Human Exploration Ethnography of the Haughton-Mars Project 1998-99

William J. Clancey[1]

NASA/Ames Research Center
Computational Sciences Division, M/S 269-3
Moffett Field, CA 94035

INTRODUCTION

During the past two field seasons, July 1988 and 1999, we have conducted research about the field practices of scientists and engineers at Haughton Crater on Devon Island in the Canadian Arctic, with the objective of determining how people will live and work on Mars.

This broad investigation of field life and work practice, part of the Haughton-Mars Project lead by Pascal Lee, spans social and cognitive anthropology, psychology, and computer science. Our approach involves systematic observation and description of activities, places, and concepts, constituting an ethnography of field science at Haughton. Our focus is on human behaviors—what people do, where, when, with whom, and why. By locating behavior in time and place—in contrast with a purely functional or "task oriented" description of work—we find patterns constituting *the choreography of interaction* between people, their habitat, and their tools. As such, we view the exploration process in terms of a total system comprising a social organization, facilities, terrain/climate, personal identities, artifacts, and computer tools. Because we are computer scientists seeking to develop new kinds of tools for living and working on Mars, we focus on the existing representational tools (such as documents and measuring devices), learning and improvisation (such as use of the internet or informal assistance), and prototype computational systems brought to the field. Our research is based on partnership, by which field scientists and engineers actively contribute to our findings, just as we participate in their work and life.

By studying human exploration as it naturally occurs in an extreme environment—which the geologists characterize as being like Mars—we have a basis for developing future exploration tools that are situated in human practices and the natural setting. The present study serves as a baseline: When scientist-astronauts are constrained by a Mars-like environment in future field analog studies of operations on Mars—with more limited resources and perhaps realistic hazards—their behavior and productivity can be compared to what happens on Earth in relatively unconstrained settings, such as Haughton (Figure 1). In this way, the problems and advantages of new tools and practices will be better understood because we will know how people prefer to live and work and what discoordinations they might be experiencing. We will also know what kinds of adaptations they may be making, which are masking the inadequacies of the tools they

[1] On leave from the Institute for Human and Machine Cognition, University of West Florida, Pensacola.

are given and procedures they are forced to follow. Too often engineers will characterize a tool as "faster" or "better" without appraising both the pros and cons relative to normal practices. Often technology developers bring tools to the field as a form of technology "push" and test them out; but this process of "operational prototyping" omits the step of first understanding how "users" naturally live and work in the field, so no comparison is possible. An ethnography of human exploration seeks first to understand field science on its own terms, and to design new technologies on that basis.

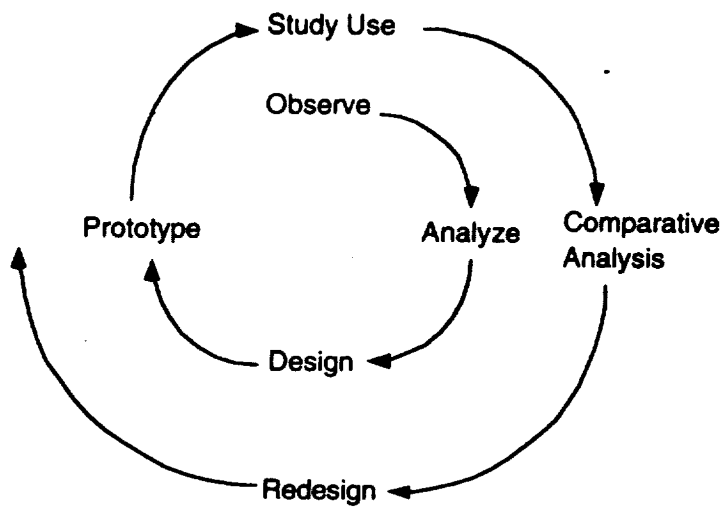

Figure 1. Design spiral: Understanding practice precedes design and enables comparative analysis after new tools and processes are enforced (after Tang, 1991)

With these principles in mind, an understanding of life and work at Haughton can provide information useful for a variety of Mars-related purposes:

- to design and automate *habitat systems,* such as the Mars Arctic Research Station (MARS), which will be placed at Haughton by the Mars Society (Micheels, in preparation)
- to determine requirements for *infrastructure and data collection tools*
- to prototype protocols and collaboration tools for *mission operation support*
- to establish needs and methods for *virtual presence* (for the public, scientific communities, and immediate collaborators of the crew), including remote sensing.

In subsequent sections, we describe the ethnographic method employed at Haughton and survey some of the patterns we have observed and design hypotheses we are investigating.

ETHNOGRAPHIC METHOD: WORK PRACTICE AND EXPLORATION

Our observational and recording approach is eclectic, combining methods from anthropology, cognitive science, and computer modeling:

1. **Participant observation** (Spradley, 1980): Learning about practices by participating in the life and work at Haughton

2. **Field notes**: Writing extensively about our experiences, on the basis of which patterns in behavior, understanding, and social relations will emerge
3. **Video interaction analysis**: Extensive video of everyday life and scientific work, seeking to uncover interactions between people, places, and things
4. **Interviews**: Recorded interviews, often about the time a member of the expedition is leaving, focusing on their understanding of purpose and accomplishment, plus examining notebooks.
5. **Surveys**: Post-expedition questionnaires about use of the internet, email, and computer tools while at Haughton, contrasted with use of software and data analysis after returning home.
6. **Domain analysis**: A systematic description of the concepts and terminology of the culture
7. **Simulation modeling** (Clancey, et al., 1998): A discrete-event simulation of human behavior at this location

Ethnography began as a method used by anthropologists studying human cultures in exotic locations, exemplified in the present context by Ituzi-Mitchell's (in preparation) study of Paleo- and NeoEskimos. Literally, ethnography is the written study of a group of people, that is, a culture. Its application has been generalized by social scientists to include the study of corporate life for the purpose of redesigning work systems, including especially computer systems (Bowker, et al., 1997; Clancey, 1995a, b, 1997; Greenbaum & Kyng, 1991; Horgan, et al., 1999). The origin of this "business anthropology" may be found in the "socio-technical systems" research of the 1950s (e.g., see Emery and Trist, 1960), which forms the basis of our study of scientists and engineers working at Haughton.

Only a handful of anthropologists have actually studied scientific work in the field (Goodwin, 1995; Latour, 1995; McGreevy, 1994; Roth & Bowen, in press). To be clear, an expedition is not a culture in the traditional sense because of its temporary nature (lasting a few weeks or at most a few months) and often transitory membership (of more than 44 participants in HMP-99, on average only twelve were in the field at the same time). An expedition is a kind of short-term project, which brings together people from different organizations, with common support and living arrangements. In practice, the group is interdisciplinary and hence forms small work groups in the field (typically two or three people spending most of the day together). Nevertheless, as in all human endeavors, there is a cultural aspect to such expeditions, largely derived from the broader and now blended "communities of practice" (Wenger, 1998) to which these scientists and engineers belong. In this respect, we include expedition communications with outside collaborators in our study (especially email consultations) and are specifically interested in designing tools that will facilitate communications between Mars expeditions and the scientists and general public back on Earth.

Furthermore, our concern with *exploration* focuses on the local scientific work on Devon Island, such as the geologists' practices and tools for mapping the crater. Other ethnographic studies of exploration are possible, such as a broader study of how Devon Island has been explored over the past decades or the historical study of Arctic expeditions seeking to find a Northwest Passage. Indeed, many lessons for planning extended space missions can be gleamed from historical analogs (Stuster, 1996). However, in contrast with voyages of discovery, a modern scientific expedition tends to work from a base camp (rather than moving over hundreds or thousands of miles). The sense of exploration here is not a discovery of entirely unknown landscapes (though ice-bound islands were still being discovered as recently as 20 years ago), but more detailed exploration of already photographed and mapped terrain, such as ravines in Haughton Crater. In contrast with discovering that the crater exists, an HMP expedition discovers and investigates parts of the crater itself—mapping and sampling outcroppings, oases, and lakes. This kind of exploration involves using existing regional maps to identify areas of interest; thus, the ridges, lakes, and valleys of Haughton Crater are being named during HMP expeditions for the first time.

Finally, the ethnomethodological analysis of how scientific descriptions and diagrams are created, adapted, and interpreted (e.g., see Lynch and Woolgar, 1993)—another aspect of the study of scientific practice—is much narrower than our study of exploration at Haughton. Although creation of notations, tool adaptation, and meaning construction are relevant to the design of new tools and may be found in our setting, our concern is necessarily broader, including how life and work are interwoven in shared space and how the expedition communicates with the outside world. Furthermore, our goal is not to write an ethnographic analysis per se, in the form of a purely descriptive story of the HMP expeditions. Rather, our work is constrained by pragmatic engineering and organizational concerns in designing the MARS habitat and determining how the Martian surface can be explored efficiently wearing space suits and working with robots yet to be invented.

Drawing on NASA's "Reference Mission" (Hoffman and Kaplan, 1997), current operating practices in the space program, computational tools being tested during the expedition , and previous experience at Haughton (Clancey, in press), we chose to focus our ethnographic observations this year on:

- Traverses (traveling by ATVs in the crater)
- Planning (especially allocating resources for the next day)
- Handovers (exchanges between crew members on different expedition phases)
- Use of space (especially shared areas)
- Communication through the internet (especially with colleagues not at Haughton)
- Conceptual change.

During the expedition a number of new patterns emerged, providing new topics for study:

- Variety of notebooks
- Revisiting sites
- Naming places and mapping
- Repairs and improvements
- Use of manuals

Subsequent sections briefly describe some of these topics and the kinds of patterns one may observe.

SPACE-TIME INTERACTIONS

During the 1998 HMP expedition we had observed that two work tents, one shared by all expedition members and the other used by a subgroup, tended not to be used equally. The shared tent was used for just short periods of time; the subgroup's tent was often occupied. To understand such differences and to determine when the tents were actually used, we recorded the use of work space more systematically during the 1999 season, using time-lapse video. For example, a camera was placed outside between the (now expanded) shared work tent, the (new) natural sciences tent, and the (new) large dome tent, with a view of the ATVs parked on the terrace in front (Figure 2).

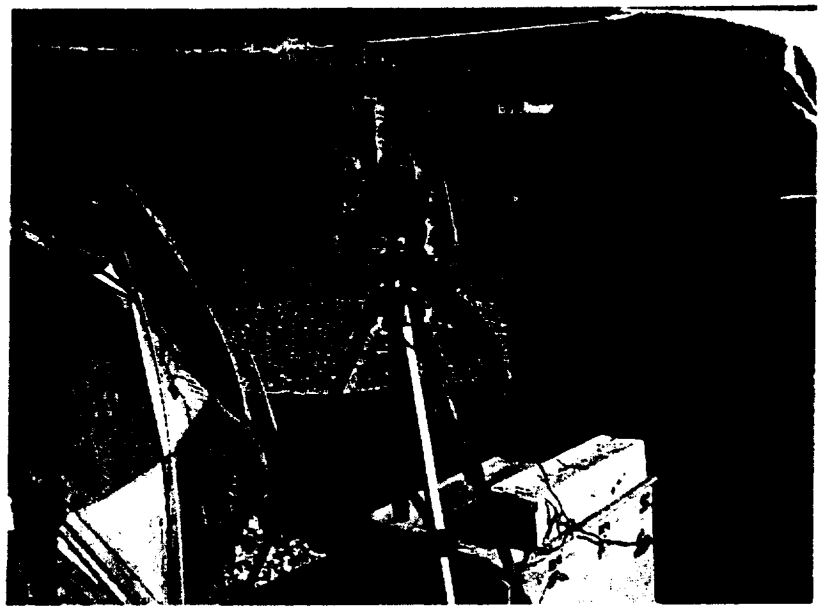

Figure 2: Example placement of camera for time-lapse video, recording entry and exit from dome and work tents, plus the central staging area used for traverse preparation.

During a three-hour period (11am-2pm) quarter-size video frames (320 x 240 pixels, see Figure 3) were directly captured to computer disk every 3 seconds (a compromise between storage and visible information). This video therefore logged occupation and motion between four key areas of the base camp, as well as capturing use of some personal tents. The layout was of special interest because motion between the work and dome tents corresponds to the top and bottom floors in a proposed layout for the MARS.

The resulting video was coded in a spreadsheet, indicating the times when someone entered or left the tents and ATV area. Durations of visits and number of people occupying each area were calculated using Visual Basic macros in Excel. Averages and totals were graphed to show correlations (for example, see Chart 1). One unexpected result is that the data allows measuring the effect of a schedule change (delay in departure of a traverse by 1.5 hours) on both individual and group occupation of the different areas. For example, movement between the dome and work tents (the two "floors") peaked each time occupation at the ATV area peaked, and reached a minimum during the delay period.

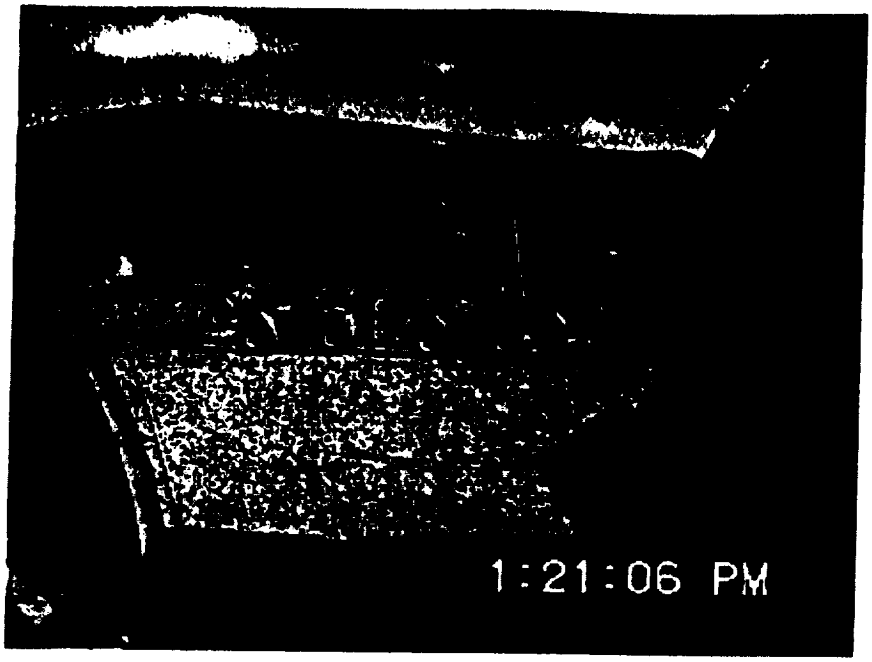

Figure 3: Example frame, showing an exit event from work tent and (at least) two people at the ATV staging area.

Factoring the analysis by individuals (Chart 2) shows a great variation that can be best explained by considering the actual activities of individuals and their roles in the camp. For example, the person who occupied the work tent for the longest total duration during this three-hour period also crossed between the work and dome tents the most number of times. This person served as a base manager and provided general infrastructure support, requiring many interruptions to assist in a variety of matters around the camp. On the other hand, a biologist who spent a relatively long time in the work tent tended to leave infrequently, so his average duration per visit was relatively long, too. Paradoxically, the base manager's desk was in the deepest corner, so he continuously passed behind those who didn't leave their seats. Further analysis of what the base manager was doing (kitchen chores? facilities maintenance?) would be required for relating work areas to avoid disrupting the rest of the crew during these movements.

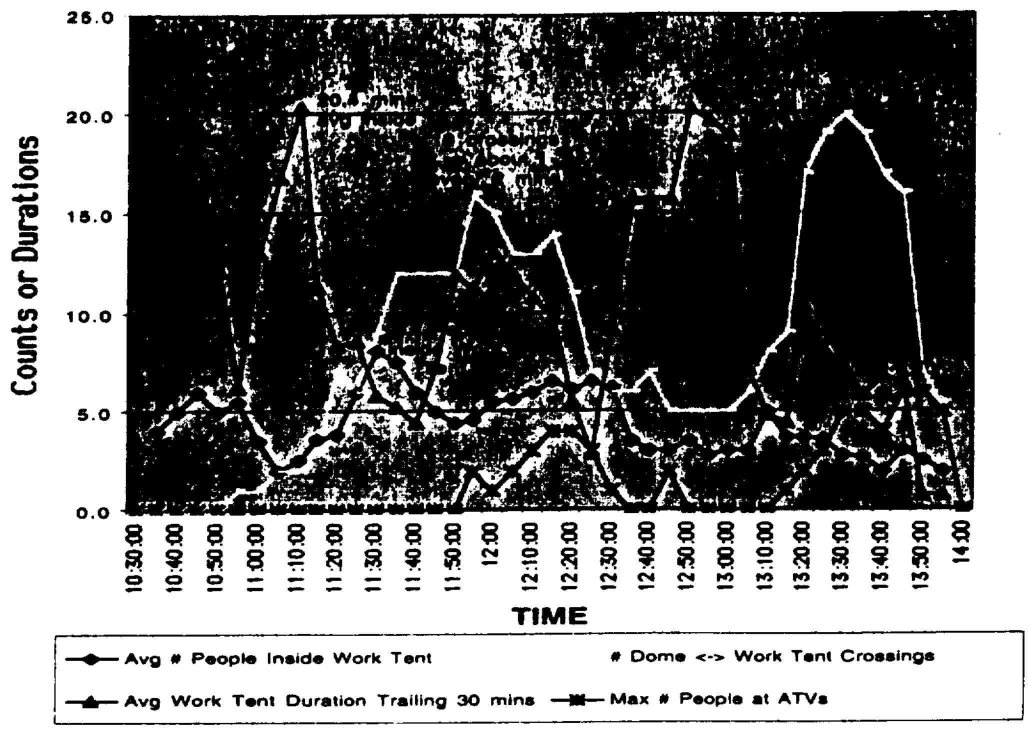

Chart 1. Average number of people inside work and dome tents and at ATVs, showing correlation at noon and 140pm expected EVA departure times. During intervening wait, work tent duration increased dramatically and crossings between tents drops.

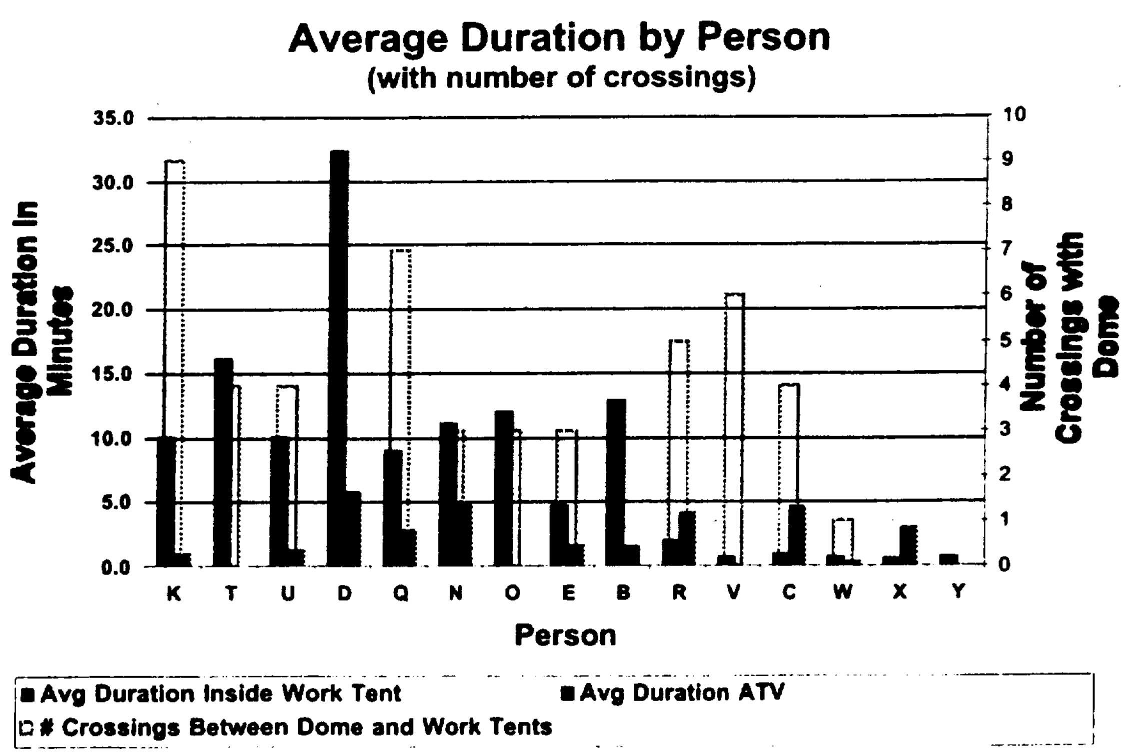

Chart 2. Individuals on X-axis sorted by decreasing total time inside work tent, showing variability in crossings and duration at the ATV, dependent on individual activities and roles. For example, K was in the tent the longest during this period, but was responsible for different tasks at many locations, so crossed between tents the most often. V was looking for someone, so crossed often, but didn't stay in the work tent. D was working relatively undisturbed, not leaving his seat in the work tent.

DOMAIN ANALYSIS

Video analysis is an important way to detect and quantify patterns. As indicated, the relations that emerge raise more questions about the details of what people are doing, how they use space, and how they chronologically chunk the work day. Such information is gathered by participating in the various activities and making notes about what people are doing. But then how are those notes to be correlated and summarized? One way of systematically organizing observations is to classify them according to a framework of relations. We used a domain analysis framework suggested by Spradley (Table 1). The relations are illustrated with two examples, one relatively mundane (corresponding to explicit knowledge, which people typically mention in their conversations, e.g., kinds of rocks), the other not typically explicated in everyday conversations (tacit knowledge, e.g., kinds of traverses during an expedition).

Table 1. Domain analysis relations and examples illustrating kinds of knowledge

General Relation	Explicit Knowledge Example	Tacit Knowledge Example
Kinds of	Rocks	Traverses
Steps in	Setting up a computer on the local network	Getting started in the morning
Places to	Practice the shotgun	Leave the ATVs
Reasons for	Arrival of a plane	Walking by the river
Parts of	An ATV	The dome tent
Things	In the kitchen tent	That can fall off an ATV while moving
Ways to	Dress	Participate during dinner
Times of	The expedition	The day (e.g., breakfast time for late risers)

Each of the relations can then be represented as a root of a hierarchy, with one tree corresponding to each relation and covering concept. For example, parts of an ATV is a relatively complex, but obvious hierarchy of parts. Some of the other relations, which are not often explicated in discourse during the expedition, may also be complex. For example, there are many reasons for revisiting a site (Figure 3). In presenting this diagram to other participants, two other reasons surfaced—recovering a sample left behind on a previous visit and looking for a lost tool.

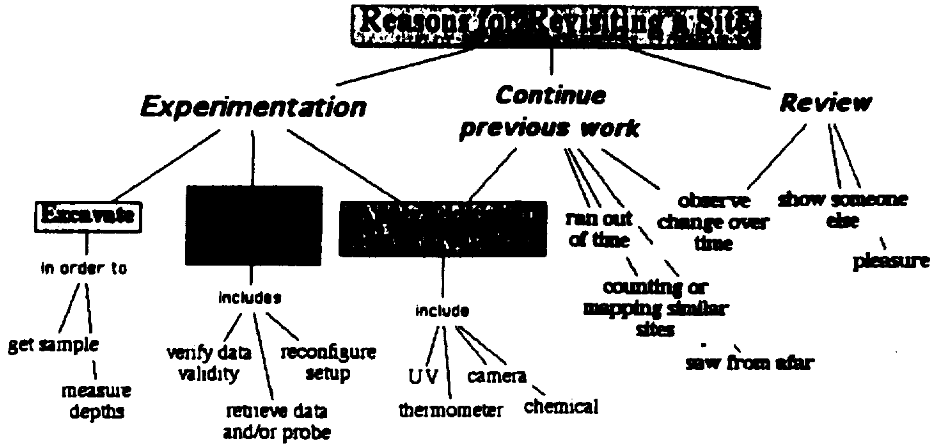

Figure 3. Domain analysis: Reasons for revisiting a site (diagram implemented using Cmap tool[2]).

Another central aspect of work practice at Haughton can be characterized as stages in a traverse:

- ***Planning*** the activity
- ***Organizing*** at start (e.g., gathering at the ATVs)
- ***Launching*** into the activity (e.g., leader departs, others follow)
- ***Punctuated events*** (e.g., full stops)
- ***Regrouping*** (bringing the group back together)
- ***Ending*** the activity
- ***Following-up*** (action items)

The reasons for revising a site and the stages in a traverse exemplify the kind of patterns that become evident only after participating in the expedition over many days, recording one's experience, and then reflecting on recurrent events. These particular patterns are relevant to mission planners, who have very limited experience with supporting human exploration (traverses on the moon and EVAs from the space shuttle are scripted to the minute). For instance, a mission planner might have thought a priori that traverses on Mars should be planned to maximize coverage of an area, avoiding returning to the same spot twice. In practice, daily planning of field science usually begins by considering what sites need to be revisited. Revisits are not caused by poor planning (though incidents like forgetting to bring a tool do occur); rather revisits are inherent in the work being done (e.g., observing a place on regular intervals) or emerge from discovery (e.g., realizing that something new may be surveyed or counted, which requires more time).

In addition, an ATV robot that accompanies a team of scientist-astronauts would have to be designed with operating procedures that incorporated the choreography indicated above, including conditions so it would "know" when to start, pause, turn off its engine, work on its own, return to the main group, and so on. Because such patterns are tacit and may vary in unanticipated ways with terrain, timing, and weather, a robot would also need to be capable of violating these "rules" and learning new practices. Notice that this procedure cannot be determined by interviewing the field scientists (in the manner of a "knowledge engineering" interview used for building expert systems). Rather it

[2] Cmap is a tool for representing and sharing "concept maps"; the tool is provided by the Institute for Human and Machine Cognition, University of West Florida.

constitutes tacit "know-how" that is induced as non-verbal conceptual coordinations during social interactions in the field (Clancey, 1999).

Many other aspects of everyday life and work were analyzed and described during the expeditions, including learning in the field, improvised repairs and improvements, and the layout of individual notebooks. For example, we recorded every marked occurrence of learning that we observed, such as asking someone for help or referring to a manual. We deliberately photographed every instance of improvisation, and noted that many of these involved creative uses of string or wire, such as unjamming the zippers of the dome tent by relieving tension on the shrunk fabric. We interviewed people who regularly used a field notebook, considering how they structured the notebook and how it relates to computer files. These and many other research topics (listed above) warrant more systematic observation and measurement in the future. But on the basis of the patterns we observed, work system design hypotheses are already emerging, which will help prioritize future research at Haughton. These are described in the next section.

HYPOTHESES UNDER INVESTIGATION

Ethnographic observation and recording is very much a bottom-up process, moving from an unbroken continuity of experiences to named patterns and themes for in-depth investigation. Although at this writing analysis of the data from 1999's expedition is far from complete, the combination of past experience in NASA and at Haughton in 1998 has suggested some initial themes. These are expressed as hypotheses here, which further analysis and observation could support, refine, or refute.

- **Exploration is not just about covering the most area in the most time; continuously *revisiting places* is essential.**
  Although survey and reconnaissance is critical for exploring an area, scientific work requires reworking an area (Figure 3). Robot design is often suggested as a way to increase the coverage in site exploration; field practices suggest as well the importance of having a robot return to a marked location. However many of these visits required fine adjustments and improvisations to scientific equipment, which are well beyond current robot capabilities. (For example, installing a new battery at a repeater station once required changing the shape of the battery's terminals.)

- **During an expedition like the Haughton-Mars Project, *conceptual change* is mostly about *organizational roles*, not only or even primarily scientific theories.**
  In the cognitive science community, "scientific discovery" is heralded as an important topic in the study of human learning. We had thought that studying field scientists would be a good way to understand such learning as it naturally occurs. We found instead that most data is analyzed and compared in laboratories back home (yet on Mars, 500 day surface visits are likely to change this practice). Furthermore, many conversations at Haughton concerned how people interpreted the nature of the HMP (e.g., its role in the context of space exploration), individual contributions at Haughton (and how this might change for a small crew restricted in ability to work outdoors), and how our home organizations relate to each other (e.g., what is the emerging relation of the HMP to NASA and to the Mars Society?).

- **Living on Mars will *change scientific practice,* physically constraining how the work is done and how analysis and publication are coordinated.**
  Although we were specifically interested in understanding field science to establish a baseline, the nature of an analog or simulation is that it must experimentally modify practices, facilities, and tools to correspond to the simulated situation (in this case, living and working on Mars). For the first two seasons, the focus has appropriately been on understanding Haughton as a geological analog of Mars. Including a habitat simulation as part of the project (Micheels, in preparation) may require that scientists participating as crew members wear a simulated space suit, restrict their time outdoors (because of radiation), and use realistically constrained data collection tools (e.g., perhaps voice recognition, not pencil and paper). By doing this, highly sophisticated communication and automation tools perhaps become meaningful. Technologists have been fostering techniques such as video conferencing and placing data on a server, which field scientists at Haughton do not always need. Without a long-duration expedition at Haughton, it will not be easy to simulate how analysis and publication practices will change, and hence what tools will be useful.

- **Systematic domain analysis *before deciding what to build* can improve designs of facilities and tools.**
  Computer system developers, particularly "knowledge engineers" routinely carry out detailed analyses of domain knowledge, such as building an expert system. But this analytic technique is most often applied after a decision has been made about what tool to build. In contrast, an ethnographic study, particularly using the methods of cognitive anthropology, is both broad and detailed by its very nature (Table 1)—helping us determine not just how to build a useful tool, but *what tools to build.* In a few weeks of work we were able to identify computer applications that were not considered in our laboratories back home.

  For example, while accompanying a geologist on traverses and studying his notebook afterwards during an interview, we found an elaborate logical scheme for numbering sites and relating observations to photos and a map of the crater. This suggested a hybrid tool that is not currently available: A digital camera with a relatively large LCD touch screen (about 3 inches square) allowing the user to draw directly on the photograph, marking and naming areas of interest. In addition, the user would be able to "hyperlink" a spot on an image to another image or area, allowing detailed images to be linked to overviews, and images to be linked to a photograph of a map. The playback system would then allow the user to employ "hotspots" for jumping between photos. This is a classic example of how participant observation and analysis in the field, just using off-the-shelf technology such as a digital camera, leads to new design ideas. Similar methods could be employed by participant observation during a habitat simulation.

- **Despite the current emphasis on robotic exploration, an important use of computers will be for *life support automation and mediating communication* with Earth.**
  Simulation at Johnson Space Center and elsewhere has focused appropriately on life support systems that will recycle waste and hence make possible a multiple-year mission to Mars. A habitat simulation at Haughton would allow the tasks of monitoring and maintaining life support systems to be placed in the context of surface

exploration activities and time-delayed communication with Earth-based support. Certainly experience on Mir, the Shuttle, and Space Station are highly relevant; indeed, experience on Mir suggests that maintenance of such systems could dominate the crew's activities. Use of "artificial intelligence" to develop software "operations assistants" will be important, but again the crew will be required to physically find and repair plumbing, wiring, climate control systems. At Haughton we observed that maintaining the electric generators, satellite communication system, and internet link was a fulltime job.

- **If formal protocols on Mars-Earth communications are imposed, "Mission Control" will not learn about *human activities on Mars* and its role may become insignificant.**
As an experiment during the 1999 expedition, Johnson Space Center personnel in the Technology and Exploration Offices, set up a "Devon Support" facility in Houston and protocol for communication with the expedition at Haughton. Documents were exchanged daily for almost three weeks, involving a "downlink" status report from Haughton and an "uplink" information package from Houston. Video conferencing was used in addition, often at 7pm, to transmit daily accomplishments and provide reports on consumables (fuel, water, food), health, and safety. This experiment provides a useful baseline for understanding the roles and needs of the participants (including members of the expedition and support team). However, given the size of the expedition there was little opportunity for informal information exchange. Consequently, the Houston-based support team learned relatively little about the daily life and interests of the scientists. Furthermore, most of the logistic support required for the expedition was provided by the Canadian Polar Continental Shelf Project (PCSP) in Resolute, on neighboring Corwallis Island. One way to understand the future role of "mission control" would be to examine the communication and support practices between Haughton and PCSP, viewing them in part, perhaps, as an analog for the relation between a remote Mars site and a Mars base camp. Furthermore, the web site maintained by the Haughton-Mars Project provided a great deal of information to Houston, which was outside of the controlled protocol exchange. How this information, which included candid photographs and sometimes detailed field reports, is interpreted and used by a support operation could be a focus for a future study.

BROADER CULTURAL THEMES

The participants of HMP-99 came from very different backgrounds. Consequently, they had different purposes for being at Haughton, and their activities in the field varied considerably. The people present during the 1999 expedition fell into three groups: scientists/computer systems engineers, pilots, and journalists/filmmakers. As indicated in the introductory sections, an ethnographic study of exploration writ large would consider how these subcultures were manifest and interacted in the field. But our concern is with developing tools and practices for scientist-astronauts, so the focus here is on the shared understanding of identity, capability, and behavior among the scientists and engineers.

In Spradley's (1980) terms, shared understandings are "cognitive principles" that constitute assumptions about the nature of common experience. For example, HMP members demonstrate in their actions an overarching sense of purpose and capability to be productive; they also rationalize their participation in ways recognizable to each other. People display this understanding to each other most obviously in the nightly ritual of after-dinner autobiographical stories (e.g., mentioning a childhood interest in the space program) and in how they comport themselves in group planning conversations (e.g., by articulating scientific interest in part of the crater, as well as in deferring personal needs to accommodate the expedition's overall goals). The patterns of shared understanding include:

- Almost everyone has a lifelong interest in the space program; everyone strongly supports living and working in space.
- The overarching objective, the reason for being at Haughton, is to have people go to Mars.
- The expedition is not wedded to NASA's organizational structure or support (key members of the group are not from NASA), but the HMP must work with NASA when necessary.
- Scientists at Haughton adhere to academic principles of systematically recording data, presenting results only after peer review, and generally have a sense of productivity that is oriented to producing a written report with findings presented in graphic tables and charts.
- Members of the HMP are physically competent to avoid injury; specifically, people are vigilant about the risks and dangers of the environment and self-sufficient in personal clothing and hygiene.
- Members sustain and develop individual interests, while enhancing and promoting the HMP's goals.
- Behavior at Haughton expresses a commitment that is secondary to family and sexual concerns.
- Members are always "on stage" with the expedition; there is no purely personal or outside pursuit. In particular, there are no "days off"; people are always working regardless of what they are doing (e.g., lounging on the ATVs is not viewed as "time off," but momentary resting). There is no real distinction between work life and personal affairs.
- People believe that "whatever we do, it should be fun."
- Unlike on historical seafaring expeditions (Stuster, 1996), there is no class distinction between scientists and the people providing logistic support (e.g., the satellite communications specialist); everyone lives together. However, there is a bias to view geology and biology as first among equals ("hard sciencies"), with computer science and engineering being auxiliary.
- The HMP federation of individuals and subgroups manifests a progressive, liberal orientation, which itself represents the open, unfettered social organizations that may colonize Mars.

These observations provide a broader background for understanding group dynamics on a Mars mission and how the crew will relate to support on Earth, and how these the explorers will relate to the general public. For example, the above description constitutes information that may not be obvious to the public. If such values were reflected in a public web site portraying a Mars mission, people might come to embrace the life style and values of the "away team" and hence support the mission more vigorously. Thus, design of computer tools and communication might take into account not only primary scientific and engineering concerns, but portray the members of the crew, NASA support team, and related communities of practice as real people, with characters and personalities that others can care about and identify with.

A public relations approach for revealing the everyday life of space exploration may seem simple and mundane, but it is violated routinely in space missions. Astronauts' experience is filtered by formal, on-board press conferences. The problem is systemic, for even mission control does not always know what the astronauts are feeling or experiencing. For example, astronauts experienced headaches and nausea during recent work in the space station, but "none of the astronauts reported symptoms to ground controllers while the mission was in progress" (Berger, 1999). The origins of the antiseptic portrayal of astronauts is a complex cultural theme, perhaps mutually reinforced by the internal politics of flight-schedule planning; the astronauts' desire to carry out difficult work without being subject to the glare of TV at every turn; and the public's interest in ready-made heroes. Similarly, the observation of life at Haughton shows a dimensionality of experience and commitment that is not commonly reported during NASA's missions and, if exposed in tales of Mars exploration, could potentially increase support for the space program. Achieving this in a balanced way would involve unfolding how mundane activities and learning are inherent in scientific fieldwork (as exemplified by the reasons for revisiting a site, Figure 3). In short, astronauts (and scientists more generally) are human beings—they enjoy themselves, do silly things, and yet act responsibly, with awareness of the privileges society has given them.

NEXT STEPS

The study of human exploration is a broad and exciting topic, benefiting from the methods and insights of the cognitive and social sciences. The study at Haughton during two field seasons has established, at least, that the prevalent focus of cognitive science on data collection and "discovery" in the modeling of human learning ignores the practices by which people live and work in the field. Indeed, even Latour's (1995) astute account of representational practices among field biologists never mentions how people live in the field as a temporary community. The land, which becomes a "protolaboratory" (p. 158) must first become a *home*, with routes, landmarks, and boundaries imbued with the group's identity and sense of purpose.

More specifically, developing technology for Mars will be hindered if it is based only on constraints imposed by the Mars environment (such as the inability to use a pencil and notebook in the field), without considering how people productively use their time, allocate resources, organize space, and make records under natural conditions on Earth. Thus, some of the learning burden is shifted to tool designers, rather than inserted as an afterthought in a better "interface" or handed over to the trainers who must prepare the users to cope with awkward technology.

New processes and tools can be comparatively evaluated by understanding current practices (Figure 1). A variety of ethnographic, participatory methods, including video analysis, formal description, and interviews, enable us to perceive and articulate the habits, preferences, and cultural themes that constitute the practice of field science. Scientists' difficulties with new exploration methods may reflect a learning process in changing practice or inappropriate design of tools or procedures. To understand where human adaptation is required and where better tools are required, future HMP expeditions will experimentally incorporate more constraints that simulate living and working on Mars. Ongoing ethnography of field science at Haughton will then incorporate a comparative analysis of the relatively unconstrained experience in 1998 and 1999, relative to the analog experience in the MARS.

Our ongoing research may include the following:

- Simulation of MARS habitat activities—"A day in the life of the crew at the Mars Arctic Research Station" based on field practices at Haughton and the newly designed habitat facilities.
- Analysis and modeling of EVA videos—develop a simulation model to control the behavior of (perhaps ATV-based) robots that can collaborate with each other and the field scientists.
- Use the domain analysis represented as Cmaps to organize information about the MARS on the Internet.
- Bridging the gap between Earth-style field science and imagined-Mars tool design—constrain the scientists to live and work as if they are on Mars and help technologists understand the nature of difficulties that develop.
- Understanding the limits of what can be learned from Haughton analog studies—classify aspects of the MARS experiment according to the degree of fidelity relative to a Mars expedition and understand the confounding effects of those aspects that are not simulated or naturally like Mars.

A great deal of work remains to be done. Fortunately, the easy collaboration between scientists of different disciplines at Haughton makes rapid learning possible, as we interact directly in the field, conveying our tools and methods as we live together.

ACKNOWLEDGEMENTS

This work has been supported in part by the Mars Society, the Haughton-Mars Project lead by Pascal Lee, and the NASA/Ames Research Center. I am grateful for the support and assistance of the members of the Haughton-Mars expeditions, who have generously provided time to share their ideas and experience on Devon Island. The work reported here a collaboration with Maarten Sierhuis and other members of the Computational Sciences Division. An important part of this study involved ongoing email exchanges with our team members "back on Earth," Roxana Wales and John O'Neill, who provided encouragement and many useful suggestions for what to observe and how to interpret our experiences. Mike Shafto and Charlotte Linde provided additional suggestions for improving this paper. I also thank Brigitte Jordan (Xerox-Parc) and other anthropologists who have provided helpful advice for pursuing this study.

REFERENCES

Berger, B. (1999). NASA takes steps to prevent illness on station. *Space News*. August 2, p. 4.

Bowker, G. C., Star, S. L., Turner, W., and Gasser, L. (eds.) (1997). *Social science, technical systems, and cooperative work: Beyond the great divide*. Mahwah, NJ: Lawrence Erlbaum Associates.

Clancey, W. J. (1995). The learning process in the epistemology of medical information. *Methods of Information in Medicine*, 34(1/2): 122-30.

Clancey, W. J. (1995). Practice cannot be reduced to theory: Knowledge, representations, and change in the workplace. In S. Bagnara, C. Zuccermaglio, and S. Stucky (eds.),*Organizational Learning and Technological Change (Papers from the NATO Workshop, Siena, Italy, September 22-26, 1992.)* Berlin: Springer-Verlag.

Clancey, W. J. (1997). The conceptual nature of knowledge, situations, and activity. In P. Feltovich, K. Ford, & R. Hoffman (eds.), *Human and Machine Expertise in Context*, pp. 247–291. Menlo Park, CA: The AAAI Press.

Clancey, W. J. (1999). *Conceptual coordination: How the mind orders experience in time.* Mahwah, NJ: Lawrence Erlbaum Associates.

Clancey, W. J. (in press). *Visualizing practical knowledge: The Haughton-Mars Project.*

Clancey, W., Sachs, P., Sierhuis, M., and van Hoof, R. 1998. Brahms: Simulating practice for work systems design. *International Journal of Human-Computer Studies*, 49: 831-865.

Emery, F.E. & Trist, E.L. (1960). Socio-technical systems. In C.W. Churchman et al., (eds.) *Management sciences, models, and techniques.* London: Pergamon.

Goodwin, C. (1995). Seeing in depth. *Social Studies in Science*, 25, 237-274.

Greenbaum, J., and Kyng, M. (eds.) (1991). *Design at Work: Cooperative Design of Computer Systems.* Hillsdale, NJ: Lawrence Erlbaum Associates.

Hoffman, S. J., and Kaplan, D. I., (eds.) (1997). *Human exploration of Mars: The reference mission of the NASA-Mars exploration study team.* NASA Special Publication 6107.

Horgan, T. H., Joroff, M. L., Porter, W. L., and Schön, D. A. (1999). *Excellence by design: Transforming workplace and work practice.* New York: John Wiley.

Ituzi-Mitchell, R. D. (in preparation). Anthropological considerations on human colonization of Mars: Insights from the indigenous peoples who first settled the Earth's Arctic. *Proceedings of the Second International Conference of the Mars Society.*

Latour, B. (1995). The "Pédofil" of Boa Vista. *Common Knowledge*, 4(1), 144-187.

Lynch, M., and Woolgar, S. (eds.) (1993). *Representation in scientific practice.* Cambridge, MA: MIT Press.

McGreevy, M. W. (1994). An Ethnographic Object-Oriented Analysis of Explorer Presence in a Volcanic Terrain Environment. NASA TM-108823. Ames Research Center, Moffett Field, California.

Micheels, K. (in preparation). The Mars surface habitat: Issues derived from the design of a terrestrial polar analog.

Roth, W-M, & Bowen, G.M. (in press). Digitising the lizard or the typology of an (externalised) retina in ecological fieldwork. *Social Studies of Science.*

Spradley, J. P. (1980). *Participant observation.* Fort Worth: Harcourt Brace College Publishers.

Stuster, J. (1996). *Bold endeavors: Lessons from polar and space exploration.* Annapolis: Naval Institute Press.

Tang, J. (1991). Involving Social Scientists in the Design of New Technology. In J. Karat (Ed.), *Taking Software Design Seriously: Practical Techniques for Human-Computer Interaction Design*, pp. 115-126. Boston: Academic Press.

Wenger, E. (1998). *Communities of practice: Learning, meaning, and identity.* New York: Cambridge University Press.