mission…. We ended up going the clockwise direction, primarily, for safety.… [One] really can't argue. We're all so concerned about power decreasing, because the winter's coming on… What if you get in there and get these shadows and can't get out?

Woodruff, too, was frustrated with the clockwise/counterclockwise debate: "We are here with the most interesting stuff in Gusev, and there we say, 'Okay, drop the rock hammer and leave!' If we don't get to safe haven, we're going to die."

Woodruff's comment dramatizes the degree of emotional connection between the scientists and what is happening on Mars. The idea that the rover might get stuck is experienced as death. The scientists are so identified with the rover that a well-known Mars astrobiologist said at a conference,[11] "The MER robots are really scientists; they are functioning as scientists." It is telling that the scientists experience their work and themselves as inseparable from a technology that simply does their bidding.

For these scientists, the rover has come to represent the mission as a whole, and indeed, talking about the rover has become shorthand for talking about their scientific work. When they describe their work, they speak of the rover's work. Daily reports rarely report on the scientists' activities, they report on the rover's actions: "*Spirit* continued to make progress on the rover's winter campaign of science observations."[12] Besides the convenience of such verbal shorthand, this way of speaking reflects the scientists' projections of themselves into the machine. When they say, "The rover is exploring," they mean, "We are exploring." Losing one's individual contribution to the collectivity is made bearable because it is shared equally and because each scientist identifies with the rover, a compensatory gratification. Biltmore loves the feeling of "two boots on the ground," imagining what the rover can see and reach; others describe the rover as "send[ing] postcards," "becoming more courageous," "finding evidence," and "exploring." No one scientist is allowed to take individual credit for discoveries on the mission, yet in these phrases, some prideful self-description is projected onto the machine.

Integration of Styles and the Public Scientist

Embodiment in the MER requires new integrations among different styles of thought – among these different scientific sensibilities and between the aesthetics of scientists and engineers. For example, the scientists argue about when to drive and when to stay in a given location, a decision that translates into how many measurements to take at a given location. Dolan sees these debates as usually boiling down to a conflict between the geologists and everyone else, with the geologists usually wanting to "get to some more interesting place" and the chemists characterized as never seeing a piece of "soil or a rock that they didn't want to analyze." Dolan interprets the chemists' passion for analysis as emanating from the new instrumentation available to them: "Because they have these instruments there, they want to use them. And they want to stop at every god-damn rock!"

Biltmore uses the language of his professional identity to express similar frustration when the rover pauses too long over what he considers uninteresting terrain. He says, "I'm not into petrology, I'm a geomorphologist." Biltmore like Dolan, sees the geologists on one side of a great divide: "You could see early on who was a field geologist and who wasn't in the group. Because a field geologist saw the value in driving and looking around, in surveying the land. Whereas a lot of people just wanted to sit there and analyze every little sand grain."[13]

When asked to complete the sentence, "Working with a rover is…?" Rainer talks about "working with a team of people . . . and a lot of them engineers." The MER teams have to integrate scientific sensibilities; they also have to take account of the compulsions of engineers to nourish and protect the rover.[14]

At the Jet Propulsion Laboratory, scientists and engineers on the MER mission often work together, always cooperating and often collaborating on problems. But their physical turfs and roles are as clearly defined as on a ship.[15] The separation of floors and rooms, with different key and badge access, formalizes engineering and science into two interleaved, but parallel activities. The engineers build the car, are its mechanics, and chauffeurs. The scientists indicate where they want the car to go, where it should stop, and what it should do during each stop. The hierarchy is there; yet at the evening meetings of the Science Operations Working Group, the scientists are reminded of the engineers' concerns, constraints, and of their ultimate dependency on them. The working group meets in a room suited to high-level diplomacy. Arranged into a large U-shape, there are tables for representatives of the study groups and tables for the engineers. A mission manager sits at the rear of the room. All tables have red lights on table-mounted microphones. The group's humor centers on control of decision-making, about who will operate the equipment. The scientists and engineers joke about their fundamental relationship in which the engineer is the service professional and the scientist is the client. As they jostle over who has custody for the rover, their challenges ask how much of this guardianship is open for discussion.

Indeed, the assembled group characterizes the effects of their MER work as healing the disciplinary divide between engineer and scientist. They claim that working with the rover has caused scientists and engineers to each think more like the other. Baxter says: "I enjoy those times when I can kind of bridge the gap between science and engineering." Woodruff says that the scientists took the initiative to explain what they were doing to the engineers, "to explain to

them what we'd be seeing." As with the negotiation of the disparate identities of the scientists, the scientists and the engineers were willing to pull together in large measure because they felt that they were doing something of historical importance. As Woodruff said: "The magnitude of what's happening up there goes way beyond any personal interest or even group interest. It's just a fantastic mission, and just being part of it, and making it work is the only thing that people were interested in. And if it takes [a] 'take it give it,' kind of thing, this is exactly what's happening."

Out of the crucible of the MER experience came a public face for the mission, including press conferences, magazine stories, even an IMAX movie. What the rovers do every sol has been documented on the JPL web site, with representative images and explanations of their significance. On selecting the first photographs of the lander, Squyres said, "We want to make a good first impression on the world."[16] Or, as Dolan put it, "It's incredibly public." He told me that while sitting on a plane, "People would realize: *My god! You're running those rovers!* How incredibly informed everybody was, it was amazing! Just amazing, everybody was involved." Biltmore says, "When I meet somebody and they ask me what I do, I say astrogeologist, and almost immediately I say I'm working on the Mars rovers. 'Cause everybody knows what that is." Woodruff compares their exploration to the voyages that discovered the New World: "Five hundred years ago, you would take a boat and discover another place… You would record that, come back and tell your story to a limited number of people. The word was spread at the speed of the horse, or human voice. Today 6 billion people on January 4, 2004, discovered a new site on another planet. This is human exploration. Not human because humans were there, but because we were ALL there, together, through a robot!"

Biltmore, Trainor, and Woodruff told long, detailed stories about the night *Spirit* landed on Mars. Woodruff describes *Spirit's* landing, "At that point… we jumped all over the place. It was an incredible ride… very personal…. There is the team aspect, of course. But yeah, it has been a personal journey. Very personal journey." Squyres felt overwhelming emotion when the rovers landed. "This is so good, I can't believe how good this feels….Pancam is really on Mars after all these years. The whole damn thing is on Mars. I dissolve into tears."[17] He concludes his book on the MER missions with the comment: "I love *Spirit* and *Opportunity*."[18] He confesses the prejudice that one shouldn't say such things lightly about machines, but the emotion overwhelms him. These machines are "our surrogates, our robotic precursors to a world."[19]

The scientists involved in their MER missions identify with these rovers because like us, the rovers move, they sense, they scrape rock, move things around, take photographs, and send them home. For the MER scientists being a member of a mission team realizes a personal dream of being an explorer. Yet in the indirect world of telescience, these individuals who were trained in academic cultures that reward individual achievement must sacrifice a sense of personal agency and lose their individual voices. Projecting their identities into the robots helps to make this bearable. Everyone is equally anonymous, yet equally present in the robot, moving together, meters at a time across the Martian surface. For observers of the project, speaking of the rover as "discovering," is simple anthropomorphization. For the project scientists, it is a way to preserve identity.

Joined at the hip but advocates for their own particular disciplines, pursuing private scientific inquiries on the side, valued for their place on the team, but tolerating the submersion of identity because it is equally shared and because they are able to express themselves through the rover, this new technologically-mediated science creates new scientists. Through the rover they forge a team that explores Mars as a group, coaxing their robots through treacherous Martian sand and steep rocky craters. Earlier technologies, some orbiting silently above a planet, some simply planted on a planet's surface, gave scientists stretches of time to consider and formulate hypotheses. MER with its two boots on the ground—moving along, shifting perspectives to confront new terrain—demands a different kind of thinking, a continually reoriented thinking-in-place. "Doing science" devolves into teleconferences, image manipulation, and computer analyses that provide their only contact with, yet further alienate the scientists from the rocks and chemistry of Mars. Nonetheless, each person, in discovering a way of participating in relation to the robotic technology and its products, finds a unique place in a bigger picture.

MER importunes with its demands for high maintenance. It requires daily devotions of a particular sort. The scientists must attend personally day after day, year after year to the robot's next actions, and then attend again to the stream of data they have commanded. Such demanding devotion needs scientists with the imagination to organize a new "big picture" of discovery through the mediation of MER. The rover is the hero of this new narrative. In the epic of the rover the scientists write themselves back into the story of their own personal journeys, in what must be, for now, the remote exploration of our planetary system.

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[1] I am indebted to the six MER scientists who shared their personal experiences in interviews and reviewed the text of this chapter. Oscar Biltmore, Bettye Woodruff, and Karl Trainor also helped orient me during the nominal mission at JPL in January-February 2004. The MER Human-Centered Computing ethnography team that I advised at NASA/Ames included Charlotte Linde, Zara Mirmalek (University of California, San Diego), Chin Seah, Valerie Shalin (Wright State University) and Roxana Wales; their observations and our conversations played a crucial role in my understanding of MER operations. This work has been supported in part by NASA's Computing, Communications, and Information Technology Program, Intelligent Systems subprogram.

[2] The initial planned operational period of a mission is known as the "nominal mission." At sol 25, *Opportunity* is still in this phase and will be so for three months. During the nominal mission, its scientific team lives in Pasadena. In the six months after the nominal mission, the team works closely together, joined electronically, from their home institutions. In the years that follow, a rover team becomes fully distributed. My report is based on observations of MER science teams in 2004 and follow-up interviews in late summer 2006 with six MER scientists from diverse aspects of the program and at different points in their careers. Broadly speaking, the MER scientists are planetary scientists, focused on the exploration of the solar system. But each gives a more specific answer when asked "What kind of scientist are you?" In profession they range

from astrogeologists to specialists in artificial intelligence and robotics to planetary geologists to biogeochemists.

[3] The membership of the MER science team is public, and many scientists have been interviewed on the internet or by the press. In this essay, I preserve the anonymity of the MER scientists. Ages are at the time of Spirit's landing on Mars, January 4, 2004.

[4] Donald Schön, *Educating The Reflexive Practitioner* (San Francisco: Jossey-Bass Publishers, 1987).

[5] Sherry Turkle, "Whither Psychoanalysis in Computer Culture." *Psychoanalytic Psychology: Journal of the Division of Psychoanalysis* 1, no. 21 (2004): 16-30.

[6] Steve Squyres, *Roving Mars: Spirit, Opportunity, and the Exploration of the Red Planet* (New York: Hyperion, 2005), 328, 334, 336.

[7] Ibid., 81.

[8] This way of proceeding stands in contrast to how telescopes such as the Hubble are managed. There, proposals by investigators and small teams requesting particular observations are made months in advance. Here, with the MER, the scientists move together in their exploration of Mars, making decisions each day and usually getting the results within a few sols.

[9] Donald Schön emphasized how designers effectively coordinate developing concepts with physical artifacts and models through a reflective and manipulatively iterative process of "seeing as" and "conversation with materials." See, *Educating the Reflexive Practitioner.*

[10] Squyres, *Roving Mars*, 325.

[11] Invited address, Mars Society Annual Convention, Washington, D. C., August 2006.

[12] JPL Spirit Update August 25, 2006, URL:

http://marsrovers.jpl.nasa.gov/mission/status.html

[13] Three and half years into the journey, the "chemists" versus "geologists" conflict has softened significantly, although Oscar Biltmore still wants to drive and drive!

[14] Within the planetary science community, *scientists* are specifically those who work in the fields of inquiry that drive space exploration, especially geology, physics, chemistry, biology, and astronomy. Psychologists, ergonomists, and social scientists are often called *human factors specialists*. Thus scientific work outside of planetary science is viewed only instrumentally. For MER, as for all planetary science missions, "scientists" are defined as those people who know how to gather and interpret the instruments' data; their expertise relates to the scientific purpose of the technology. Correspondingly, "engineers" are defined as those who know how to make, test, package, and control the instruments; their expertise relates to the manufacturing and operation of the technology. See also: W.J. Clancey, "Field science ethnography: Methods for systematic observation on an expedition," *Field Methods* (August 2001) 13(3): 223-243.

[15] Conflicts have been known to occur between scientists and engineers on oceanographic expeditions. H.R. Bernard and P. D. Killworth, "Scientists and Crew: A case study in communications at sea," *Maritime Studies and Management* (1974) 2:112–25.

[16] Squyres, *Roving Mars,* 246.

[17] Ibid,, 251.

[18] Ibid., 377.

[19] Ibid., 377.