Visualizing Practical Knowledge:
The Haughton-Mars Project

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Introduction

When people talk about "knowledge" they usually refer to *descriptions*—facts, theories, heuristics that are often written down—and "knowledge in the head"—tacit *understanding*, which is conceptual. We must be careful not to equate *descriptions* with *concepts* or to identify all knowledge with scientific or professional expertise (Schön, 1987, Clancey, 1997a). I will call the aspect of knowing that is not technical, "practical knowledge," and show how it can be studied and exploited in the design of information technology.

To improve how we *envision* knowledge, we must improve our ability to see knowledge in everyday life. That is, visualization is concerned not only with displaying facts and theories, but also with finding ways to express and relate tacit understanding. Such knowledge, although often referred to as "common," is not necessarily shared and may be distributed socially in choreographies for working together—in the manner that a chef and a maitre d'hôtel, who obviously possess very different skills, coordinate their work (Scribner, 1984; Greenbaum and Kyng, 1991; Resnick, et al., 1991). Furthermore, non-verbal concepts cannot in principle be inventoried (Clancey, 1997b). Reifying practical knowledge is not a process of converting the implicit into the explicit, but pointing to what we know, showing its manifestations in our everyday life. To this end, I will illustrate the study and reification of practical knowledge by examining the activities of a scientific expedition in the Canadian Arctic last summer—a group of scientists preparing for a mission to Mars.

Practical knowledge challenges for a Mars mission

As might be expected, going to Mars involves technical problems in rocket propulsion and navigation. But a Mars mission also requires that we invent a new kind of operations, a new way of relating ground and space activities, with corresponding support tools that will make a three-year mission possible. We must reconsider how work is done because a Mars mission cannot be carried out like an Earth orbital mission: 3 years cannot be planned by the minute; traditional operations roles are inverted (ground becomes transient, space becomes permanent); and the average 40 minute communication delay prevents ongoing "looking over your shoulder" and assistance from technicians and scientists in the "backroom." In short, we must understand how practical knowledge is

learned on the job. Necessarily, this changes the tools we provide. For example, today we are implementing new electronic procedure manuals on the space shuttle. For Mars, we will need tools by which astronauts can write and revise their own plans.

The field of software engineering today is something like the building crafts before architecture developed as a discipline. Methods are locally adapted and the systems are incrementally modified to fit the needs of a particular user population. But too often software does not fit the context in which it is to be used. Invariably, discussions of computer system "architectures" view workplaces as just networks, communication devices, and workstations. Engineers know how to integrate objects and processes, but not how to relate people and their practices in new ways. Designing work systems requires something like architecture, an understanding of how people actually use tools, their activities, and how new devices would facilitate human interactions.

One effort to develop an architecture for computer system design is called "human-centered computing." This is a research effort, starting with the scientific study of people and machines. What can people do today that no computer can do (e.g., conceptualize and relate ideas in different modalities)? What can computers do more accurately than people (e.g., filter and sort data based on defined criteria)? How shall we put these two capabilities together to create a synergistic system?

From the perspective of practical knowledge, we want to help make groups more adaptable. This means facilitating learning, of which one important method is to facilitate conversations between people. In the same way, rather than talking about "usability" of systems alone, we design for *learnability*.

The key ideas in human-centered design are: adopting *a total systems perspective* (considering organizations, procedures, technologies, and facilities together) and *designing in the context of use*. Ethnographic observational techniques are especially useful—participating with people in their own work environment to better understand their problems, opportunities, and aspirations. *Ethnography* is the written study of human culture. This observational methodology reveals the presence and effects of human interaction, conversation, identity, genre, and rhythm in everyday human life.

In summary, human-centered computing is a multidisciplinary design methodology, incorporating a variety of goals—making usable systems, augmenting cognition, and

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promoting learning. I illustrate the ethnographic approach of human-centered computing in a case study.

Ethnographic study of the Haughton Crater Mars analog expedition

Haughton crater is located near the coast on Devon Island, about 500 miles north of the Arctic Circle and 900 miles south of the North Pole. The crater is about 20 km in diameter and was formed by a meteorite impact about 24 million years ago. The Haughton-Mars Project (HMP) in 1998 was an expedition to Haughton Crater, organized by Pascal Lee, a NASA astrogeologist. The crater was chosen because its breccia and permafrost-created formations are similar to what we see in photographs of Mars. Thus, Haughton's icy crater environment is a "Martian analog." Twenty four people participated in the HMP-98 expedition, arriving in 3 phases from June through July. During the ten days of phase 3, I carried out an ethnographic study of the expedition's activities. This included extensive photography. Figure 1 shows an overview of the base camp, which is a good place to get started in understanding how an ethnographer sees the world.

Figure 1: Base camp of Haughton-Mars Project 1998

Notice in Figure 1 that the tents are not placed randomly. They are in a curved line, with two larger tents in the middle. People align themselves to boundaries, they find natural

features and previously placed objects, which they can conceive as being edges, and position themselves accordingly.

The tents are placed along a "cliff," the edge of a river terrace. The three similar tents at the top left might have been placed coincidentally together. But in fact they are the tents of three people from a robotics lab who travel together, work together, eat together, go to bed at the same time, and so on. They are a subgroup within the camp, partly isolated from the rest, as even their placement on a corner shows. They work at 3 am (the sun never sets in July) on their robotic helicopter, when the winds are light; they don't go out with the rest of the group on geology and biology traverses.

The placement of tents illustrates that identity of people can be visible in how they arrange themselves in a physical setting. For example, I placed my own tent near the tent of the National Geographic writer, because that's someone I wanted to know. Thus the environment itself becomes socially structured, reflecting and promoting the relationships people desire.

Ethnographic study of expedition activities

An ethnographic study of scientists working in the field ("scientific fieldwork") is not common in anthropology. However, the methods I employed are quite similar to the ethnographic study of office work (Greenbaum and Kyng, 1991), which in turn has been based on methods employed by anthropologists throughout this century in the study of non-Western cultures:

- *Participant observation:* Learning about the culture by participating in everyday activities

- *Field notes:* Extensive written documentation of everyday activities; these notes are reorganized, sorted, and culled over extensively in months or years following the observation, as new patterns are revealed

- *Video interaction analysis:* Extensive use of cameras, both still photographs and video, detailed and wide-angle, to show relationships of people, artifacts, and environment over time

- *Interviews:* Talking to people during or immediately after apparently important events to understand their conceptions of what is occurring and how they are interacting with

each other. This includes reviewing notebooks and showing photographs and video to help the members reflect on their own practices.

• *Work practice modeling:* Although not common for anthropologists, formal analysis and description of observations is helpful to formulate design implications for computer systems.

An ethnographic study of the Haughton-Mars expedition involves studying activities in the camp and activities in the field. For example, in the camp, I observed the following regular activities:

• Pre-scheduled radio calls ("sched calls"; from Resolute airport at 7am and 7pm as a safety check and to confirm plans)
• Kitchen conversations after meals
• Conversations at the all-terrain vehicles (ATVs; see Figure 2)
• Reading or writing on an ATV
• Using the satellite telephone
• Waiting for transportation (helicopter, ATV)
• Typing up notes in work tent
• Reprovisioning recording equipment
• Washing in the river

Although one might anticipate some of these activities prior to joining the expedition, most are only visible by observation, and only "obvious" after days of reflection. In particular, patterns within patterns are only visible perhaps months later, when writing or talking about one's experience. For example, when writing my field notes towards the end of my stay at Haughton, I realized that I was one of the first to have breakfast, and shared the mess tent with only the same person every day. Through this interaction, I learned that this person cleaned up the dishes from the night before—a practice that was invisible to the rest of the participants. In conversation with this person, I learned about his background and interests—illustrating how circumstantial encounters and being located together leads to development of interpersonal relations.

Understanding the structure of practices in the expedition is not obvious. It requires days of observation and reflection, and especially going over one's notes and photographs even months afterwards. This is why ethnography emphasizes writing everything

down—when you re-present the material, rearranging it and juxtaposing different events, further patterns will emerge.

Example observation and design implication

Figure 2 is a good example of ethnographic data and how it can be applied to designing work systems. By considering how space is used and where conversations occur, I discovered that, besides the obvious use of the kitchen table for long discussions throughout the day, most conversations in camp occurred on and around the ATVs (all terrain vehicles). There are several reasons for this pattern—the space is close to the work and mess tents, where people tended to come and go throughout the day, and crucially, the ATVs were parked in one place. The people who were at Haughton for the entire expedition (about a month) generally took possession of an ATV and parked it by their tent. But most people used whatever ATV was available and parked it in the middle of the camp, near the fuel supply. Interestingly, these ATVs were not just left randomly, but parked more or less in a line, along a power cord that stretched from the work tent (on the left) to a generator on another terrace about 100 feet away.
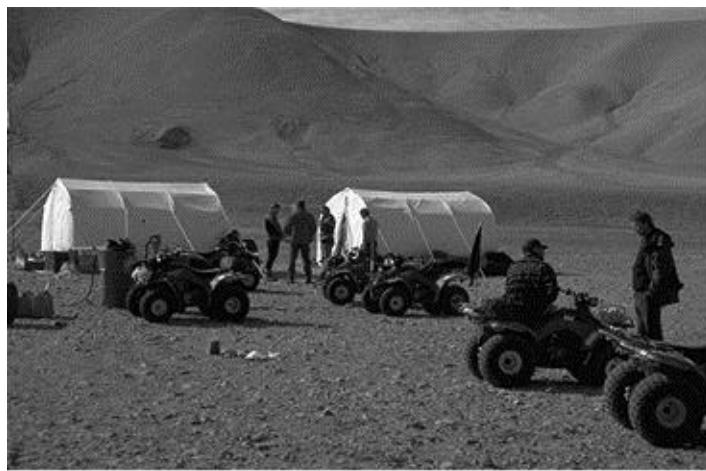
Figure 2: Emergent spaces for conversation created by tacit understanding of how to park ATVs

Where to park the ATVs was never discussed; the group constructed this emergent structure implicitly, in their own individual behaviors. The pattern tended to replicate and reinforce itself by a positive feedback mechanism—as a practice, people tended to return

the ATVs where they got them, and returning to camp, people tended to pull up again and again to that power cord.

Now, arriving back in camp, one might find someone sitting on an ATV (another reinforcement for parking in that spot). When the weather was good the ATV provided a long seat and convenient place to read or write. Often two or more people would be in the ATV area, and as a new person joined the group, others would leave. So the grouping of people was itself an emergent structure, patterned after the organization of the ATVs, patterned after the organization of the tents, fuel, and power cord, and this was patterned after the geographic pattern of terraces near the river.

Having observed how people liked to use the ATVs for gathering and talking, I conveyed this to the group leader, who then exploited that information for arranging a meeting. We wanted a recent member of the group, a flight surgeon from KSC, to show us his medical kits and explain what supplies should be available during such an expedition. The mess tent was far too small for this, so the leader rearranged the ATVs into a kind of 'campfire circle' (thus using another spatial layout familiar to everyone).

This is not a technologically sophisticated example, but the concepts are general. One design heuristic is to leave flexibility in facilities so objects can be moved and used in unexpected ways. In this respect, tables and chairs that move are potentially more valuable than those bolted to the floor or too heavy to move. More generally, people naturally exploit and rearrange their environment to facilitating talking and working together. In particular, the use of a "campfire circle" shows how people exploit familiar design metaphors. Alternatively, we might have arranged the ATVs in rows, as in a classroom, for a formal lecture. But in this setting, an informal, outdoor talk after dinner suggested a campfire arrangement.

Study of other expedition activities

During the course of ten days in the field, an ethnographer observes "the rhythm of work life." Besides routine scientific activities such as collecting samples—what you expect scientists in the field to do—there are associated activities for observation and reconnaissance. For example, at least one day was devoted to flying helicopter surveys of the crater and investigating the glaciated eastern area of Devon Island. This shift to a "macro" study of the environment is part of the rhythm of scientific field work. That is,

"collecting data" includes much more than gathering particular rock and water samples. Understanding the context in which samples are gathered is essential for understanding their meaning.

Similar attention is paid to activities of other members of the expedition. For example, when the robotic helicopter started flying, everyone else in the camp lined up on the upper terrace to watch. This is one way of developing "social knowledge," learning about the competencies of other people in the group. On the International Space Station, such awareness will be essential for safety—being tacitly aware of the dangers of nearby activities.

Other activities sustain and reproduce the capability of the group over time. For example, each time a person or group (a new "phase") joins the expedition, the group leader gathers people around for a kind of ceremony. People are introduced to each other and the newcomers are introduced to the camp. As a side benefit, people may hear an introduction they heard already (helping them remember someone's background and interests). Individuals also have the opportunity to reinvent themselves, to emphasize some details in their history in a different way, finding a more fitting persona to fit the group they are now coming to know.

Just as activities are specialized as "openings," other activities are "closings." Two examples of closing activities during the expedition are "the final days of the expedition" and "the departure activity." The nature of the work changes, our concerns are different now. We think about getting the last samples and photographs. We think about places we wanted to see. We take out the ATVs for a final view from Tripod Hill at 11pm. We walk down to the river to check out the stones and pick up a few more for our collection.

The departure activity is a classic organized group activity. We discuss the night before what needs to be done, we seek volunteers, we agree who will work with whom at what time. We identify needed materials (boxes, tape), we highlight safety issues (guns, food, shelter). During the next day, informal assistance is solicited in taking down the tents, as some people take pride in volunteering and others become scarce.

Many activities are organized in advance, but improvised throughout. The prime example of an organized, but highly improvised group activity is a *traverse*, which I will subsequently explain in more detail.

Ethnographic study of "traverses"

Traverses were the most central activity for phase three of the HMP-98 expedition. Phase two, which I didn't observe, focused on experiments and data collection (e.g., drilling core samples from the permafrost). Phase three was about exploration using the ATVs. Traverses are of special interest in planning for Mars because this will also be the key way of reconnoitering—using small transportation units that hold a few people at most, to explore the landscape. The story of the first six missions to the moon, is also the story of traverses, including a "rover" vehicle that carried two people in Apollo 15, 16, and 17.

At Haughton, people traveled on a dozen traverses over the course of a week, following the Haughton River, exploring the breccia highlands, following feeder creeks through the "lake sediments" area to the west, and on one very long day-trip, examining the "valley network" outside the southeastern crater area.

Understanding the practice of traverses, as for any organized activity, involves understanding a traverse as structured process. Every traverse had the same internal structure:

- *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)

In general, we find in organized activities a mixture of explicit plans and rules, improvisation, and an emergent ensemble (Maue, 1979). Maue describes a general procedure by which people construct new activities: "There is a beginning, the player proceeds in turn, that which is done becomes precedent, some acts are unacceptable, there is an ending." Members of HMP-98 learned about traverses and how to participate in them without a text book or training. This is an example of learning practical knowledge on the job. Understanding traverses is necessary for understanding the *context* in which field work was performed at Haughton.

Study use of computer technology in the field—The mobile workstation

My original reason for joining the HMP-98 expedition was to study my colleague's "mobile workstation"—to observe its capabilities and to convey the methodology of design in the context of use (Figure 3). The design concept involves computer technology for recording data and integrated records. Our prototype mobile workstation was just a laptop computer strapped to an ATV, with a black hood that allowed the screen to be viewed outdoors.
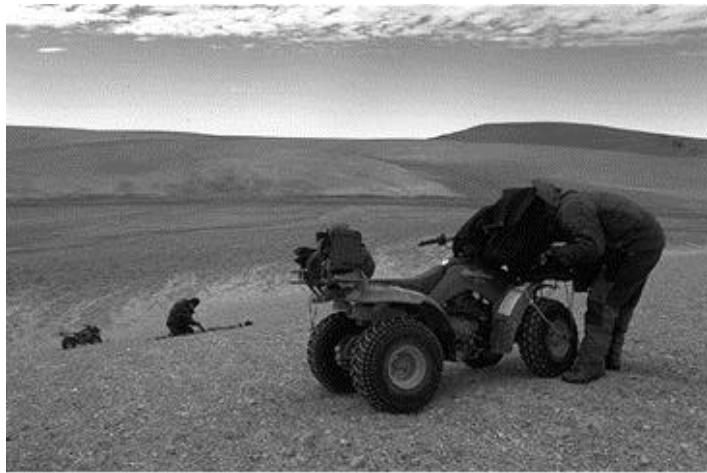
Figure 3: "Mobile workstation" — recording activities of astrobiologist on a steep slope at Haughton Crater

The photo illustrates why analog studies are necessary. In planning the experiment, we never considered or discussed the use of the workstation on a hill. Yet, in the field, that's where some of the biological studies were carried out. These hills were so steep and slippery with gravel, it was necessary to park the ATV many meters away from the field scientist (visible to the left). Consequently, the video camera produced only a tiny image of the excavation work.

In retrospect, we might have interviewed experienced people in advance and determined that a hand-held camera would be better. But in general, the interaction of work practice, spatial layout, and technologies is not easily anticipated. Even with better equipment, we'd need the experiment in the context of use to determine, for example, whether a robotic camera could be devised that would automatically follow and record the field work.

Study representational media

Figure 4 illustrates the problem of field recording—how are the data in different media recorded at this one site correlated? For example, the biologist on the left is using pen and paper to correlate the temperature reading with the depth of the thermometer. The video camera is recording sound and image together. But wouldn't it be useful to relate the photographs with the complete audio recording (taken over the forty minutes of this excavation and study)? Yet this is only one stop from at least a half-dozen during that traverse, and just one traverse from the entire expedition. No database exists that brings all the participants' data together, relates individual data and observations at a given place or time, or produces a coherent scientific image of the crater.

Figure 4: Typical use of recording media in scientific fieldwork. Data is not easily correlated.

This example suggests a single recording device that combines video, photographs, audio, time, and GPS (global position system) would be helpful. But even then, the thermometer would probably need to be separate. How is that data to be related? And finally, knowing how to present the database would require further study of how data is actually used during and after a mission. What presentations of live data from Mars would be useful to scientists and engineers back on Earth, who are monitoring the mission and making suggestions?

Study individual notations and order of data collection

At a different level, we are interested in how the information created during field work is recorded as data. In Figure 5 we are looking over the shoulder of a geologist, who is assisting a physician in recording water samples. The notebook belongs to the physician, but is being filled by the geologist. Who will use this data? For what purposes? Are the these two people, like the biologist, imagining a journal article or technical report that will be based on this data?

Figure 5: Shared field notebook (sample #6 was logged by the physician, all others by the astrogeologist)

What if we automated the data recording process? Would we lose valuable ideas that are occurring to the geologist as he writes down his observations? How is context recorded? To answer these questions, we analyze the record in detail. We see a steady pattern in the notebook, a kind of template that the geologist is following. In order, he logs the water sample number, a brief description of the site, the picture taken at this site, and the GPS (global positioning system) location information. Sometimes information is left out—a picture number is not recorded. Examining his photographs would tell us whether he forgot to take the picture or just didn't enter the number.

When reviewing this enlarged photograph of the notebook with the geologist, I learned that the physician made the second entry: He drew a squiggly line to show a break from the geologist's notes. The geologist then continued with the third and fourth entries,

drawing a straight line between them. In fact, the geologist and physician are sharing this log, taking turns at entering information. Now we realize something much more important—not only are they taking turns, they are *using the same general format* for entering information. Most likely the physician is following the geologist's cues, for we know from his camp introduction that he has never done fieldwork before. The physician's quick adoption of the format provides evidence that the pattern is not idiosyncratic, but might be a useful template to supply in a computer-based tool.

Conceptual development and constraints in scientific fieldwork

It should now be apparent that ethnographic study of fieldwork includes very specific details as well as the broad patterns of human interactions. An important broad pattern is how people conceptualize their overall activity in the expedition—why are they at Devon Island? What is their contribution? How does their work here relate to their larger goals, tasks, and identity?

For example, if we asked the biologist when he was on a traverse, "What are you doing?" he would refer to the particulars around him. He might say, "I'm excavating this lemming burrow to see how it is connected." This is commonly how we explain what we are doing. But there are always broader, contextual conceptions that frame and shape what we see, do, and say.

Besides being "on a traverse" we find that the biologist is "writing a paper"—a broader activity that directs and orients his observations and thinking. He is organizing his day and his attention during a traverse by considering the genre of a scientific article—the genre of tables, maps, theories, typical descriptions, and broad frameworks. Rather than just "gathering data," the biologist is getting the information he needs to create a comparative table of oases, to draw a map of oases distribution, to support a theory of oases formation, and to describe a typical oasis. He is also considering broad themes that his paper might address— "Polar Winter," "Darkness of Impact," "Biology of Impact Craters." He frames his observations in those terms and reminds himself to get additional data to fill out these genre templates. After a week, he has not only the data he needs, but knows the figure captions and title for his paper.

One might look at the biologist's activity in several ways. From a non-scientist's point of view it might appear surprising. Is it too much oriented towards producing a publication?

Shouldn't he be observing the setting more broadly, in a theory-neutral way? On the other hand, his time is short; he has just a few days to get information, and his information must be useful. The templates of an article provide a way of relating data usefully—the ideas of comparison, distribution, formation, and typicality are central to biology. These are disciplined ways of thinking, orientations that make the biologist an efficient, insightful observer.

Nevertheless, the biologist's highly disciplined fieldwork was not preordained, but itself developed during the first few days of the expedition. Originally, the group leader envisaged studying lemmings when he saw the oases the year before. In early excursions after his arrival in the third phase of HMP-98, the biologist saw no lemmings, but decided to place some traps anyway. When no lemmings were trapped, the item of interest became the oases themselves, leading to activities of excavating, mapping, and measuring. Revisiting the same locations with a larger team, new discoveries were made (bones, more feathers) and additional theories were articulated about oases' formation. Returning home, the biologist investigated previous related work, and eventually wrote a paper that placed his study in the context of other biological formations in the Canadian Arctic.

Although the idea of learning on the job may sound dubious to a manager of office work and most businesses, for a scientist learning on the job is a necessity. If the scientist is not forming new ideas and new theories, he is not working. Just as learning occurs during a typical work day, we can track the conceptual change that occurs during a week's expedition.

Apollo's two-day stays on the moon didn't provide much opportunity for forming new ideas and plans. Time was strictly controlled, and two days is not much time for shifting objectives and plans. But in a week at Haughton, scientists experience broad shifts in their objectives and plans, as observations and interpretations feed back to shape the next day's activities, producing new objectives, new observations, and eventually a different understanding of what one is doing at Haughton.

Brahms: Multiagent simulation of situated action

Brahms is a tool for modeling (describing) and simulating practical knowledge (Clancey, et al., 1998). We developed Brahms in order to make visible, to visualize, practical

knowledge in office settings. We are constructing a simulated 3-d interface, which will show people and their environment, indicating the changing locations of people and materials. Making a model accessible to non-technical people is an important design constraint. We intend to use such visualizations in facilitating conversations between workers from different areas of a business in work systems design projects (Greenbaum and Kyng, 1991).

A key reason for the ethnographic study of HMP-98 was to determine whether Brahms could be used to model scientific fieldwork on Mars. The study revealed that the system was broadly applicable, but significant additions to the modeling language are required to describe characteristics expected for fieldwork on Mars: a model of the terrain and climate, how people work while they are sitting in a "rover," interactions with robots, the interplanetary time lag, the affect of 38% gravity, etc.

We also plan to use Brahms as a framework for carrying out future analog studies at Haughton-Mars in a rigorous way. By describing the various dimensions of practice—people, activities, tools, environment—we can specify what aspects are analogs, and what is being ignored. We can then question interactions that may result and invalidate our observations relative to what would occur on Mars. For example, is it necessary to wear space suits with stiff gloves in order to understand work on Mars?

With the aim of developing good simulations of scientific fieldwork, to be used in robot design, automated health and safety systems, and communication networks, we will continue the ethnographic study of future expeditions to Haughton Crater. We plan to carry out experiments to understand: individual and disciplinary differences in field activities; interpretation of plans and checklists; forms of "group memory" over phases; communication allowing "virtual presence" between the field, base camp, and scientists in the south ("Earth"); and how scientists interact with robots and workstations.

Conclusions

The ethnographic study of practical knowledge during HMP-98 exemplifies the distinction between the study of *practice* (when, how, local interactions, and subjective viewpoints) and the traditional human factors emphasis on *process* (what, why, flows, and formal descriptions). Most process models focus on "stuff" (data and work products) that moves through space and is transformed in time. Practice models focus on

interactions and context that determine who does the work, including the broader conceptualization of identity and participation in a community, and how these influence the creation of information and the quality of the work.

Going to Mars requires a paradigm shift in how we think about knowledge, work, and plans. Knowledge is more then technical; it includes how we structure and use our environment, our activities, and our relations to each other. An ethnographic analysis emphasizes:

- *Social-psychological view of work:* Activities/identities versus tasks/functions

- *Local knowledge:* the worker as a generator of concepts, notational languages, and presentations versus a "tool user"

- *Learning strategy:* a self-organizing crew with emergent roles and practices versus fixed, "optimal," predefined roles and procedures

In three years, a crew of four or six on a Mars expedition may change their roles relative to each other. They will learn each other's skills, becoming assistants and then colleagues. This is positive aspect of human interaction. Study of small, isolated groups indicates that individuals may also stop talking to each other; we must plan our missions for that possibility as well.

The ethnographic study of HMP-98 illustrates the broad ways in which we conceptually coordinate our interactions—activities, identities, and genres. These are socially constructed forms that constrain how and where we look, what we see, our interpretations, our ways of talking and conversing, our dress and posture, our interests and values. All provide meaning to our life by setting boundaries, ways of aligning ourselves, ways of being. In our actions, we give meaning to the forms themselves by realizing them, making them visible, such that our conceptions of what we are doing (these identities, activities, and genres) are manifest in our behavior, and thus what they mean and how they are defined is changed.

The study of scientists pretending to be on Mars reveals that knowledge is not just about past experience, codified as facts and theories, but includes future-oriented imagination and prototypic skills and methods. The common interpretation of "envisioning knowledge" assumes that knowledge is somehow captured in images or graphics. But

consider the photographs from Haughton and how the ethnographic perspective enables us to gain knowledge from images. Like the biologist examining Haughton's oases, we not only describe the patterns we see, but inquire about their developmental formation. Especially, we see relations between people, tools, and environment and generate a new understanding *from* these images.

In considering tools for envisioning knowledge, the Haughton-Mars study suggests that we develop technologies not just to inform, specify, or regulate human behavior, but that we provide means for people to visualize and hence create their own future.

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