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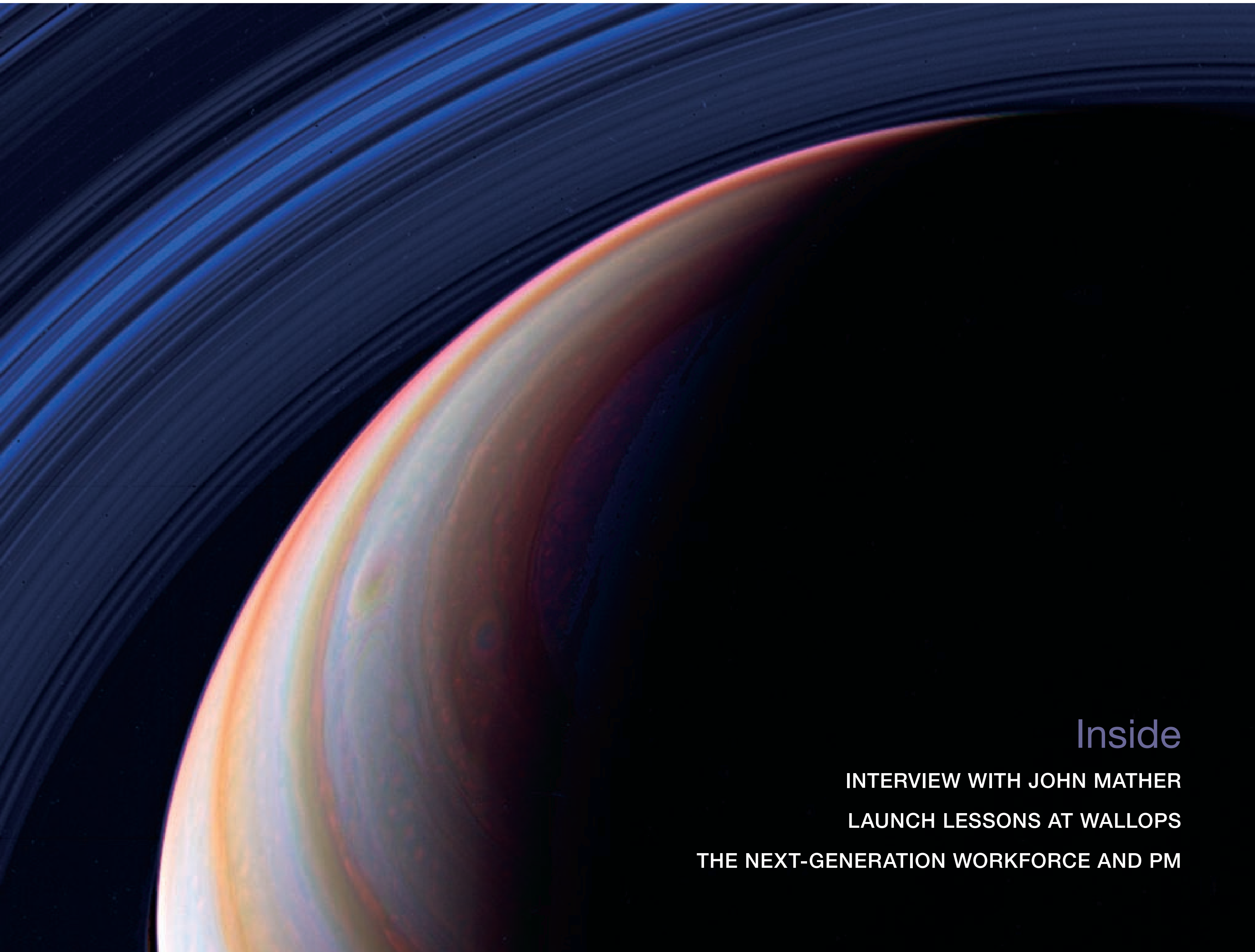

Inside

INTERVIEW WITH JOHN MATHER

LAUNCH LESSONS AT WALLOPS

THE NEXT-GENERATION WORKFORCE AND PM

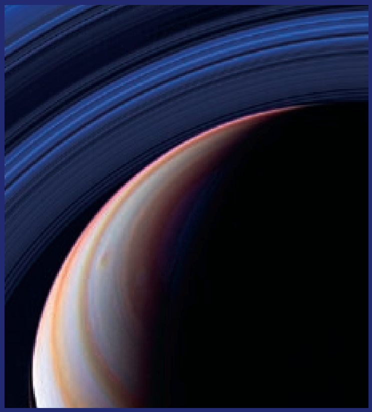

Photo Credit: NASA/JPL/Space Science Institute

ON THE COVER

The Cassini spacecraft surveys Saturn's outstretched ring system in the infrared from a vantage point high above the planet's northern latitudes. This image was taken at a distance of approximately 900,000 miles from Saturn with Cassini's wide-angle camera, using a combination of spectral filters sensitive to wavelengths of infrared light. The Cassini-Huygens mission is a cooperative project of NASA, the European Space Agency, and the Italian Space Agency.

Contents

DEPARTMENTS

INSIGHTS

STORIES

ask
Issue No. 28

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The Academy of Program/Project and Engineering Leadership (APPEL) and *ASK Magazine* help NASA managers and project teams accomplish today's missions and meet tomorrow's challenges by sponsoring knowledge-sharing events and publications, providing performance enhancement services and tools, supporting career development programs, and creating opportunities for project management and engineering collaboration with universities, professional associations, industry partners, and other government agencies.

ASK Magazine grew out of the previous academy, the Academy of Program/Project Leadership, and its Knowledge Sharing Initiative, designed for program/project managers to share best practices and lessons learned with fellow practitioners across the Agency. Reflecting APPEL's new responsibility for engineering development and the challenges of NASA's new mission, *ASK* includes articles that explore engineering achievements as well as insight into broader issues of organizational knowledge, learning, and collaboration. We at APPEL Knowledge Sharing believe that stories recounting the real-life experiences of practitioners communicate important practical wisdom. By telling their stories, NASA managers, scientists, and engineers share valuable experience-based knowledge and foster a community of reflective practitioners. The stories that appear in *ASK* are written by the "best of the best" project managers and engineers, primarily from NASA, but also from other government agencies, academia, and industry. Who better than a project manager or engineer to help a colleague address a critical issue on a project? Big projects, small projects—they're all here in *ASK*.

You can help *ASK* provide the stories you need and want by letting our editors know what you think about what you read here and by sharing your own stories. To submit stories or ask questions about editorial policy, contact Don Cohen, Managing Editor, doncohen@rcn.com, 781-860-5270.

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In This Issue

Most NASA missions have majestic goals. The Apollo program that put men on the moon, the rover landings on Mars, flights to the outer planets, and the space telescopes and other instruments revealing truths about distant galaxies and the origin of the universe are tributes to the ambition, curiosity, and resourcefulness of generations of scientists and engineers. NASA's history is in part the story of men and women who have had an extraordinary ability to imagine new questions and invent ways of answering them.

The robotics researcher and fiction writer Karl Iagnemma ("Equations and Lies") writes about the fundamental mystery of the kind of creativity that comes up with a problem or perspective no one has thought of before. He goes on to detail some of the long, hard work required to turn that flash of inspiration into the reality of a functional robot or convincing piece of fiction.

A lot of what we do at NASA consists of that kind of hard work: the endless hours of design, review, manufacture, and testing, all the painstaking nuts-and-bolts tasks that lie behind that photograph of Saturn's rings or the ability of Spirit and Opportunity to roll across the surface of Mars. Many of the articles in this issue of *ASK* focus on the often unglamorous work on which the success of glamorous projects depends. In the interview, for instance, John Mather talks about the endless hours of discussion between scientists and engineers to devise instruments that could measure subtle variations in the background radiation of the universe *and* be possible to build, and about the importance of knowing how to run productive meetings. "On the Wallops Range," by Charles Tucker, describes the almost fanatical pursuit and application of the lessons of experience to ensure successful launches. Wessen and Porter's "The Cassini Resource Exchange" explains a novel method for distributing project resources. Several articles ("Space-to-Space Communications," "Apollo: A Young Engineer's Perspective," "Making and Monitoring Critical Assumptions") illustrate the importance of thorough testing—of hardware, software, and the assumptions that shape and guide projects. The fact that the Project Management Institute has recognized NASA as one of twenty-five outstanding organizations in project management (see "*ASK* Interactive") is another indication of the Agency's ability to do the down-to-earth work space exploration requires.

As Dan Holtshouse's Apollo article also makes clear, successful projects maintain a vivid sense of the connection between all the daily, demanding, meticulous labor and the grand, dramatic goals. It was being continually aware of the fact that they were building something on which the lives of astronauts and the pride of the country depended that made it possible for them to work those many exhausting hours and devise test after test to make certain this new technology would work. Mather, too, notes that the COBE team cheerfully worked long hours in part because "they knew they were doing something important." Certainly one of the critical jobs of the successful project manager is to keep people from losing sight of the grand goal as they struggle with the complexity and frustrations and even sometimes the tediousness of their daily work.

This is part of what Ed Hoffman is talking about ("From the APPEL Director") when he notes that teams can get in trouble by focusing too much on a narrowly defined set of project milestones. He emphasizes the importance of relating all project activities to the organization's overall strategy—that is, to the inspiring larger goals that justify all that hard work.

Don Cohen
Managing Editor

From the APPEL Director

Getting Results in a Project World

BY ED HOFFMAN

One issue has emerged as a common concern in my recent discussions with project practitioners representing a broad cross-section of public and private sector interests around the world. Are project failures increasing? Is some vital component of good project execution missing? This concern is not surprising. It is reinforced by the Katrina tragedy, by failed Iraq War construction projects, by falling debris hitting cars in the Boston Big Dig, and by delays in fulfilling orders for the new Airbus super jumbo jet.

American project managers in particular possess a reputation for getting it done, and rightfully so. After all, our know-how and technology got us to the moon and back several times. They will get us back to the moon, permanently this time, and then on to Mars and beyond. But recent failures raise nagging questions about why so many project teams have not succeeded.

This is not to say failures cannot eventually become huge successes. We forget the flawed mirror in the Hubble when we marvel at the magnificent images of our wondrous universe it produces. Our memories of the first buggy Internet Explorer browser fade when we use the current fabulous multimedia-capable version of the software. The best teacher is failure, if the right lessons are captured and absorbed by individuals and organizations. But I wonder if the current publicized project failures could cluster around some powerful issues that are often neglected?

Of course, there are some well-known components of successful execution, including accurate requirements, good planning, risk management, adequate resources, and talented and committed personnel. But I think there are other critical conditions for project success that are seldom acknowledged and therefore rarely attained.

First, projects need to be intricately and actively tied to the organization's overall strategy and reviewed and debated frequently by leaders and practitioners to assess their relevance. Too often, projects operate in isolation, focused on a narrowly defined set of milestones that ultimately fail to connect with interrelated activities and objectives. As a result, they neither support nor benefit from that wider context. Second, the execution of required activities and processes often falls short of what is needed. Lack of clarity about objectives, specified activities, and accountability means that the focus on executing the organizational strategy will eventually diminish, even though everybody is working long and hard hours. Finally, open communication and transparency are critical for project success, sustaining commitment and follow-through by practitioners who truly embrace the goals.

One reason I continue to believe in our efforts at *ASK Magazine* is that they allow practitioners to communicate project knowledge across diverse organizations and help to connect project teams with the broader organizational context.

One more point: As I continue to talk to practitioners and visit a wide range of projects in many organizations, I'm more and more convinced that good leadership is a non-negotiable component of success. Only excellent leaders can ensure that the issues I've raised are effectively addressed. ●

ON THE WALLOPS RANGE: A Geek's Guide to Lessons Learned

BY CHARLES TUCKER

"I tell people I'm a true geek," Jay Pittman says, laughing. He's driving on a two-lane strip of blacktop flanked by summer-green crops, heading seven miles southeast from the main base of Wallops Flight Facility toward a tiny barrier island off Virginia's Eastern Shore, where the Wallops launch and research range stretches along a sandy strand of the Atlantic Ocean.

Photo Credit: NASA

The TacSat-2 launches from Wallops Flight Facility.

WE GOT COMPLIMENTS FROM OUR EXTERNAL REVIEW PARTY … AND SOMETHING ELSE—THERE WAS A CONSTANT REFERENCE TO LESSONS LEARNED FROM PAST MISSIONS AS WELL.

"I'm a computer science mathematician," he adds, by way of explanation.

Pittman is also chief of the Wallops Range and Mission Management Office. Before taking that job in January 2002, he ran a systems software engineering group in the engineering directorate of Goddard Space Flight Center, where he led teams of civil servants and contractors providing "end-to-end" software services to Wallops missions.

"That was exciting!" he exclaims, as if to reinforce his self-described geekiness.

But if Pittman gets jazzed reminiscing about software engineering, it's nothing on the order of his enthusiasm for his current post. "Honestly, this is the *best job* in the whole world," he says.

How did a computer geek end up doing rocket stuff? The "end to end" comment tips his hand. "Even as far back as college"—he's a Virginia Tech alum—"I really didn't care that much about the software itself. What I really enjoyed was the process." The *getting there*, from one end to the other.

Across the past six decades, Wallops—the only launch range owned by NASA—has been the site of more than 16,000 launches, from sounding rockets and balloons to orbital launches. By virtue of the facility's small size, nimble and low-cost operations, and, to use Pittman's term, "super-responsiveness," the process is unique.

In one six-month span, from December 16, 2006, to April 24, 2007, the Mid-Atlantic Regional Spaceport, Pad 0B, at Wallops Island was the site of two orbital launches. Both the TacSat-2 (Tactical Satellite-2) and NFIRE (Near-Field Infrared Experiment) missions were launched on Air Force Minotaur I rockets—TacSat for the Air Force Research Laboratory, NFIRE for the Missile Defense Agency. Both launched on schedule to the second.

Their success hinged on the ability of the project teams to get the missions off the ground quickly: seventy-two days for TacSat-2 from the time of delivery of launch vehicle; forty-nine days for NFIRE. Achieving that quick turnaround depended on an apparently paradoxical type of project management—tight supervision and democratic participation—in a style that suits Wallops's soup-to-nuts approach.

"Almost all our projects are concept to launch—end-to-end projects," Pittman says. "It's an extremely dynamic process." Which makes the range chief and the range a perfect fit. "That's one of the best things about this job: the opportunity to sort of sit in the midst of these project managers, to be responsible not only for watching over these projects as they get to completion but then, at the end of a mission, to get back in and sort of push out all the experiences to the other project managers in such a way that everybody gets better."

For Pittman—the man managing the mission managers—the process is everything. Following a successful launch, it starts immediately all over again with the lessons learned from the mission that just concluded. From Pittman's perspective, the success of the first Minotaur launch was "really only complete when we did it again with NFIRE. The lessons learned from TacSat-2 were a big part of the success of the follow-on mission. We kept those in front of us the whole time," leading up to the second Minotaur launch four months later.

Befitting a computer science mathematician, Pittman takes a pragmatic, stepwise approach to the problem of converting lessons learned from a static collection task to a dynamic activity. He's clear-eyed about the purpose of the process. And when he talks about lessons learned, he becomes animated, drawing out words for emphasis, in his native Virginian drawl.

"The *key thing* about lessons learned is that you have to put them in a context where they are *visible* and *actionable*. They can't feel like a beating. And they can't be so wispy as to be ignored. That's the magic.

"If you think about all the reviews we do at Wallops, when we do a launch readiness review we generally have the same agenda whether we're doing a Minotaur or a sounding rocket or whatever. It's all the same stuff; it's just a question of scale.

In fact, we do exactly what Vandenberg does, exactly what the Eastern Range [Cape Canaveral] and everybody else does. What we do for lessons learned is, we categorize the lessons and actually stick them in a bucket that corresponds directly to a topic that has to be addressed at the major reviews. And we put that in the hands of the project managers—and also in the hands of the reviewers.

THAT'S ONE OF THE BEST THINGS ABOUT THIS JOB … TO BE RESPONSIBLE NOT ONLY FOR WATCHING OVER THESE PROJECTS AS THEY GET TO COMPLETION BUT THEN, AT THE END OF A MISSION, TO GET BACK IN AND SORT OF PUSH OUT ALL THE EXPERIENCES TO THE OTHER PROJECT MANAGERS IN SUCH A WAY THAT EVERYBODY GETS BETTER.

"So our review panel for TacSat-2 came in not only with the materials that they were going to review, but with very *specific* lessons learned about each one of the areas. And what happens is, there begins to be a dynamic between the project managers and the review panelists. So just by allocating lessons learned in this way, we ensure a personal dynamic is going to occur between the manager and the panel."

But that's just the beginning, says Pittman.

"There are ripples to this that are even *more* important," he continues, "because that's just how we get it through the review—and how you get it through the review is *nothing* compared to what you really need to be doing to do the work. Now we've created a process where the project team says, 'Geez, why are you doing it this way?' and the project manager says, 'Well, I knew you were going to ask this. I don't want to see us not learn this lesson.' So now the project team members start to *anticipate* that the project managers are sensitized to these things, and they start doing them.

"*That's* the theme. That's the process. We've become almost obsessed with this idea that we're going to proceduralize everything."

To make the magic work—to really make it "actionable"—the trick is to make the lessons learned applicable.

"The real problem," says Pittman, "is crunching down the relevant stuff and putting it in front of people and making it relevant to their jobs. When you do it like this, you have just *vast* re-use of best practices. And people become very sensitized to things that didn't work, and the next time they say, 'We're never doing that again!' You've sort of made it a stepping stone on a path that they normally walk.

"And when you do that, then you've achieved something."

In his office back at the Wallops main base, Pittman scrolls through screen after computer screen of lessons learned inputs and reports for the TacSat-2 mission. The culmination of all this information is, among other materials, a 225-page presentation-style compendium of lessons learned. The document begins with a bar-chart summary of findings in nearly forty categories, from testing and countdown to range instrumentation, through mishap plan, budget, decision authority, and ground systems to safety, security, requirements, facilities, waivers, and so on. It includes both a summary of major trends and a detailed report for each of the categories. Each detailed report in turn has a lesson statement, an impact statement, a recommended action, and a response from the range and mission management office.

"Look at this!" Pittman says, staring intently at the screen. "We even learned stuff about waivers. There's one waiver process that was so broken that we finished TacSat, and the day after we started the waiver process for NFIRE because it was just so *whacked*. Here's the data behind all that.

"Or look at this. We didn't have a good line of sight to the launchpad. It was obscured. So we put that into a category that would be applied to a review and recommended actions, then the team turned it into actions and we fixed the problem [for the NFIRE launch]. In fact, most of these were fixed sitting right here, when I'd call somebody in and say, 'Apply some of your budget to fixing that problem.' And it goes away. Ultimately, there were more than 200 of these that we then rolled into about fifty overall lessons."

In all this enthusiasm for the process, it's clear that Pittman takes particular pleasure in the democratic inclusiveness of the procedure: "We pride ourselves on the fact that we get lessons learned from everywhere. We get them from radar operators and security guards—*those* are the people who tell us, 'You know what, you guys, this looked good in the review but it didn't work on launch.' And then we had to do this and that and the other thing.

"We took the [TacSat-2] launch team, put them in a room, and looked at how many lessons we got from the team. Are there any groups of people that we got no lessons from? Surely it wasn't perfect in Security—where are our inputs from Security? And right on down the line."

Transparent. Relevant and applicable. Not wispy, but not burdensome. On the Wallops range, the magic of lessons learned works. "On NFIRE," Pittman says with some pride, "we got compliments from our external review party about the constant reference in the second mission to the TacSat lessons learned. And something else—there was a constant reference to lessons learned from past missions as well. A lot of what we did on NFIRE and TacSat, we did because we knew it to be the right thing for a *sounding rocket.*"

Now Pittman is off and running. With thousands of Wallops missions as a reference point, the Range and Mission Management Office chief is just warming up to the subject. ●

CHARLES TUCKER works with Dr. Edward W. Rogers, chief knowledge officer at Goddard Space Flight Center, on organizational learning and knowledge management initiatives using case studies of Goddard and other NASA missions.

Does a Good Engineer Make a Good Project Manager?

BY GEORGE N. ANDREW

Many at NASA believe the myth that good engineers make good project managers. My twenty-eight years of experience in engineering and management have taught me that engineers are often poorly equipped to manage projects, but it isn't always their fault.

Good engineers know a lot. They know how and when to multitask; they can focus on details as well as the big picture; they interpret requirements and make good judgments about which are necessary and which are merely desirable; they make educated decisions about risk; they are team players and listen to others' opinions; they brainstorm, whittle down to viable options, and make decisions; they empower, mentor, and teach others; and they take and give constructive criticism. Many of these qualities are also essential for being a good project manager. So why don't all good engineers become good managers?

A Difficult Transition

When I made the move from engineer to manager, upper management expected me to handle all project issues and concerns and report back plans to correct them. Trying to do that on my own, with no formal training, I ran the risk of becoming a micromanager and a stranger to my family. I eventually realized I needed help from my whole team. Sharing the load meant the project could be successful, and I could leave work at a reasonable time and have a family life. I also believe that letting my team know that I couldn't do it all myself encouraged them to come to me when they, too, needed help on a particular task. No one ever told or showed me that this was something I should do as a manager—and must do to become a *successful* manager—and learning the lesson was painful.

I made mistakes and couldn't avoid all the pitfalls that come with moving from a specialist role to a managerial one. During unfavorable (not constructive) feedback, I learned I was doing a poor job of managing my budget and schedule and that my team was filing complaints about me. That was tough to hear, but it told me what type of manager I had become. In some areas I was a "micromanager" and in others I was a "hands-off manager."

One of my early projects as a manager involved a guidance system for a launch vehicle, which I let the contractor handle completely because, at the time, I had little guidance system expertise. At the critical design review, it became clear that the contractor had accidentally designed for a suborbital launch trajectory, which meant the vehicle would come back to bury itself in the earth, rather than an orbital trajectory. Had I taken time to familiarize myself with the system along the way, I could have caught the problem early on. I was paying too much attention to the areas with which I was most comfortable and familiar and avoiding the unfamiliar because it was uncomfortable, and I had a greater chance of messing it up. A tight schedule and low budget compounded the problem. At this point, I had two choices: proceed on my current path and more than likely continue to be unsuccessful, or acknowledge my error and get some help.

I WAS PAYING TOO MUCH ATTENTION TO THE AREAS WITH WHICH I WAS MOST COMFORTABLE AND FAMILIAR AND AVOIDING THE UNFAMILIAR BECAUSE IT WAS UNCOMFORTABLE, AND I HAD A GREATER CHANCE OF MESSING IT UP.

Instead of falling deeper into fear and ignoring the tough feedback, I asked the company vice president, who had been a

This article mentions different managerial archetypes. Below are qualities I have observed or experienced from each type.

THE MICROMANAGER

The micromanager seems never to delegate; always has to do things himself; doesn't plan (and wonders why there is always a problem); looks to blame instead of encourage results; performs crisis management; believes whatever is done isn't done well enough; thinks there is never enough time to get anything done; seems to always claim the fame; rarely rewards subordinates; and is motivated by fear.

THE HANDS-OFF MANAGER

The hands-off manager seems to always delegate; never does things herself; asks others to do the planning; reviews very little work from her subordinates; approves everything either without reviewing it or asking questions about it; doesn't understand why or what decisions are made, as she doesn't make the decisions; seems to work in the shadows of others; may or may not reward subordinates; may or may not claim the fame; and is motivated by fear.

THE EMPOWERING MANAGER

The empowering manager delegates with an observant eye; shares in the work; works with others in planning; always looks ahead; empowers those that work for him; reviews work and suggests improvements; pushes those who work for him to step forward; encourages creativity; looks to solve the issues and not place blame; looks to do the right thing; manages time; and is motivated by confidence and trust.

project manager, why I was perceived as doing poorly in some areas. I found a mentor and sought training outside the firm to help recognize my faults and failures. I also set aside time in regular staff meetings to ask my team how I could help them do a better job and what I could do to be a better manager. Taking that risk was frightening and overwhelming. I was fairly sure that raising those questions would strengthen their impression that I was less than capable of doing the job. Instead, I began to regain the team's trust, and we began to work better together.

Finding a mentor and training to improve my people management skills were the most important steps in turning my failure into success. I learned not only how to work with people better but also how to recognize the fear of failure that was sabotaging my ability to succeed.

Making the Change

So perhaps the question should not be does a good engineer make a good project manager, but rather how can we help a good engineer become a good project manager?

Good systems engineers have experience seeing the big picture and multitasking. Good detail design engineers are well versed in managing details. These strengths can also be pitfalls. A systems engineer may fall into the role of a hands-off manager by losing sight of the details, while detail design engineers run the risk of becoming micromanagers. Both should aspire to become empowering managers who have natural leadership skills and can balance a project's demands with their team's abilities. Recognizing an engineer's strengths and limitations should be the first step in making the change from engineer to project manager.

What both types of engineers need most is training in how to work successfully with a team. Supporting and leading a team requires a different skill set than supporting a system. Good engineers need training in how to become good managers, no matter how talented they are. Thinking that they will be good managers because they are good engineers only perpetuates the myth and sets them up for failure.

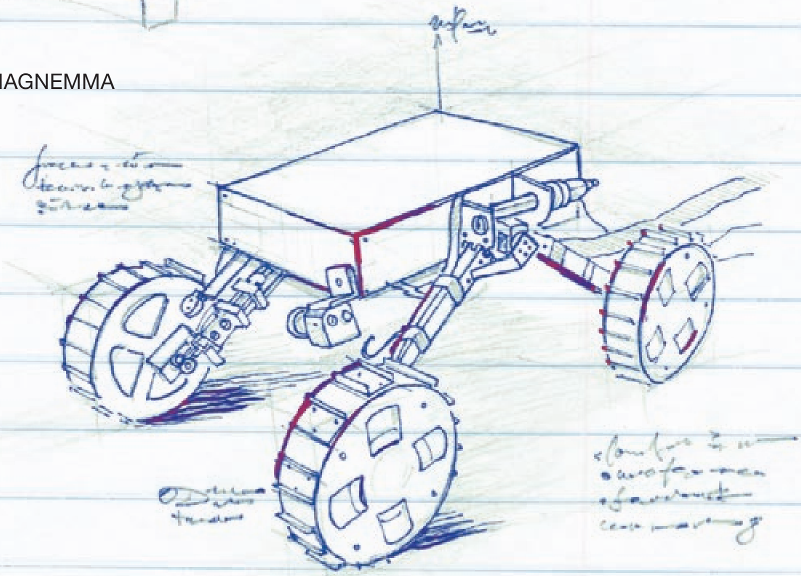
I am not a perfect project manager, nor a perfect engineer for that matter. I have learned how to ask for help, empower my team, give credit where and when it is due, continuously work with a mentor (seeking a new mentor when I am without one), take bad news and issues up the chain, and develop (with my team) a recovery and implementation plan. We managers need to prepare our high-performing engineers better for the new responsibilities they will face as project managers. The first step is recognizing that technical ability alone and even technical ability combined with natural leadership skills are not enough to make the transition successful. ●

This article is based on a presentation from NASA's 2006 PM Challenge. The original presentation may be found online at http://pmchallenge.gsfc.nasa.gov/Docs/2006attendee-presentations/2006presentationsCD-attendee/George.Andrew.pdf.

GEORGE N. ANDREW is an independent consultant with twenty-eight years of experience with spacecraft and launch vehicles, including fifteen years in project management. He has developed and presented numerous tutorials and authored several articles on systems engineering in spacecraft and launch vehicles. He is currently working as a program systems engineer on the NOAA GOES-R series weather satellites at Goddard Space Flight Center.

Equations and Lies

BY KARL IAGNEMMA



Let me tell you a story.

When I was a young, eager PhD student at Massachusetts Institute of Technology (MIT) searching for a thesis topic, I would take long, late-afternoon walks around the Institute, hoping to stumble upon inspiration in the paint-scabbed hallways. Inevitably I ended up in Building 4, the domain of the music department. The pianists would be practicing, usually something difficult and melancholy, and music would trickle from the instruction rooms and fill the corridor. For a moment, my unwritten thesis would be forgotten, and I would remember that there were, in fact, other things in the world besides simplex algorithms and Bode plots and Kalman filters. (These random musical interludes were, I'm sorry to say, some of my most pleasurable moments as a graduate student.)

I eventually found a thesis topic in the field of robotics. Specifically, I investigated autonomous control algorithms for planetary surface exploration rovers. (Full disclosure: my research was sponsored by the wonderful folks at NASA's Jet Propulsion Laboratory.) To complement my major field of study in robotics, I chose as a minor field a subject that had interested me since I was a boy: fiction writing. Making up stories. Lying, though in a classy and interesting way. If musicians could find a home at MIT, I figured, then so could an aspiring fiction writer.

When I proposed this course of study to my PhD thesis committee, I expected to be reminded that my work lay in the realm of fact, not fiction. Instead, the three professors nodded vaguely. "If that's where your interests lie …" one offered. I interpreted this as enthusiastic approval.

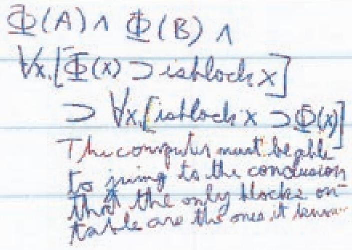
Fast-forward three years. I was strolling the Institute corridors, my thesis recently defended, my mood brighter than it had been in a long, long time. Through a combination of sweat and luck, I'd had my first book of short stories published, and the event was accompanied by an article in the campus newspaper. I happened to bump into one of my thesis committee members. He offered me a bemused grin. "I read about your book in *Tech Talk,"* he said. "I didn't know you were writing short stories!"

"Well, I did minor in fiction writing," I said. "You approved my course of study. Remember?"

"Ah!" he said, as though a profound mystery had been explained. "I thought you were studying *friction!"*

And so it has continued in both my careers, as a robotics researcher and fiction writer. Whenever I reveal that I'm a researcher who writes fiction—or a fiction writer who dabbles in research—I'm met with curious disbelief, as though it's impossible to pursue such singularly distinct activities.

But what I've come to realize is that the two efforts—conducting engineering research and writing fiction—are much more similar than my thesis committee members (and many other people) might think.



… THE TWO EFFORTS—CONDUCTING ENGINEERING RESEARCH AND WRITING FICTION—ARE MUCH MORE SIMILAR THAN MY THESIS COMMITTEE MEMBERS (AND MANY OTHER PEOPLE) MIGHT THINK.

I don't mean to suggest that research efforts have plots or characters (save for the eccentrics that haunt university and government laboratories alike). What I mean is that the process of performing research is similar to the process of writing a work of fiction—or at least it is for this researcher/writer.

I view both research and fiction writing as exercises in structured creativity. Both begin with a blank page then progress through different stages, each focusing on an increasingly fine level of detail. To illustrate this process, let me briefly describe two of my own recent experiences: researching methods for autonomous vision-based terrain sensing by Mars surface exploration rovers, and writing a short story called *On the Nature of Human Romantic Interaction*. The goal of the research was to develop a method for autonomously analyzing images of Martian terrain to identify the location of large rocks and hazardous drifts of regolith (the loose, dusty material that covers solid rock below). The short story described a—fictional—failed PhD student who yearned to formulate an equation that would predict the time evolution of his flaky girlfriend's affection for him.

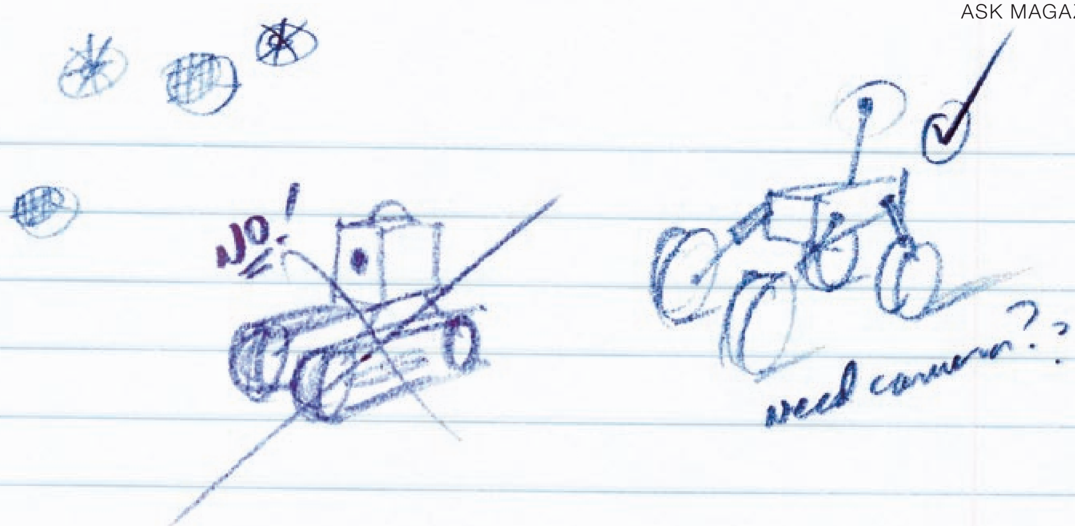
Where did these ideas come from? I have no idea. Like all ideas, they emerged from the subconscious swamp of everything I've read and overheard and dreamed about and forgotten. Nearly all my ideas are bad ones; a few, though, throw off a certain indescribable spark. And choosing an idea—hauling it from the subconscious swamp into the harsh light of critical examination—is the first, and most difficult, stage in the creative process.

This first stage, more than any other, relies on an individual's talent. I am convinced that talent in the research domain is expressed primarily in a person's ability to choose interesting research problems to address. I've worked with researchers who were shockingly intelligent, and others who possessed formidable analytical skills—but the ones I consider most talented were neither the smartest, nor the most skilled, nor the best schooled. They were the ones who had an unteachable ability to ask the question, "What if we could do X?" (Here, X represents something startling and useful that many other researchers have overlooked.)

Talent in fiction writers can follow a similar pattern. Great writers are often unexceptional stylists—I'm thinking of Philip Roth, Richard Ford, and Robert Stone, to name a few—but possess an ability to describe a character or event or setting in such a way that its essential nature is revealed. Think of John Cheever's (or John Updike's) vision of American suburbia, or E. L. Doctorow's depiction of early 1900s New York. Great writers, like great researchers, can find beauty and meaning in even the most commonplace material.

The difficulty of this first stage arises from its fundamental lack of *structure*. When faced with a blank page, our minds often tend toward the mundane—an imitation of a story that we heard last week; a minor variation on a technical approach that we read about last year. While it is easy to rehash an old idea, it is very hard to create something truly new. Art and science agree on this point: newness is a necessary (though not a sufficient) condition for any good work. Writers since Sophocles have struggled to *make it new*, since even the most shop-worn concept—boy meets girl, boy loses girl, boy feels awful—can become fresh, and powerful, when imbued with a distinctive voice, placed in a unique setting, or described in a style that challenges our assumptions about the way language must be used. In scientific research, newness is essential: if an idea is not new, it does not represent an advance in the state of the art, and, therefore, it is not worth investigating.

The next stage of the creative process involves exploring the space of our idea. Now that we know what we're after—the problem we want to solve, the story we want to tell—we hunt for methods, techniques, and tricks that will let us solve our problem, or tell our story, in an interesting and meaningful way. Often the struggle lies not in formulating a potential approach to a problem, but deciding which among *several* possible approaches will allow us to most elegantly—or rigorously, or beautifully—achieve our goals. To solve a given mathematical problem, for example, one must often choose between pursuing an analytical solution or relying on numerical analysis. In fiction writing, the same story can usually be told from various different points of



view; the choice of point of view—first person or third person (or second person, even)—strongly influences the lyrical and dramatic possibilities of the work.

In our efforts, we have progressed from a pair of blank pages to ones filled with scribbled notes and crossed-out questions, scrawled reminders in the margins. Our desk is piled with journal articles written by previous researchers, novels written by other writers. And as we probe equations and sketch scenes, we conduct what amounts to a search through the constrained space of our idea, hunting for something *good:* an analysis technique that lends insight into a particular form of equation; a combination of character and tone and setting that yield the unmistakable whiff of good fiction.

In our rover research example, this stage requires us to identify visual features of the Martian surface that yield clues about the terrain's physical characteristics. Are features drawn from terrain color more descriptive than those drawn from texture? Should we approach the problem as one of classification or segmentation? And in our fictional example, is this failed PhD student in his late twenties or early forties? Did he quit graduate school by choice, or did he flunk out? And should the story be told from his point of view or that of his flaky girlfriend?

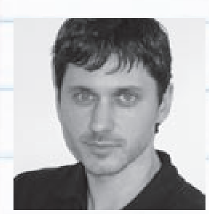
(For those of you scoring at home: in the rover research we decided to pursue a Bayesian approach to multiclassifier fusion, to merge the outputs of supervised classifiers operating on image color, texture, and elevation features. In *On the Nature of Human Romantic Interaction*, I wrote about a forty-one-year-old ex-PhD student named Joseph who dropped out of the (fictional) Michigan Engineering Institute but continued to man the twenty-four-hour computer hot line as he wooed his young girlfriend. (The equations describing the time evolution of her affection, by the way, were of the Lotka-Volterra variety.))

The final stage of the creative process is revision and refinement. We've figured out how to solve the research problem at hand; we understand what story we want to tell, and how we'll tell it. Our simulation results are promising; our characters are vivid and our scenes compelling. Our conclusions feel surprising but somehow inevitable.

What remains is to bring the work to a state of near perfection by making minor (or, occasionally, not so minor) changes. This stage focuses primarily on individual words and numbers: adverbs and adjectives and gain levels and parameter values. Should the image features be extracted over an 8 x 8 pixel window, or 12 x 12? Should a filter be used to mitigate noise, or not? And if so, what are the best locations for the filter poles?

And should Joseph—poor, hapless Joseph—be forty-one years old, or will making him forty-three increase a reader's sympathy for his plight? Should his girlfriend be named Kate or Alexandra? Should the evening sky be "eggplant-colored," or "the color of a deep bruise?" Our work nearly finished, we scrutinize every choice—every metaphor, every variable—hoping to transform something decent into something good, something good into something excellent. And eventually—weeks, or months, or even years after we began—we quit, exhausted, unable to bear another moment's contemplation of the work. The creative process ends with a whimper, rather than a bang.

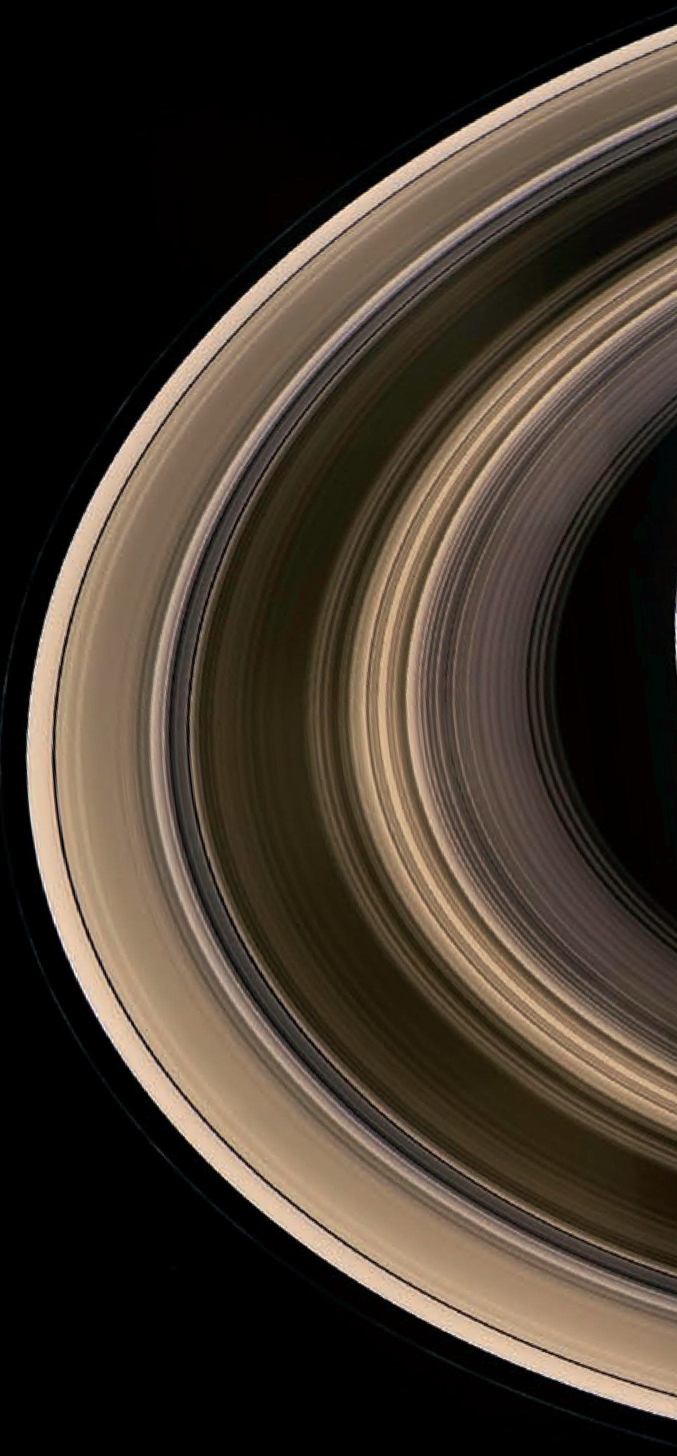
There are individuals, I know, whose creative processes are profoundly different than the one I've just described. Writers who pen a single, inspired sentence, then watch a story unspool with little revision. Researchers who bash every problem they encounter with a single, well-worn analytical hammer. I'd suggest that these differences, however, say more about differences in personality than they do about the (supposed) gulf between art and science. *What if?* can be answered in many different ways—through an elegant assembly of equations, or through pages of interesting lies. ●



KARL IAGNEMMA is a principal research scientist at MIT and author of the books *On the Nature of Human Romantic Interaction* and *The Expeditions*.

THE CASSINI RESOURCE EXCHANGE

BY RANDII R. WESSEN AND DAVID PORTER



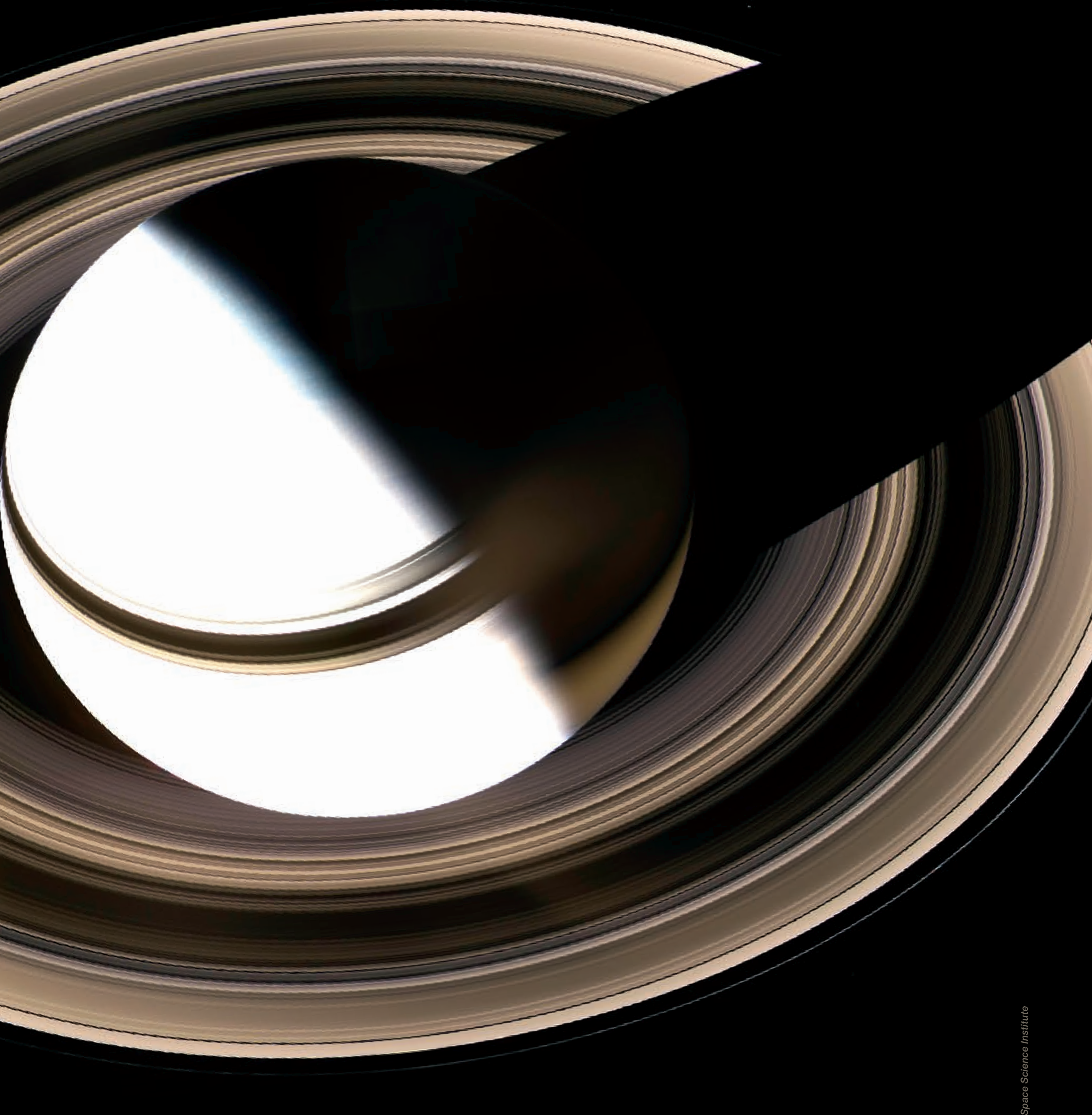


Photo Credit: NASA/JPL/Space Science Institute

Saturn sits enveloped by the full splendor of its stately rings. Between the blinding light of day and the dark of night, there is a strip of twilight on the globe where colorful details in the atmosphere can be seen.

It's amazing what you can do when you don't have a choice. That exactly describes the Cassini mission to Saturn when its twin sister CRAF (Comet Rendezvous and Asteroid Flyby mission) was canceled. CRAF and Cassini were designed together by the Jet Propulsion Laboratory for NASA as part of the Mariner Mark II series of spacecraft in the early 1990s. The thinking was that developing a common spacecraft for deep space exploration would mean substantial cost savings for both the comet and Saturn missions. In addition, the common spacecraft design would give the Saturn craft the benefit of the larger fuel tanks needed for CRAF's orbital mission around a small comet, and CRAF would get a large communication antenna from Cassini, which needed such a dish to return data from a billion miles away. This design approach also promised to benefit all future outer planet spacecraft.

Unfortunately, the cost of the two spacecraft grew too large, and in 1992 CRAF was canceled. This placed Cassini in a precarious position politically. Canceling one of two missions did not reduce the cost of the remaining spacecraft by half; the savings were only on the order of 25 percent. The challenge was to complete the development of the Cassini spacecraft without accruing massive cost overruns.

But substantial cost growth is the rule and not the exception when building planetary spacecraft. Cassini had to develop a large and complicated science payload as well as the spacecraft itself. The program had $200 million and four years to build twelve sophisticated science instruments designed to explore the Saturn system. Cassini had to find some approach for controlling the appetites of its instrument development teams for additional resources. The usual method involved the science instrument development manager holding a reserve for instrument development problems. This method produced an unsurprising, undesirable outcome: as instrument teams ran into trouble, they asked the science instrument development manager for help.

This placed him in a difficult position. He had to determine if the request for additional resources was valid. Did the instrument development team make an honest mistake that increased the scope of their instrument, or did they take additional development risks knowing there would be reserves to help them if they got into trouble? Instrument teams tend to think reserves are their own personal insurance policies.

Cassini's leaders knew that in the past this approach didn't stop the cost growth of the instruments. But either a large cost overrun from an individual instrument development team or small overruns from many instrument teams could result in the cancellation of the program. Some other approach had to be used to control the growth of instrument resource demands. Desperate times called for desperate measures. The program looked to its home institution, the California Institute of Technology (Caltech), and contacted the economists from the humanities and social sciences department. The Cassini program managers wondered if economic theory could be used to control real-life development costs.

The first thing the economists did was work to understand the particular Cassini problem and then review past missions to obtain a historic perspective. After analyzing the problem, they realized that Cassini's instrument development challenges could be resolved with a market-based system.

These systems use markets (the demand for particular commodities) to obtain better information about what is and is not really needed. They are used all over the world in all types of industries to solve scarce-resource allocation problems. But could this economic tool solve Cassini's science instrument development issues? How could individual instrument provider

INSTRUMENT TEAM A MIGHT REQUEST $200,000 FROM TEAM B THIS YEAR IN RETURN FOR GIVING TEAM B $212,000 NEXT YEAR.

demands possibly be in the best interest of the overall science payload? Finally, if the program decided to go with a market-based system approach, how could it be sure the system would help solve their particular problem? After all, they only had one chance to build their science payload within budget. Should the program use such a radical and unknown approach? Could they afford not to?

The Cassini team needed to be convinced somehow that a market-based system could solve their problem. Fortunately, the economists had a technique to allay some of the team's concerns. They would use experimental economics to test the tool that would be used by Cassini. Experimental economics can be thought of as a kind of "wind tunnel" for human behavior. That is, it can construct an operational environment that accurately simulates the behavior of the instrument development teams. Students at Caltech could be paid according to how well they performed. Each student would have to make decisions about choosing riskier or less risky development approaches to simulate the building of their particular instruments. The lab environment would introduce random "good luck" and "bad luck" events affecting the student-run instrument teams. Those students who performed well (that is, had the smallest growth in demand for additional resources) would be paid the most. Those students who had a large growth in resource demand would be paid the least.

Once this environment was established, parameters could be adjusted to understand how changing circumstances affected students' behavior. By performing experimental runs with various parameters, the full range of instrument development team behaviors could be modeled. The results of running such experiments at Caltech showed that the students did indeed behave like instrument teams and that a market-based system could be designed to control the resource growth of the twelve Cassini instrument development teams.

In 1993 the Cassini program opened the Cassini Resource Exchange. To help the instrument development teams get over their fear of this radical online tool, each team was assigned a Caltech student who would do the actual bidding for instrument resources under directions from the instrument managers. The students were also motivated to find and complete trades because they were paid according to their ability to make successful transactions.

Initially, instrument data rate, budget, mass, and power were available to be traded. The science instrument development manager had veto power to disallow any trade that was not in the best interest of the instrument teams or the Cassini program itself. In fact, the instrument teams did a great job defending their own instruments and needed no intervention. In addition, instrument teams involved in the trade had to come to a consensus on the terms of the trade and agree that all completed transactions were in the program's best interest.

To be honest, there were skeptics. Some believed that the instrument teams would play "mass futures"—that everyone would hold on to excess mass and wait for the price per kilogram to go through the roof: buy low, sell high. Others thought that capitalism was great but were not sure what it had to do with building science instruments. My favorite criticism came from individuals who thought market-based systems were a form of gambling. One thought the Cassini mission should be renamed the Casino mission!

The Cassini Resource Exchange was available from 1993 to 1995, the last three years the instrument teams were building their instruments. Some interesting trends became apparent. The first was that most teams traded for dollars and mass but were intimidated by the idea of trading for power and data rate. Both power and data rate had to be traded across multiple modes. That is, you could not trade five watts for $15,000. You had to specify how much power you wanted to trade in multiple spacecraft power configurations. This got confusing fast for the instrument developers, and most didn't trust the system. Since it was difficult to check the results manually, most teams just stayed away from trading those resources. However, instrument teams loved "money market" trading of funds from their individual budgets.

A money market trade occurred when a particular instrument team ran into financial trouble in a particular year. An instrument team would find that its overall (multiyear) budget was fine, but they had problems in the current year. Instrument team A might request $200,000 from team B this year in return for giving team B $212,000 next year. A team would state how much they needed this year and what they were willing to pay out the following years. If no team was interested, the instrument team could request less money this year or increase how much they were willing to pay later. The beauty of this type of trade is that team A solved its financial problem and team B would get a return on its "investment." Both teams won.

Thanks to the Cassini Resource Exchange, the program was able to successfully build and deliver all instruments on time. As for the instrument resources, the overall cost of the Cassini science payload grew by less than 1 percent. And the science payload mass shrank by 7 percent. The science instrument development manager was able to return excess mass to the Spacecraft Development Office.

When a spacecraft/instrument problem arose, the Cassini program was able to do something that had never been done before. It held a "mass auction." In this particular case, the program needed funds for stiffer plasma wave antennas and the Spacecraft Development Office had excess mass. This problem was basically a bad interaction between the antennas and the spacecraft. Since it wasn't anyone's fault, the program asked the instrument teams to submit "blind" requests for mass. If instrument teams needed mass, they would submit sealed envelopes with how much mass they were willing to buy and at what price per kilogram. Once the bids were in, the Spacecraft Development Office opened the envelopes and arranged the bids from the highest to lowest price per kilogram. The program then sold mass to the highest bidders until enough money was raised to pay for the stiffer antennas.

The success of the Cassini Resource Exchange allowed for a rapid transfer of this technique to the commercial sector. The Caltech professors who developed the system started a company and created a trading system based on the Cassini algorithms. In one case, the Los Angeles Air Quality Management Board used this approach for controlling smog emissions in the Los Angeles basin. The RECLAIM system gave polluters an allocation of how many tons of pollutants they were allowed to dump into the environment. Each year the overall number of tons would be reduced. Individual companies could decide either to pay for expensive air scrubbers and then sell the "credits" that resulted from polluting less than their allocation or to buy credits from other companies. The results have been impressive, and these market-based "cap and trade" systems are being considered for the entire state of California, seven states in the Northeast, and even the Kyoto Accord for controlling greenhouse gases.

Resource trading has been evaluated by many NASA projects and was used again on Terra, the Earth-orbiting platform, to solve instrument development issues. Once again the technique did a wonderful job controlling instrument growth. People still think of a market-based system as risky, and many remain unconvinced of its ability to solve their resource problems. As more and more companies switch to market-based techniques to solve their issues, however, project managers may begin to do the same. I'm not saying that we will replace systems engineers with resource brokers, but one day soon you may be bidding your way to the launchpad. ●

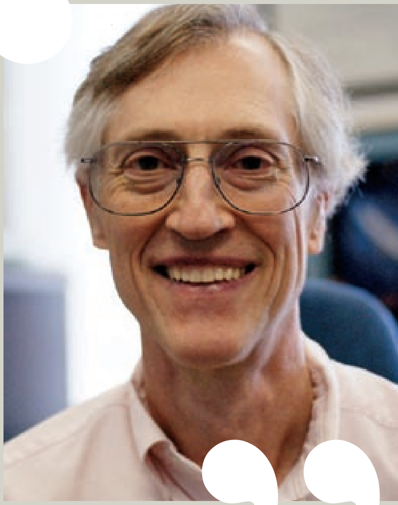
RANDII R. WESSEN joined the Jet Propulsion Laboratory in 1984. He has worked on Voyager, Galileo, Cassini, and the Mars Exploration Rover projects. He has teamed with David Porter on market-based systems research for the past twelve years.

DAVID PORTER is the George L. Argyros professor of finance and economics at Chapman University. He received his MS in mathematics and PhD in economics from the University of Arizona.

INTERVIEW WITH

John Mather

BY DON COHEN



John C. Mather was study scientist and project scientist for the Cosmic Background Explorer (COBE) and principal investigator for the Far Infrared Absolute Spectrophotometer (FIRAS) on that mission. He shared the 2006 Nobel Prize in Physics with George Smoot for measurements of cosmic microwave background radiation that support important elements of the big bang theory of the universe's origin.

He is currently senior project scientist for the James Webb Space Telescope and chief scientist for the science mission directorate at NASA Headquarters. Don Cohen spoke with him in his office at Goddard Space Flight Center.

COHEN: On COBE, how did you get from a research idea—measuring cosmic background radiation accurately—to a project that works?

MATHER: We were all hardware-oriented scientists. We tried to solve some of the obvious engineering problems, like where to put the observatory to get a protected environment. Fairly early on, we found the orbit we needed to use. The scientists were functioning as much as they could as engineers, trying to design a mission concept that could actually be built. Of course, we didn't know how to make something spaceworthy or deal with such a huge scale of effort. We were assigned to work with the IUE [International Ultraviolet Explorer] project team, which was about to launch the IUE. So there was a complete engineering team already in existence, and we had some brilliant engineers to work with at that point. They said, "We'll take you under our wing; we'll work with you to figure out what you need." Since I was the

RUNNING MEETINGS WELL IS A tremendously IMPORTANT SKILL: how to hear FROM ALL THE PEOPLE SO THAT YOU DON'T MISS GOOD IDEAS; how to send PEOPLE AWAY knowing SOMETHING'S GOING TO HAPPEN.

study scientist, I spent my life with them trying to figure out how to make this project real.

COHEN: What was that process like?

MATHER: I met with engineers practically all day every day. We would just talk: How can you do this? How hard is that? How well do you have to do this? Of course, there were quite a few things that we couldn't calculate. This was before everybody had a laptop that could calculate anything; I wrote handwritten memos with my version of a calculation of a requirement.

COHEN: In your book, you say engineers think of scientists as "arrogant and naïve."

MATHER: We come from different cultures and have different ways of thinking. Engineers are trained to make something that really works. The scientist says, "I know I can't do this or that, but I want to find a way around all the things that can't happen." That's why I spent so much time with engineers. They knew what could be done, and I knew what we wanted to do. They'd say, "You can't do that," and I'd say, "If we change our request a little bit, could we do *that?*" That's how the project evolves. I like to work on seemingly impossible engineering tasks. A scientist has to work with the engineering team to find a way around the impossible. It's fundamentally a science-engineering job. The part that says, "Let's find a path that combines the engineering possibility with the scientific wish"—that *is* science. Not all scientists have a talent for that.

COHEN: Have you worked with the kind of scientists who don't work well with engineers, who just say, "These are my requirements?"

MATHER: None of the people I work with are like that. There are people you would call theorists who have no interest in hardware or talent for it. We need those folks, too. They figure out what this information means.

COHEN: How does a hands-on scientist develop the practical skills he needs?

MATHER: You have to do hands-on stuff. In graduate school, I had to learn something about everything on the instrumentation we did there. The other scientists I worked with on COBE did the same. They built balloon payloads; they built laboratory hardware; they sawed, drilled, and soldered; they made circuit boards. You have to do stuff until you get some instinct about what hardware is like and how it acts. Someone was telling me recently that almost anybody who is anybody in ultraviolet astronomy got his start with Stu Bowyer at Berkeley. He was doing sounding rocket programs. A sounding rocket is like a miniature space program. It's got all the problems that space observatories have, but it's over in five minutes. A student has the opportunity to learn every aspect from beginning to end by working on such a small project. Similarly with balloon payloads, which most other people who have developed into hands-on space scientists have done. Those are the two basic categories: start off in school working in a lab where they do this stuff, and learn by doing. Watch how other people do it. If you were to look around at people who are now scientific leaders within NASA, you would find a large fraction of the PIs [principal investigators] and project scientists on flight programs got their start on sounding rockets and balloons.

Alan Stern [associate administrator for NASA's science mission directorate] at headquarters is pushing hard to show that there is a career path for PIs or project scientists that leads through hands-on stuff. Now, for instance, if you look at the PI requirements for the SMEX AO [Small Explorer announcement of opportunity] that we're about to open, you have to prove that you've done something on a space mission, which includes balloons, sounding rockets, and real space missions. Alan is saying, and I think he's right, "Show me that you've learned how to do stuff."

COHEN: On COBE, were you able to communicate your excitement about looking for fundamental facts about the universe to engineers, and did that help the collaboration?

MATHER: Yes, and it did help. They knew they were doing something important. That's the only way I can explain why they cheerfully came in nights and weekends. Eighty-hour workweeks were not uncommon, especially at the last part of the project. I think we eventually developed a pretty good relationship between scientists and engineers, because we'd learned to know and trust each other. Now people tell me this was the best project they ever worked on.

COHEN: Do they tell you why?

MATHER: For two important reasons. One: the work was obviously important. Two: it was in house. Engineers love to do things. Going out to California to watch somebody else do work is not really much fun.

COHEN: In your book, you say the work was done in house because you couldn't have contracted out such groundbreaking instruments.

MATHER: We did not feel there was any way to write a contract to do what these instruments had to do. Even after we had settled on the design, it was hard to say, "These are the requirements," because we just couldn't analyze well enough. Maybe these days we could analyze better in advance because we've got better computers and numerical modeling tools.

COHEN: Would you still recommend in-house work on groundbreaking technology?

MATHER: I would, but not unconditionally. In-house teams face hazards as well. University labs can do certain things better than we can. It's harder for us to bring in the radical thinking of graduate students. Thinking about small prototype equipment is a good thing to do at a university lab. We did that with COBE, in fact. They built a prototype for the FIRAS instrument at MIT and told me that I had designed it wrong, that the focusing wasn't working. That was correct, and we fixed it. I don't think we would have found it as quickly and as easily in our labs here. When you're hunting over a wide range of territory with lots of ideas to try out, it's hard for an engineering team to shift into that mode.

COHEN: What kinds of problems—other than engineering realities—did you face?

MATHER: Some were organizational. We had something called "matrix management," which we love and hate. The good thing about it is there's a huge pool of talent you can draw on. The bad thing is those people are not yours. When you want their time, they may be busy doing something that someone else said was important. We had a cartoon that showed two boats with lots of oarsmen. Matrix management is people paddling in every direction and no manager at the end of the boat. The other one is project management the way project managers like to do it: they know who's in the boat; there's a guy at the end beating a drum; everybody is paddling in the same direction. Our problem wasn't about scientists versus engineers. It was engineers, managers, and everybody fighting over a scarce resource.

So priority really matters. COBE was set up as an in-house project that could draw on Goddard resources, but it had low priority. We were a training program; we helped recruit bright, young people. When Hubble had difficulties, they could swipe our engineers. It's hard to make progress when you're the lowest priority. You don't get very far when your team is frequently taken away from you.

COHEN: When the *Challenger* disaster happened in '86, it became clear that you wouldn't send COBE up in a shuttle and would have to cut its weight in half for a rocket launch. You've written about deputy project manager Dennis McCarthy pulling people together in a "skunk works" to continue the project.

MATHER: It was the only way to do it. And once it was clear that it was going to be possible, headquarters said, "Great, do it now." So we went from the lowest priority to the highest, or second only to the Hubble telescope. Suddenly we were able to accomplish things and build a project management structure with people dedicated to the team and working together in one place. The fact that JWST [James Webb Space Telescope] has priority matters immensely and mattered from day one. When Dan Goldin, then head of NASA, said, "This is really important, and we're going to do it," brilliant people came from everywhere to work on it. If he had said, "It's a good idea, but it will have to compete with a lot of other good ideas," I don't think we would have made nearly the progress we've made.

COHEN: The advantages of bringing people together seem clear. Can it be done without a crisis?

MATHER: There's no particular reason why every project can't be like that. The challenge for management, though, is deciding whether they can afford to put a person on a project full time. The project manager says, "I need to know who's on my project all the time. If someone completes a particular job, I've got something else for him to do." The matrix manager says, "If that person's job is done, I want him to work on another project." It's hard to cope with matrix management flexibility if you're a project manager. The lesson learned on matrix management is it's OK, but assign people full time and make sure they know whom they're working for during big blocks of time. In the earliest days of COBE, we had people charging a tenth of their time. They were able to go to a meeting, but they didn't have time to produce anything useful. A tenth really equals zero. It drove us crazy, and I don't think it made those people happy.

COHEN: What was it like working with McCarthy and [project manager] Roger Mattson?

MATHER: I loved working with those guys. Roger's been gone now a long time, bless his heart. Dennis is still around. When you walked into his office with a problem, you'd talk for a while, and then he'd sort of give you a wink and a grin. You'd know

THE DIRBE … INSTRUMENT WAS specially designed TO FIND the stuff NOBODY COULD EVER SEE BEFORE: ALL THE LIGHT FROM the earliest galaxies. WE THOUGHT we'd never have A TELESCOPE BIG ENOUGH TO SEE THOSE GALAXIES. NOW, WE THINK we have, AND we're building it.

he understood what you'd asked for and was going to do something about it. Tony Fragomeni, the observatory manager, was another person I loved working with. He used colorful expressions that were not always polite, but people knew he meant what he said and was going to get the matrix organization to work with him.

Tony used to sit at the end of the table with a plastic baseball bat and make sure he heard from the right people. Running meetings well is a tremendously important skill: how to hear from all the people so that you don't miss good ideas; how to send people away knowing something's going to happen. You have to say, "I understand that this is the decision." Absolute clarity is required. If you dither around and put off the decision for another week, you'd better have a plan for what you're going to do instead. Drawing decisions out of discussions and actions out of ideas is the secret for getting anything done. If we could have a training program for scientists and engineers, I would say the number one thing would be how to run a meeting. You can piss away people's good will and their time and money with meetings that do nothing.

COHEN: I'm struck by the fact that COBE experienced several "happy accidents"—like the time a delicate instrument escaped damage in the 1989 San Francisco earthquake because the man who would have been testing it went off to be married that day and put it in safe mode. Are there ways projects can increase the chances that the accidents that happen will be happy ones?

MATHER: The thing that helps ensure happy accidents is people working like crazy to make the good things happen. Of course we were aware that earthquakes happen in California, so stuff was strapped down.

COHEN: There's an element of forethought.

MATHER: There's some forethought. The test program is a way of trying to make happy accidents happen. Murphy was right: things will go wrong. Our job in the test program was to think of them all and make sure we had a test that would find them before we launched. In order to have good luck, you have to work like mad thinking of things that could go wrong. Harvey Moseley says being a scientist is about fixing what's broken. Building a space mission is like that. The test program tries to break it. There's no possibility of designing something right the first time.

There was one case of technological change made for the DMR [differential microwave radiometer] instrument. We were delayed for various reasons and needed to save some money, so we ended up eliminating one of the frequency bands of the DMR and using the saved resources to up the technology on the others. If we hadn't done that, we wouldn't have found the big bang bumps. That's one of those happy technology accidents. This one was accidental because cosmic bumps had never been predicted well enough to tell us how hard we had to try.

COHEN: You made an educated guess that this trade-off was worthwhile.

MATHER: We knew it would be worthwhile; we didn't know it was critical. If we had not made that change, we might not have discovered the CMB [cosmic microwave background] bumps. Or it would have required four years to get the sensitivity we got in one year. That's one of those happy accidents of technology.

COHEN: Are the scientific aims of the James Webb Space Telescope you're now working on an extension of what came out of COBE?

MATHER: For sure. COBE and WMAP [Wilkinson Microwave Anisotropy Probe] and Hubble have all been pointing us at science of the early universe. With COBE, the DIRBE [diffuse infrared background experiment] instrument was specially designed to find the stuff nobody could ever see before: all the light from the earliest galaxies. We thought we'd never have a telescope big enough to see those galaxies. Now, we think we have, and we're building it. The COBE DIRBE instrument found light from unknown sources that are still unknown. If you find something that wasn't supposed to be there, you should build something to find out what it was. JWST is it.

COHEN: Did your COBE experience help with designing JWST?

MATHER: It's hard to be specific about that. When you start a new mission, the hardest problem is figuring out what shape it is and where it is going to be. It's a geometry problem. The orbit you put it in tells you the thermal environment. The shape tells you what temperature it's going to be. The whole thing is geometry at the beginning. I love geometry. In high school, I would sometimes lie awake all night trying to solve a geometry problem. There was a lot of that with the initial phase of the JWST. It's remarkable that the concept we're building now looks an awful lot like the concept we had on the boards a few weeks after the start of the JWST studies. It took a few weeks to find the right shape and the right orbit, at least in general terms. Everything else is detail.

COHEN: When is it supposed to go up?

MATHER: 2013. It seems like a long time, but it's only six years, and we're running like crazy. We have a good plan, and we're quite far along.

COHEN: What are the main challenges?

MATHER: The biggest challenge is not screwing up. Even manufacturing stuff that we know how to make is hard. Probably the hardest part that anyone will see is the mirrors. We've got eighteen wonderful beryllium hexagons to build. We've got to get process control so we do every one of them right. It's so easy to find a way to screw up. If one person pushes the wrong button one day, you lose some important piece. We'll have a long period of time to test the observatory after it's finished. We are counting on that to find and repair any problems that are still there.

COHEN: Do you find some of the same spirit on JWST that you had on COBE?

MATHER: When things are working well, people enjoy the process. They don't mind going to the meetings. People on this hall who don't work on JWST have told me they hear laughter coming out of the project meetings. They say, "I want to work on that project." A good sense of humor combined with getting the right thing to happen is important. I think the project management sets the tone a lot of the time. It's not easy to tell people how to do that; some people have that talent. ●

Space-to-Space Communications:

IN-HOUSE HARDWARE DEVELOPMENT

BY MATTHEW KOHUT

Photo Credit: NASA/Jet Propulsion Laboratory

The Goldstone Deep Space Communications Complex, located in the Mojave Desert in California, is one of three complexes that comprise NASA's Deep Space Network (DSN). The DSN provides radio communications for all of NASA's interplanetary spacecraft and is also used for radio astronomy and radar observations of the solar system and the universe.

When Johnson Space Center's Matt Lemke showed up for work as the project manager of the space-to-space communications system at the end of 1994, he looked forward to leading a team of NASA designers on the biggest project in his division. Lemke was an experienced avionic design engineer who was relatively new to project management. He would soon discover that he was starting with little more than an immature prototype system and an unforgiving schedule. He did not anticipate that the project would have to reverse-engineer its drawings from scratch, unravel major latent design defects, extend its delivery date by 300 percent, limit its systems testing to make up for lost time, or test the radios for anomalies on the launchpad right before its first in-flight trial on a shuttle

The space-to-space communications system (SSCS) is designed to provide voice and telemetry among three on-orbit systems: the Space Shuttle orbiter, the International Space Station (ISS), and the Extravehicular Activity Mobility Unit (EMU), the space suit worn by an astronaut during a space walk or extravehicular activity. SSCS is designed to allow simultaneous communication among up to five users. The system consists of space suit radios (SSER), the shuttle orbiter radio (SSOR), and the space station radio (SSSR). The three have common elements but also unique features and different designs.

NASA decided to treat the SSCS as an "in-house" development, meaning that its own personnel would design and deliver the system. The Agency held a competitive bidding process and selected a prime contractor to refine the design and manufacture the radios.

A Difficult Reorganization

The formal start of the SSCS project coincided with a reorganization within the engineering directorate at Johnson. Two divisions, the Tracking and Communications Division and the Flight Data Systems Division, merged into a new Avionic Systems Division. At the same time, a new project management office was created to manage the engineering project teams that in the past had interacted directly with the Space Shuttle or ISS programs. Both administrative changes affected morale, and several key engineers with radio expertise opted not to work for the project management office, which now had oversight over the SSCS project. At about the same time, the Johnson engineering directorate awarded a new general engineering support contract. As a result, all the contractor designers on SSCS left the project before Lemke took the reins. The engineering drawings those designers had completed for the prototype were nowhere to be found.

In short, Lemke began his first significant NASA project management assignment under a new internal organization, with no engineering drawings, none of the designers who had worked on the earlier phase of the development, and a project team with no expertise in the complex SSCS radio system architecture.

In Lemke's estimation, hard work was the answer. He relied on a team that was ready to give its all, despite its inexperience with the inherited technical design. The project itself was a motivator: it was the biggest project in the division, the work was important and challenging, and it offered a rare opportunity to do hands-on hardware development.

Starting Over

The in-house team of designers began the painstaking process of deriving drawings from the prototypes, using calipers, ohm meters, and other reverse-engineering tools to determine the exact specifications of the boards. Every measurement was an opportunity for a mistake; a single missed connection might mean that an entire circuit wouldn't work. The team's progress proved excruciatingly slow, and Lemke realized that at this pace the project would never be completed.

When he explained the situation to the contractor, he was assured its engineers could recreate the drawings. Lemke initiated a contract change and handed the boards over to his contractor, which was eager to prove itself on this project, its first at Johnson. Eight months later, the drawings were complete. The project was now where it should have been when Lemke arrived for his first day on the job.

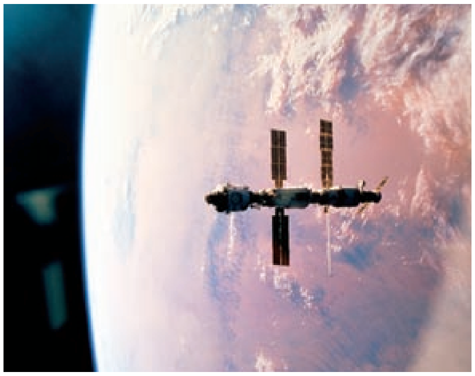


Photo Credit: Johnson Space Center

The Space-to-Space Communications System provides two-way communication among the Space Shuttle orbiter, the International Space Station (shown here), and the Extravehicular Activity Mobility Unit.

Fire-Drill Mode

The time the project had lost recreating the drawings inhibited the maturation of the design. The contractor was supposed to have spent those months turning the engineering prototypes into radios that could be manufactured and building test units. Instead, it recreated the laboratory units, which didn't meet the project's requirements. This became clear from the performance of the design verification test units (DVTU) the contractor had faithfully built based on the reengineered drawings. The DVTUs didn't work well as a five-radio network for multiparty conversations.

With the scheduled delivery date for the space station radio closing in, Lemke elected to make the necessary fixes in a piecemeal fashion rather than add an additional DVTU cycle to address the problems on a systems level. Hoping to meet the delivery schedule for the space station, division management agreed.

At this stage, the contractor informed Lemke that none of the units would consistently pass the specification tests. In response to growing concern that the NASA design had problems, the SSCS chief engineer expressed confidence in the design and asserted that the problem was the contractor's manufacturing processes. Lemke pressed his contractor to stick to the design and build the qualification test units as though they were flight units.

The problems the contractor had predicted began to surface in the qualification units. Since the modem and receiver boards were identical for all three radios, flaws in one were reproduced in the others. A seemingly endless series of quick fixes were being made at the same time that the contractor kept producing more radios. This led to constant reworking of all the existing radios. The project operated in "fire-drill mode," scrambling from one problem to the next, leading to schedule changes on a weekly basis and no time for rigorous systems testing.

Division program management was assured that the fundamental problems were understood; all that remained was hard work to get the units delivered. This seemed a reasonable time in the project life cycle for Lemke to transition into another job opportunity while his deputy, Dave Lee, took the helm for the remainder of the project. The managerial transition was a smooth one, but no one involved recognized the hidden defects in the design that would soon emerge. Within a year, Lemke would be re-enlisted, along with temporary reinforcements from some of the division's best engineers.

Flight Time

The radios made it through acceptance, performance, and qualification testing. Some individual radios did not perform as well as expected, but they passed. The time came to modify the Space Shuttle orbiter and the space suits to accommodate the new radios. In the fall of 1998, the SSCS underwent a test flight on Space Shuttle mission STS-95. The flight uncovered some minor glitches, including an instance in which one radio would not talk to another. This problem was attributed to operator error and solved by re-cycling the system's power (turning it off and back on). The SSCS team thought the radios were ready for a real in-flight trial.

The project delivered its first radio to the space station in November 1998. At this point, problems seemed to be decreasing; there were still lots of fixes, but the technical work seemed manageable. The delivery schedule, however, remained daunting, as the project team faced demands for twenty-four flight radios and almost 300 spare modules. The next major effort was preparation at Kennedy Space Center for mission STS-96, which would launch in the spring of 1999.

One month before the launch of STS-96, the project was granted special access on the launchpad to conduct burn-in testing of the radios. (Burn-in testing typically involves running electronics products with the power on for a number of hours to uncover defects resulting from manufacturing aberrations.) SSCS project manager Dave Lee and Lemke, who at this point was a consultant to the project, flew to Kennedy to lead the test. After the problems on STS-95, this test was established to regain the program's confidence that the SSCS system was stable, reliable, and error-free.

The SSCS team was granted permission to spend the entire evening of May 10 on the launchpad with the shuttle orbiter *Discovery* for dedicated SSCS radio tests. The first few hours were uneventful. A few anomalies were noticed, but the team, still committed to vindicating the radio's reputation, rationalized them as flaws of the ground support equipment.

Then a thunderstorm approached, producing severe radio frequency turbulence across the marshy plains of the launchpad vicinity. With each crack of the thunder, the SSCS radio signals buzzed and oscillated crazily. As they heard new sounds in their headsets, the radio operators characterized them with descriptive nicknames: "motor-boating," "rain on the roof," "laryngitis." Even after this test, many latent defects still remained undiscovered, the most punishing of which would prove to be the radio's hypersensitivity to other signals near its frequency range.

By morning, the radio's reliability problem was evident to every senior manager at the center. With the launch seventeen days away, the shuttle crew had to be trained in recovery procedures in case the radios malfunctioned in flight. A highly talented mission operations engineer, David Simon, helped the SSCS team characterize the problems, and he taught the crew how to respond by creating a cue card describing all the potential problems and mitigations. (The crew was already trained in the use of hand signals in the event of a complete radio failure.)

The last-minute training proved necessary. Astronauts experienced "motor-boating" during a spacewalk. The pre-established procedures allowed them to recover gracefully from the malfunction, and the crew successfully carried out its mission despite the problems with the radios. On the ground, the SSCS team was ecstatic that nothing derailed the overall success of the mission.

Aftermath and Recovery

But SSCS had failed dramatically in a high-risk and high-visibility situation, and the debriefings of the STS-96 crew drew the attention of NASA's senior management. The shuttle and the EMUs had to be retrofitted with the original radios for the next flight. The failure also marked the beginning of the project's turnaround. Management ordered the SSCS to fix the system. Cost and schedule were secondary to finding the root causes of the problems. Every element of the design was reviewed. This allowed the team to conduct the extensive systems testing that it had foregone in the run-up to its first flight. The project also received resources to bring in experts who could help solve the problems.

One of these experts was Mark Chavez, a soft-spoken and highly gifted radio frequency (RF) engineer, who took the helm as chief engineer. Troubleshooting a complicated design that was never fully documented or understood is a challenging reverse-engineering task. After hundreds of hours of testing and analysis, Chavez and a talented support team found the key issue plaguing the radios: a hypersensitive demodulator circuit that saturated itself every time another signal was near the SSCS frequency. The effects of the storm on the launchpad were now understood, as were other performance problems that seemingly occurred at random, such as on-orbit interference that, it appeared, was probably caused by taxicabs in South America.

Latent defects were isolated one by one in a focused and deliberate process that brought in the division's best design engineers in RF, software, and electronics. Each discovery helped explain the next problem in line, a phenomenon that division chief engineer Paul Shack described as "peeling away the layers of an onion."

Each engineer took responsibility for a specific known problem and ran extensive isolated tests to address every issue. The final graduation test was an extensive system test using every known configuration imaginable for a five-radio network—all conducted in the noisy open-air environment of the Johnson Space Center's back lot field, adjacent to all the RF noises of fast food restaurants, two-way commercial radios, and noisy cars. A huge space station airlock mock-up was trucked into the test field to serve as a simulated space station structure to reflect and diffract RF energy from the transmitters. Simulated space suits were outfitted with radios and installed in the bed of two pickup trucks that were driven around the field to try to confuse the radio network's stability. At the end of this grueling process, the team could claim success at last.

… TECHNICAL PERFORMANCE MUST COME FIRST. SCHEDULES AND COST PROJECTIONS ARE MEANINGLESS IF THE DESIGN ISN'T SOLID.

A year after STS-96, the SSCS was redeployed for STS-101 in May 2000. The phantom noises that had plagued the system previously were gone. By the time of STS-106 four months later, the SSCS achieved error-free operations for the first time. It has continued to do so ever since.

The SSCS project went through seventy-five contract modifications and six contract analysts in the process. The story has no single hero: a minimum of 181 people were directly and significantly involved in the project's ultimate success.

In hindsight, Lemke can point to three major lessons of his SSCS experience. "The first lesson is that technical performance must come first. Schedules and cost projections are meaningless if the design isn't solid. My first priority on projects today is to get the right technical team in place with the right experience and the right mentors.

"The second lesson I learned is the need for validation testing in realistic environments. The radios were fully tested, verified, and certified to meet all requirements prior to flying. Unfortunately, hundreds of hours of successful testing provided no assurance of proper operation if the testing wasn't thorough enough. It wasn't until we took a system view of the radios and tested them as they would fly that we uncovered our design flaws.

"The final major lesson was to communicate schedule issues early and effectively. Had I fought harder and more effectively for my team to have the needed time up front, we would have saved countless contract modifications, configuration changes, and fixes in flight hardware that should have been done on development hardware," he said.

He saw the failure during the STS-96 mission as a turning point that led to the resolution of the project's difficulties. "That's where we got to spend the time with our design to really get to the root cause. We got to do the testing, got to find out where the flaws were, and fix it," he said. "It was just getting the team, the time, and the management support to solve it. There were no more Band-Aids. 'Go solve it, and whatever it takes, you do it.'" ●

The Next-Generation Workforce and Project Management

BY DANIEL W. RASMUS

The workplace is changing in ways not due entirely to the introduction of new technology or new philosophies of management. The workforce itself is changing. The rise of the millennial generation brings workers who are more introspective, more connected to the world and their community, and less willing to align themselves to the needs of employers.

For organizations like NASA, which rely on the knowledge, commitment, and skilled leadership of its people, the millennial generation joining the workforce as baby boomers retire will create challenges across the next several decades. Understanding something about this generation can help organizations make the best use of its many talents.

Who Are the Millennials?

The millennials were born between 1980 and 2000. Demographers call them the millennial generation, but they have other names as well: the MyPod generation, GenY, baby boomlets, or the boomerang generation. The oldest members of this generation are beginning to join the workforce now.

In the United States, the millennials have watched their parents shift from a long-term employer to an outsourcer on short notice. They have seen a steady increase in foreign manufacturing while domestic manufacturing jobs wane. Many live in single-parent homes, and many in homes where both parents work. They have witnessed highly publicized corporate scandals, critical failures in iconic programs like the Space Shuttle, and relentless scrutiny of the business practices of successful firms. And they have heard parents and relatives complain about the retreat of employers from comprehensive health care and long-term retirement security.

This is also a generation characterized by high levels of health, prosperity, and education. From an early age they have had access to health care and a massive day care system; they have graduated from college in unprecedented numbers. Their lives have been more structured than their parents', filled with the practices, rehearsals, events, and recitals their participation in sports and arts entails.

In their limited unstructured time, they have turned from the passive entertainment of television and imaginative engagement of literature to exploring, connecting, and collaborating in the personal, dynamic, virtual world of the Internet. Unlike previous generations, they see their lives as more or less a seamless experience, where anything that interests them is part of the whole, and the traditional distinctions between work, life, learning, and service are blurred or eliminated.

Their learning, their knowledge of world events, and their lives online have shaped a generation that is self-reliant and entrepreneurial, a generation easily bored and technically savvy. Perhaps most disturbing to employers is this generation's emerging propensity to give up money and economic benefits for time.

Many millennials do not have a firm attachment to the idea of career, instead seeing new opportunities in diverse areas as opportunities to learn. This attitude is not unique to young people joining the workforce now but appears endemic to the millennials, who, many believe, will continue to behave in this way throughout their work lives.

The life experiences of the millennials have so far created a generation that possesses these traits:

- Lacks trust in corporations
- Focuses on personal success
- Has a short-term career perspective
- Is quickly bored
- Is team oriented
- Builds community
- Sees no clear boundary between work and life in general
- Is socially responsible
- Will sacrifice economic rewards for work–life balance
- Expects to work anytime, anyplace

These characteristics create new challenges for managers. Because of the magnitude of the shift from baby boomers to millennials, it is unlikely that organizations will successfully reorient the millennials to what has come to be considered a traditional work ethic; rather, the workplace will need to adapt to the attitudes and needs of this generation.

Knowledge and Talent Retention

Millennials consider their knowledge and skill more as a source of employment mobility than of career growth. Many see their knowledge as personal and portable, not organizational and collective. When it is communal, it is very communal, openly shared across their networks without regard to boundaries.

Social networking sites often reflect a disregard for boundaries and an open, exploratory view of learning, where the search for an answer, the journey itself, is as well documented as the conclusion, if a conclusion is ever arrived at.

Microsoft has developed the following guidelines that may help organizations retain and attract millennial talent:

- Create engaging environments that inspire, challenge, and motivate employees
- Integrate millennials into a variety of projects, assignments, and career opportunities
- Favor flexible work schedules, locations, and arrangements (telework, work at home, and job share)
- Use the diverse experiences and backgrounds of the workforce to create innovative work environments that challenge assumptions and create new opportunities
- Harness personal talents and skills by creating opportunities for people to contribute in a variety of roles
- Involve them in collaborative, team-based projects and environments
- Allow and support the pursuit of personal and social outside activities
- Create effective training and mentoring opportunities
- Harness knowledge created "just in time" through personal networks and recognize contributions from new methods of work

Of course, organizations should take their own cultures into account when preparing for the millennial workforce, but they will need to take a hard look at their behaviors and values and decide if they are worth retaining if they limit access to the knowledge and skills of the next-generation worker.

Process Continuity

Maintaining knowledge across the life cycle of a long program has always been a challenge. In the past, though, most job changes were internal or upward within a team, and expertise remained available. The next-generation worker's interest in a diversity of experience may lead to high rates of turnover. This means that organizations will lose knowledge unless they can find ways to rapidly transfer it to new members, or to retain it in knowledge bases or other codified forms. We at Microsoft are seeing a growing use of wikis and blogs as impromptu knowledge bases.

Microsoft sees "reciprocal mentoring" as an effective means for transferring skills. Experienced engineers, for instance, can help new peers better understand the business and the politics of the organization, as well as some of the practical wisdom of their engineering experience, while new employees challenge assumptions about how technology is used and help mentor older employees in new ways to apply it.

This kind of learning does not exclude more focused time where individuals learn from each other outside the work experience, but it does offer a way for employees to model the lifelong learning process while taking advantage of its outcomes. Reciprocal mentoring is a skill that will take time to master, but it has the potential to engage employees by providing clear value to both parties.

Professor Birgitte Holm Sørensen from the Danish University of Education sees lifelong learning as a core skill in the future. She believes that, as the hierarchy of the classroom gives way to more collaborative learning, students will be encouraged to teach their instructors about technology; she also sees educators acting as project managers who empower teams of students to manage their own educational experiences.* This approach not only models learning but begins to help students appreciate the skills they will need to communicate ideas in a way that helps others absorb them.

Technology creates an opening for modeling lifelong learning and a mechanism for delivering it. Many businesses adopt a wide variety of collaboration technologies that help them take advantage of talent in a distributed workforce and retain knowledge from employees leaving a company. These techniques will continue to improve, but they are sufficiently advanced to be effective tools today. As engineers experiment with new forms of learning, they will influence the design and implementation of future tools that will provide them with the capabilities necessary to more easily and effectively deliver continuous learning within their communities, and beyond.

Leadership

I recently received a call from a large aerospace firm asking how they could retain millennials more effectively and encourage them to go into management. They were experiencing higher than average turnover rates and had found that their millennial generation employees were not interested in joining the ranks of management. To find future leaders among the millennials, organizations must create an environment that encourages them to consider career over complete autonomy. That means organizations will need to rethink leadership and management and make them more distributed.

One way is to think about projects as communities rather than teams. Leaders are assigned in teams but emerge in communities. By embracing the emergent behavior of communities, projects can take advantage of the skills of multiple leaders, each directing an aspect of a project.

Top-down or command-and-control methods will prove less effective for the next generation, but millennials can be brought together for a mission they consider meaningful. Defining the mission, and remaining flexible enough to refine and redefine it, will create an environment in which leaders will emerge. Millennials with effective skills that include leadership abilities will emerge as leaders in projects despite aversion to a long-term commitment to management as a career.

Discontinuity

The coming retirement of baby boomers will be an upheaval unprecedented in size and impact. Organizations that thrive will be the ones that use their imagination, adapt quickly to change, entice employees with opportunities for learning, and retain them because they continue to challenge them and empower them to use their knowledge and skills to benefit both the organization and their team. During the next few years, we are likely to see movement away from traditional annual reviews and toward rewards based on project work. It is likely that many more "employees" will be or act like freelance workers. The workplace will experience increasing shortages of highly skilled workers who can engage or lead the most innovative work.

So organizations will face a discontinuity. They will enter a world where it is imperative to be a learning organization, where employees engage each other in intensive learning experiences after they are hired. The most important items on the résumé will be proof of the ability to learn, to incorporate, to synthesize learning, and to turn new knowledge into new value. Rather than a "nice to have" capability, project managers in the future will need to balance technical expertise with learning and teaching skills. Acquisition of known skills will be important to organizations, but the invention and acclimation of entirely new skills will be equally so.

Many successful workplaces will be characterized by emergent behavior, emergent leadership, and emergent communities. The outcomes of many projects may emerge from the process of carrying them out. The tension between change and consistency can be a source of innovation. The short half-life of technology, high workforce turnover, and political and scientific uncertainty will generate emergent opportunities. Embracing those opportunities will lead to innovation, shunning them to underperformance and uninspired design. Being associated with lagging technology will not satisfy the tech-infused, chronically attention-shifting millennials. They will demand an environment that inspires, one in which they are both the aspirants and the inspiration. That will mean a fervent striving toward innovation that must be satisfied to retain them. This striving may well take the new models of social interaction and open innovation in directions that are inconceivable today.

In many ways, this generation will act on what the baby boomers already know. The linearity and control promised by PERT and Gantt charts have always been something of a myth. Rapid global communication and unprecedented transparency force organizations to give up even the pretense that long-range forecasts and plans are meaningful. Social change, as well as technological change, will surprise and confound us. But if we accept the value of tools like scenarios to help navigate multiple futures, avoid rigid forecasts in favor of futures that emerge from the uncertainties that surround us, and encourage and employ the talents of our millennials, we may find new doors to innovation. ●

As director of Information Work Vision in Microsoft Corp.'s business division, **DANIEL W. RASMUS** guides the research process that allows Microsoft to envision how people will work in the future. As part of these efforts, he manages the Future of Information Work scenario program, represents Microsoft on the Board of the Directors for the Institute of Innovation and Information Productivity, and helps guide future-oriented experiences, like the Center for Information Work.

* Mie Buhl, Bente Meyer, and Birgitte H. Sørensen, eds., *Media and ICT—Learning Potentials* (Copenhagen: Danish University of Education Press, 2006).

APOLLO:
A Young Engineer's Perspective

BY DAN HOLTSHOUSE

Lunar excursion module at the Lunar Landing Research Facility.

My first job was on the Apollo program. When I left Ohio State University with a graduate degree in electrical engineering, I went to work for AC Electronics in Milwaukee, Wis., then a division of General Motors. This division was the prime contractor for the Apollo guidance and navigation (G&N) system that was responsible for guiding the Apollo spacecraft to the moon and back. There was an air of excitement at AC, and working on the Apollo program satisfied two of my long-time interests—aeronautics and computers. (Aeronautical engineering was my second engineering choice, and computers my main focus in electrical engineering.)

A complete greenhorn at work, I was put on a team supporting the integration of the Apollo Guidance Computer (AGC) with the gyro-based inertial navigation platform, which AC Electronics supplied. The computer was designed by MIT's Draper Lab and manufactured by Raytheon. Integration activities included testing all the components together as a system before the complete system was shipped to NASA for integration with the launch vehicle. There were two G&N systems on board: one on the command module (CM) and one on the lunar excursion module (LEM), each requiring its own unique systems integration and testing process.

As with any new complex system that has elements supplied by various contractors from different parts of the country, collaboration, coordination, and communication (the 3 Cs) were absolutely critical. We accomplished the 3 Cs primarily through face-to-face meetings in Boston and Milwaukee and multiple, daily phone conferences to address problems and action items. (In the mid-sixties, we had no e-mail or videoconferencing.) Because of the physical distances between vendors, we also established a program office at Raytheon with our people on site to keep up with progress and handle problems. This seemed to work well, and we ended up with on-site personnel at several other contractor venues throughout the program to reduce miscommunication and ensure successful integration with the other subsystems. Being there matters.

Final integration testing was done in clean rooms constructed especially for the Apollo program. We donned white booties, smocks, and caps before entering the test area through an air lock. We tested around the clock to meet delivery deadlines, and this led to a lot of 3:00 a.m. phone calls from the test crew that required one of us from the AGC group to go in and diagnose the problem. It took us several months to figure out that more than half the system test problems were due to human operators making mistakes in test procedures that then put the whole system under a cloud. We finally realized that we could shadow and record the operator's entries from a downlink connection, and we designed and built a monitor system (Telmons) that used a then-state-of-the-art asynchronous tape drive to record the test procedures. This eliminated a lot of the late-night calls (once they were being recorded, the operators were more careful) and relieved us of having to write lengthy reports documenting our analysis of why a system problem that could not be repeated was due to operator error. (The experience did make me a much better writer and required me to learn the workings of the rest of the G&N system.)

Before any of the system components went into final test in the clean rooms, they were tested at length at the individual component level. Here we were learning on the fly. Functional testing to see if the components were doing what they were supposed to do was fairly straightforward for the AGC and inertial platform. We knew, of course, that the equipment needed to withstand launch vibration and work in the vacuum of space, but we had no idea about the number of ways that components that worked fine on terra firma would fail in space

Photo Credit: NASA/Dennis Taylor

The Apollo Display Keyboard Assembly (DSKY) used on the lunar module.

at zero gravity. We learned, for example, that a single circuit connection out of hundreds in the computer might flex enough to cause an intermittent error during the process of "pulling a space vacuum" in the large vacuum chamber, only to reconnect at full vacuum and not want to repeat itself. To solve this problem, we introduced a series of sawtooth vacuum test profiles—increasing and decreasing vacuum in a sawtooth pattern to flex all the components more—on all our tests to ensure we stressed the equipment enough to confirm it was defect free.

We were also concerned about "floaters," that is, small pieces of contamination from manufacture that might lie dormant and undetected in all ground tests but become airborne in zero space gravity, after being shaken loose during launch, and cause a problem during flight. This turned out to be a continuing issue for the Display Keyboard Assembly (DSKY), which used mechanical relays in those days before the advent of mature solid-state switch technology. The DSKY was the crucial keyboard interface to the G&N system that the astronauts used to key in data and instructions. We learned that vacuum tests were not enough to surface all contaminates when a floater caused a failure after successful vacuum tests. We were wondering if there was only one floater, or more. We ended up developing a procedure to vibrate and shake every module, while powered up, on three different axes, to certify that they were free from defects and spaceworthy.

Soon after coming on board the Apollo program, I decided that I needed to thoroughly learn how the computer system worked. I began to study the schematics supplied by MIT but found them hard to follow, and I thought they would not be much use to the integration software programmers who needed to understand the logical operations of the computer system. So across several months we reverse-engineered the schematics to create a set of logic diagrams that filled an 11 x 17–inch book that was an inch and a half thick. Some said, "Why on earth

I WAS AT THE CAPE FOR THAT AWESOME APOLLO 11 LIFTOFF. EVEN AT THE OBSERVATION STAND A LONG WAY FROM THE LAUNCHPAD, THE SOUND OF THE SATURN V GOING UP WAS A PHYSICAL FORCE THAT POUNDED ME IN THE CHEST LIKE A ONE-TWO PUNCH.

would you ever want to do that? You must not have anything else to do." But we found during the course of the program that "the book" was instrumental in helping us debug many integration problems. It also helped unravel a dramatic system error during flight.

As many people know, a computer alarm on the DSKY went off during the LEM's descent, one that basically signified, "I'm too busy to do everything you want me to do." Actually, the computer never lost control, having been designed to be fail safe and with extra capacity, but since the LEM seemed to be heading for an undesirable landing spot, Armstrong took over control for a manual landing—and history was made. Meanwhile, back at the office, we scrambled to help find out what had happened. We used our computer logic statement book to see that unintended radar signals were being sent at too great a rate and that the AGC operated correctly after all. It was said that the Apollo G&N system worked so well that it guided Apollo 11 all the way to the moon and back and landed the crew closer to the splashdown target than the recovery ship that never left Earth's surface.

Looking back, one thing that strikes me about the program was how much focus there was on contingency planning. There were redundant systems designed in, there were alternative paths identified for performing critical functions if something failed, and a lot of software efforts came from NASA Houston to test for flight programming weak spots and "what ifs." We all knew the stakes were high if a problem developed after liftoff, so a "sustained level of worry" ran throughout our part of the program, causing us to test and retest for potential "left-field" problems that might occur. We did not want to end up blaming ourselves for having missed a potential problem that might have been discovered beforehand by thinking and working harder. The stress of that responsibility created some worry casualties, however. In retrospect, I think we, as coworkers, should have been more aware and offered help to those who were not handling the stress well.

I was at the Cape for that awesome Apollo 11 liftoff. Even at the observation stand a long way from the launchpad, the sound of the Saturn V going up was a physical force that pounded me in the chest like a one-two punch. It was the last Apollo launch that I saw and was the culmination of intense focus for me and the others I worked with on the program. Afterward, I was in need of a change, so I decided to go back to school for another round of study.

Working on Apollo was one of the most exciting times of my life. The goal of going to the moon created such positive force—a powerful draft of energy that aligned and focused the efforts of all those many contractors and people working at locations from coast to coast. Like some other national initiatives over the decades, the Apollo program continues to be a lasting benchmark and example of how to mobilize great collective efforts in achieving a challenging goal and vision. It shows what can be accomplished when everyone works together with common purpose and commitment. It was a great ride! ●

DAN HOLTSHOUSE is Executive in Residence at George Washington University and retired director of corporate strategy at Xerox Corporation.

Viewpoint: On a Need-Not-to-Know Basis

BY WILLIAM H. GERSTENMAIER

A buzzing noise wakes you from your sleep. Opening one eye, you squint at your alarm clock: 3:00 a.m. The buzzing begins again, followed by a second of silence and a loud thump as your Blackberry hits the hardwood floor. It isn't time to wake up, it's simply a new message. Thinking it could be important, you turn on the lamp, rub your eyes, and reach down to pick up the Blackberry. It's a notice to everyone in the organization regarding a one-day training course being offered a month from now. The subject? Improving your time management skills.

People have traditionally suffered from a dearth of information. The Battle of New Orleans was fought almost two weeks after the United States and England officially ended the War of 1812—it simply took that long for the message to arrive. Thanks to modern technology, a lack of information is no longer a problem; an overabundance of information is. Technology has made it incredibly easy to contact vast numbers of people at once: simply type in the name of your office's distribution list and you can let your coworkers know you'll be out sick today. Type in the wrong distribution list address and you can let the whole building know, perhaps the whole agency. Unfortunately, this simplicity has brought the problem of overload down on the modern worker—it can be extraordinarily difficult to separate the wheat from the chaff in today's electronic flow.

During a single week in October 2006, the NASA Headquarters e-mail servers delivered approximately 1.25 million e-mails. With roughly 1,000 people at headquarters, this works out to 1,250 messages per person. The nasa.gov domain has approximately two million distinct Web pages residing on its servers. This yields roughly thirty-two Web pages for every civil servant and contractor in the NASA family. How easy is it to find the page with the information you need among those two million? How many of those can you access without needing a new account username and password?

Given a choice between too much information and too little, almost everyone prefers the former. But too much information presents problems that are both obvious and subtle. Arriving at your office on a typical morning, you pull up your e-mail to find that you've received thirty messages overnight. You weed through the broadcast messages deciding whether or not they apply to you. You sort through the messages from your coworkers that you've been cc'd on, deciding whether or not they require your attention. You read through several e-mails from your boss, each also sent to everyone in the office, to determine if there are any actions you need to take or information that you can't afford to miss. If you're quick, perhaps only twenty minutes have passed, and yet already you've made dozens of decisions about what is important and processed a significant amount of information with nothing to show for it but a list of what you now actually have to respond to. Over time, the constant flow of e-mail leads to an inability to focus on a single task for any significant amount of time, preventing one from thinking deeply about the task and destroying one's creative thinking abilities. This is one of the many problems of information overload.

With instant communication—both at your desktop computer and on mobile devices like the Blackberry—comes an implicit expectation of a fast reply. In the days of post mail, no one thought anything of waiting days or weeks for a response. Today, if an e-mail isn't replied to in an hour, the sender typically gets nervous. *Why haven't they responded? Are they out sick? Are they ignoring me? Is there something I'm not aware of and need to be?* Linda Stone, a former executive for both Microsoft and Apple and an expert on information management, brought attention to this mentality in a speech given in March 2006:

> This always on, anywhere, anyplace era has created an artificial sense of constant crisis. What happens to mammals in a state of constant crisis? The adrenalized fight or flight mechanism kicks in. It's great when we're

> being chased by tigers … but how many of those 500 e-mails a day is a tiger? Or are they mostly mice? Is everything really such an emergency?

Stone calls this phenomenon "constant partial attention," and it is the true cost of information overload. When even an hour is too long to wait for a reply, how can anyone be expected to focus deeply and consistently on any given task? We need to take time to reflect on things rather than just react to them.

Photo courtesy Kerry Ellis

Steven Levy, a noted science and technology journalist for *Newsweek* magazine, wrote that "a live Blackberry or even a switched-on mobile phone is an admission that your commitment to your current activity … is fickle." He's absolutely correct: if you're talking to a colleague and the Blackberry on your belt vibrates, it's nearly impossible not to grab it and take a look. One is afraid to be out of contact for no good reason other than that one is always in contact. On the surface, you're just staying current, but what you've really just done is put the person in front of you on hold for an as-yet anonymous e-mail.

With all the information flowing back and forth, how can you be sure you are being effective, and not merely efficient? NASCAR racing cars are very efficient machines when it comes to making left-hand turns at 200 mph. It takes care and conscious attention to be sure you're not turning into the NASCAR equivalent in your job: incredibly fast and efficient, but inflexible. If you're thrown a right-hand curve, it's important that you are able to make the turn and not have to compensate with three lefts.

Perhaps you've been making left-hand turns for so long that you can no longer see the right-hand turn shortcut up ahead. With information coming at the average worker at an ever-increasing rate, it's easy to get caught in reactive mode, with no real thought given to reflecting on the situation or the task at hand. It is difficult to innovate in reactive mode; true improvement can only come if you take time for reflection. It should be noted that this requires a conscious effort—opportunities for reflection very rarely present themselves.

Not all aspects of today's information-saturated society are bad. If General Andrew Jackson had been sporting a pager on his belt, President James Madison could have saved lives with a simple, "Andy: War Over. Thx, Jim." The communication systems we use are not at fault; it is how we use them that matters. While not everyone in the office needs to know you'll be out sick, some do, and it's easier than ever before to let them know. When the boss is about to give an important presentation, you can get critical late-breaking information to him or her quickly and discretely. Thanks to wireless technology, being on the road no longer means being out of touch; you're only as isolated as you choose to be, instead of as you are forced to be. When appropriately used, technology can make everyone more productive.

The key to making information work for us, instead of against us, is management. To stem the tide of e-mail, data, and all other manner of products coming from every direction, it is critical to use the tools at your disposal to the greatest possible advantage. Most e-mail programs have rules and filters for classifying and sorting automatically; using them will help cut the time you need to spend sorting the wheat from the chaff. Metadata, an often-overlooked aspect of modern computer filing systems (click "properties" on any file to see the metadata), can make finding files on an office server quite easy, as well as assist in storing information regarding the history of the file, changes to it, the original author, and so on. Bookmarks in your Web browser can get you to deeply buried Web pages you use often much more quickly without navigating through higher levels of

THE KEY TO MAKING INFORMATION WORK FOR US, INSTEAD OF AGAINST US, IS MANAGEMENT. TO STEM THE TIDE OF E-MAIL, DATA, AND ALL OTHER MANNER OF PRODUCTS COMING FROM EVERY DIRECTION, IT IS CRITICAL TO USE THE TOOLS AT YOUR DISPOSAL TO THE GREATEST POSSIBLE ADVANTAGE.

the site. So there are tools you can use to minimize the problem, and knowing and using them will give you some control over what shows up at your desk. Changing behavior is another way to exercise control. Some commentators recommend not checking e-mail more than once per hour so you're not constantly interrupting other tasks (or reflection). This also helps break the cycle of expecting instantaneous replies.

Finally, it is important to be part of the solution and not part of the problem. Common sense and etiquette can cut down the amount of unnecessary information more than any tool. We'll use the example of e-mail, but these ideas can be used for any information product you choose:

- When sending e-mail, think carefully about *whom* you're addressing it to. It is the de facto standard operating procedure in many organizations to send out as much information as possible to as many people as possible. But think about how many e-mails you get that were sent to your entire staff that really affect only one or two people, yet everyone else had to spend time reading and deleting it. It is the sender's responsibility to determine the proper distribution, rather than the receiver's to dispose of irrelevant messages.
- Focus on the actual *content* of your e-mail. Forwarding a long string of replies to someone who has not been involved thus far puts a burden on the recipient to figure out what is going on. The sender should summarize the correspondence and include the originals only as background information, if at all. Also, when forwarding a file, it's useful to let the recipients know what is in the file, rather than sending an e-mail with no text and a single, attached file. When forwarding a .guh file, ensure that your target has the ability to read .guh files, lest they get it, find it unreadable, and (guh!) ignore it. Again, the burden is on the *sender*, not the *recipient*, to make the proper decisions.
- Concentrate on the *timeliness* of your e-mail. If you need a response in the next ten minutes, an e-mail is not the proper mode of communication; pick up the phone or go in person. Similarly, if you don't need a reply for three months, the e-mail can probably wait—the recipient almost certainly has enough things to track and manage. With the amount of e-mail bouncing around, proper timing on the sender's part can help ensure that the recipient dispositions the information properly.
- Finally, think about *why* you're sending the e-mail in the first place. It's common sense not to send an e-mail in anger, but consider the more mundane e-mails that make up the bulk of our correspondence. How often have you read a message and thought to yourself, *what was the point of that? Did anyone need to read that?* Pointless and time-wasting e-mail will forever be part of our work and personal lives, but taking some time to think about the point and relevance of your missive will help ensure no one at the other end is scratching his head and cursing your name.

Albert Einstein once said that information is not knowledge. The amount of information washing over the average desk within NASA today is staggering, and none of it means anything without some effort on the recipient's part to bring context to each piece of information so it can be dealt with effectively. The speed at which information is arriving can create a frenzied pace that, left unchecked, can lead to constant partial attention and a significant loss of productivity, both in the workplace and in one's personal life. It is the responsibility of each individual to ensure that each byte is effectively transmitted, such that communication is truly improved. Careful management will enhance your own and your coworker's productivity, and it will contribute in a large way to the success of the mission as a whole.

Failing that, there's always the "delete" key. Assuming the letters haven't worn off. ●

Recommended reading: Peopleware: Productive Projects and Teams, *by Tom DeMarco and Timothy Lister;* Slack: Getting Past Burnout, Busywork, and the Myth of Total Efficiency, *by Tom DeMarco;* The Paradox of Choice: Why More Is Less, *by Barry Schwartz.*

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EINSTEIN for Children
LEARNING AND TEACHING

BY MARC SPIEGEL

Spiegel, as Einstein, interacts with students.

Photo courtesy Marc Speigel

Explaining to other people something complicated that you are working to understand yourself can be difficult. That was my situation when I began developing my *Einstein Alive!* program to introduce Einstein and the theory of relativity to students from kindergarten through middle school. Now, years later, I have performed the show for enthusiastic audiences from the Arctic Circle to the Florida Everglades. Developing the performance has taught me a great deal about teaching and understanding. I think my experience may offer some useful hints to technically savvy people who need to communicate their expertise to others.

I am not a scientist or engineer. I am a storyteller, a writer of sorts, often of rhyme, and a mostly self-taught performer with an audience-participatory style learned on the streets of San Francisco in the 1970s. But I have always had a sense of awe about the universe. My difficulty with math and my unfortunate experience with high school physics discouraged me from pursuing science and gave me a fuzzier view of the cosmos than a scientist might have. I have always found nontechnical books on physics fascinating and inspirational, though I rarely retain technical details.

In 1995, I was a storyteller sharing mostly original tales in schools up and down the East Coast. One way I promoted myself was by attending showcases where school representatives came to watch ten-minute presentations. I heard about a showcase in Queens, New York, run by a colorful arts-in-education promoter named Joan Lavin. When I called her, she said I could be in her showcase but told me she could get me more work if I played a historical character.

I was married with two young children and a mortgage. More work sounded like a reasonable idea, but it would require me to stop what I was doing and dedicate myself to researching the life of another human being. Which one? The answer came quickly: Albert Einstein. I have always remembered the newspaper headline the day he died. I was very young and knew nothing about science, but I understood that someone very important had passed away. When I told Joan of my choice, she said, "I guess that will work, but don't do the science." I was not ten minutes into my research, however, before I found Einstein telling me, "Personal facts are not important to understand a man like me. What is important are the adventures inside my mind." Science had to be the centerpiece of any Einstein portrayal I might do.

I immediately saw two challenges. Audience participation is the heart of my performance style; I felt this performance had to be a visit with Einstein in which he would talk about his life and the adventures in his mind and answer questions from the audience. Somehow I had to develop the confidence to become Einstein and present him as alive and vibrant. The second challenge was the science. I had to learn enough about Einstein's scientific thinking to find a natural, entertaining, and understandable way of presenting it to my young audiences.

I began to read everything I could about and by Einstein, which was a great deal indeed. I solved the first challenge by having Einstein inform the audience that he was dead: "They have dredged me up again!" (I presented the idea more gently to my elementary school audience: "Don't worry, I am not a ghost! I won't go 'boo' to you. / The actor fixes up his hair and puts the mustache on with glue.") This would be Einstein brought back to life by the actor/storyteller Marc Spiegel. If Einstein ever had trouble answering a question, he could always blame Spiegel.

Learning and presenting the science was the greater challenge. I made two important discoveries in the process. First, when experts explain something, they often leap over information they consider to be elementary. I have been stopped in my tracks by the simple phrase *from which we derive* placed between two equations where I see no obvious connection. This happens with verbal explanations as well. It's an easy trap to fall into; I initially made my own similar assumptions about what my young audience knew.

Fortunately, different writers make different leaps; if you read enough explanations, you can usually fill in the gaps. Herein lies the best advice I have learned from Einstein: the two most important qualities a scientist must have are curiosity and determination.

The second thing I discovered was that most physicists are generous with their time and delight in answering questions. I especially thank Dr. William Parke at George Washington University who, among the countless ways he has helped me, pointed out an assumption *I* was making. I assumed my young audience knew what friction was when his college students' answers on exams showed that they sometimes did not. That insight led to one of the most successful sequences in my presentation.

As I gained familiarity with the science, I became more and more concerned about how to present it to children. This led me to try to explain the material while I was still learning it, which, I found, greatly aided my own learning process. Indeed, I have come to believe that if you want to learn any subject, start teaching it to children.

The rudimentary level of my knowledge actually became one of my greatest assets. I had to start on the most fundamental level. To explain the theory of relativity, I first had to vividly explain what the word "relative" meant. I talked about relativity with everyone I met, mostly people who had not opened a scientific book in decades. Along the way a good friend, singer-songwriter Michele Valerie, joked that kids in my audience would probably say, "Relative? I have an Aunt Rose who's a relative." That's where I began.

In retrospect I realize that I wrote this show as I might write a story. The ideas that the audience must understand are like characters in a story. "Relative" was my first character. I needed to introduce this character to the audience in a way they could easily identify with: "Is anyone here a relative? Does anyone here have a brother or a sister?"

Suddenly, Einstein is not lecturing about science, he is asking a personal question: "Who here has just one brother or sister and that one brother or sister is younger than you? Were you a brother before your sister was born? No. Your being a brother depends upon your sister being born. It depends on something else. That is what the word 'relative' means: to need something else."

I introduced "relative" as something familiar—a brother or a sister. But this character "relative" has more layers. Einstein goes on to say, "Other things are relative. Tallness is relative. Am I short or am I tall?" Ninety-nine percent of the time one or two students in the audience will call out "short," which

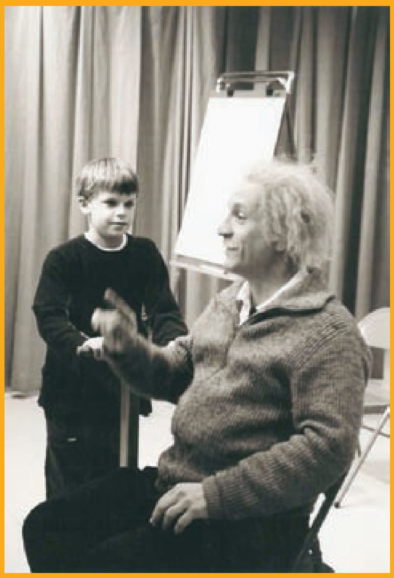


Photo courtesy Marc Speigel

Marc Spiegel explains the theory of relativity with the aid of a young participant.

offers a valuable tool in teaching anything: humor. "Who said 'short?'" Einstein asks indignantly, bringing one or two students up to stand next to him. What is *relative* now is not

THE RUDIMENTARY LEVEL OF MY KNOWLEDGE ACTUALLY BECAME ONE OF MY GREATEST ASSETS. I HAD TO START ON THE MOST FUNDAMENTAL LEVEL. TO EXPLAIN THE THEORY OF RELATIVITY, I FIRST HAD TO VIVIDLY EXPLAIN WHAT THE WORD "RELATIVE" MEANT.

a sibling, but the more abstract concept of tallness. Einstein shows that relative to the students, he is tall, but relative to the ceiling, he is short.

I introduce the second character in the story as Einstein concludes: "When something is relative, you cannot understand anything about it unless you compare it to something else; this something else is called a frame of reference." Einstein has the students on stage stretch out their arms out and make a frame with their index fingers and thumbs.

"If I place the frame around just Nicholas and myself, then I am a little tall, but if I place it around the ceiling and myself, then I am very short."

Then I introduce my third character, motion, and the problem of motion. For this I created a 3′ x 3′ platform on wheels with a brake lever, a push rod, and a chair bolted to it. The machine rolls parallel to the audience, and anyone sitting in the chair faces the audience.

Most people do not think that motion has a problem. Einstein, however, presents it as one in his *Evolution of Physics*, and that is how I wanted to introduce the theory of relativity: as a solution to a problem, the answer to a puzzle.

The basic premise of relativity is that moving and standing still are the same with regard to the laws of physics. My Einstein starts his story by showing first that moving and standing still have something in common: both require a push or a pull from something else. A push or pull makes something that is standing still move and makes something that is moving stop. Einstein/Spiegel demonstrates this by pushing and pulling the machine, by pantomiming how we walk, hit a baseball, and slam a door.

At this point Einstein has explained what relative means, what a frame of reference is, and that moving and standing still have something that is the same about them. There is one more step to take. Moving and standing still are so much the same that you can be moving and standing still at the same time. This is because all motion is relative. Indeed, all motion is relative to a frame of reference. A teacher sits on the chair that is bolted onto the machine, Einstein sits on her lap, and as a student pushes the machine across the stage, Einstein sings:

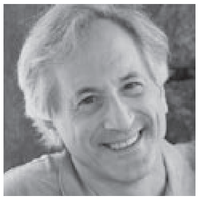
Relative to you now I am moving,
for that you need no map
But relative to Ms. Padgorndny, I'm not moving
I'm sitting still right in her lap.

That is the basic story of the elementary school program. The middle and high school programs go on to the constant speed of light and the resulting puzzle of relativity. Einstein now has two clear frames of reference to work with: the frame of reference of the room and the frame of reference of the machine. Now it is possible to talk of observers in each frame of reference measuring the speed of a person walking or a beam of light streaking between them. This leads directly to Einstein's explanation that time and space are different forms of the same thing and arrange themselves in every frame of reference in such a way that the speed of light is always measured the same by everyone.

Are there lessons in my experience for "explainers" who don't perform in schools? I don't mean to suggest that real scientists should use song and pantomime to communicate their ideas, but I think many of the same basic principles apply: don't assume your listeners know everything you consider obvious; look for vivid, everyday analogies to explain difficult concepts; interact with your audience; and use the power of story—its potential for mystery, suspense, humor, and engagement—to reach your listeners. ●

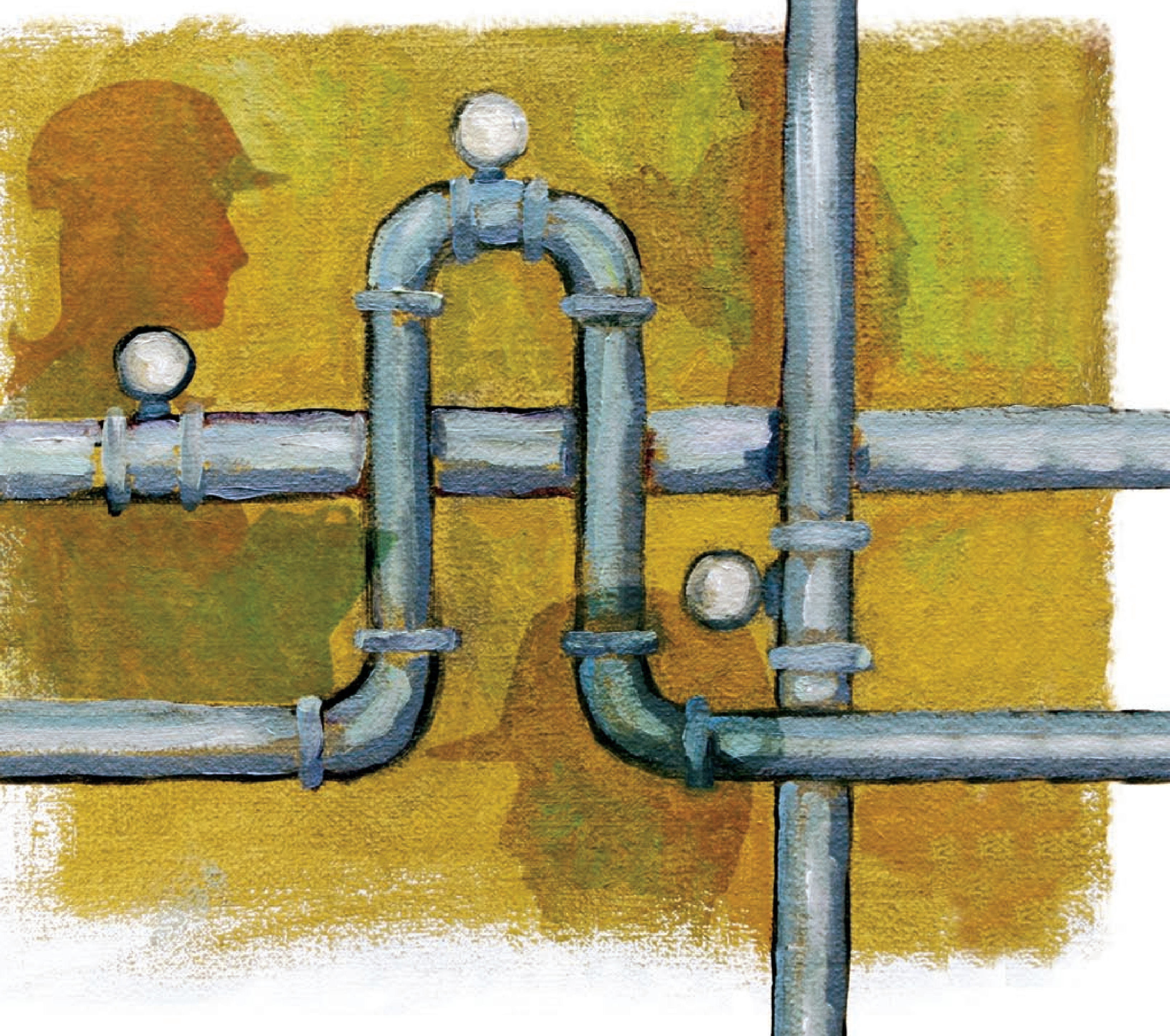
For more stories and answers from Spiegel/Einstein, visit http://www.marcspiegel.com/videos/videoquestions.html.

MARC SPIEGEL began writing and performing stories in narrative verse as a political science graduate student at Harvard. He has appeared on television, at schools, festivals, and corporate events. He has performed at several venues, including the Kennedy Center, the International Children's Festival, and the Smithsonian Institute, and he was a featured performer in the White House Millennium Celebration.



MAKING AND MONITORING critical assumptions

BY HUGH WOODWARD



I remember the day I walked into the paper plant in Oxnard under a brilliant southern California sun with a pleasant cooling breeze blowing off the Pacific. I was reveling in the opportunity to work on an interesting little project far from the wintry weather in Cincinnati, Ohio. An hour later, I was utterly depressed. I had just been given an impossible assignment.

The project had started a couple months earlier when the City of Oxnard demanded that the plant, which produced paper towels and toilet tissue, reduce its water consumption by 10 percent. A paper plant may be an easy target for politicians seeking to please an electorate, but our plant in Oxnard was already the most efficient of its kind in the world. Reducing consumption further was not going to be easy. Nevertheless, the company, sensing no room to negotiate, agreed to comply and appropriated funds to develop and install the necessary technology. Realizing the complexity of the task, they selected a project manager with years of experience in paper manufacturing: me!

Unbeknown to me and them, they had also selected a naïve project manager. I had no idea how difficult the assignment would be until I convened a project team meeting that sunny morning in Oxnard and asked a few routine questions.

"What is the scope?"

"Well, we are planning to re-use more waste water, reduce evaporation from our cooling towers, and install low-flow toilets."

"What?" I asked incredulously. "Low-flow toilets? They will save perhaps gallons a day. We are looking for over a hundred thousand gallons a day."

The team explained that the city had mandated low-flow toilets as part of the scope, presumably in an effort to be helpful.

I asked for details about the changes and soon learned they were all quite experimental. Even technology in use at other paper plants was not proven in our particular process. My anxiety increased when I started asking questions about current consumption.

"How much water are you consuming now?"

"We don't know."

"What do you mean 'you don't know?'"

"Well, we don't have meters on all our lines."

"But the city must know how much you are using. How will they know you have achieved the 10 percent reduction?"

"They won't!"

They explained that, because the plant treats its own water, it draws water from a trunk line upstream of the city's treatment facility. There was simply no provision for metering.

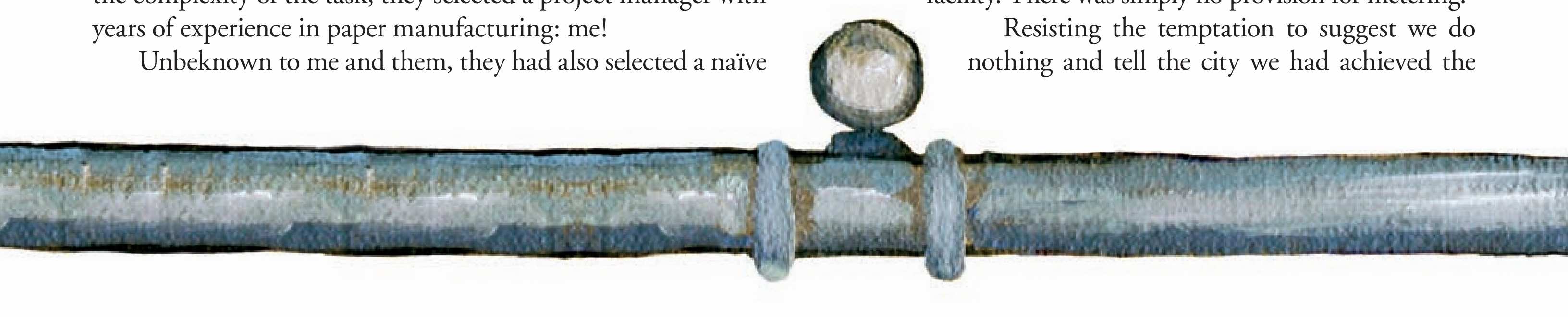
Resisting the temptation to suggest we do nothing and tell the city we had achieved the objective, I moved on to another subject that seemed important. I knew the plant was in the middle of a major expansion. In fact, they expected to more than double production within six months.

"How is the city thinking about that?" I asked.

"Well, we never discussed the expansion specifically, but we think they are expecting us to consume 10 percent less than what we would have done if we did nothing."

Finally, I asked about the water consumption in the orange juice facility. Several years earlier, the company had been looking to expand its production of orange juice on the West Coast and decided to site its manufacturing facility at Oxnard adjacent to its paper plant. Nobody knew. In fact, nobody on my project team knew anything about the orange juice operation, and they certainly had no idea how much water it consumed.

The immediate dilemma was how to get started. We clearly



had to install meters and establish a baseline. And there was nothing stopping us from installing those low-flow toilets. But what could we do beyond that? How were we to deal with all the unknowns? Every attempt to establish a project plan deteriorated into arguments about the expansion, the orange juice facility, and whether or not the new technologies we were planning to install would work.

We eventually decided the only way forward was to make some assumptions. We called them "critical assumptions." For example, we assumed the orange juice facility would make no contribution toward the 10 percent reduction. We also assumed the new production lines would consume the volume of water predicted by the design calculations. And we assumed the low-flow toilets would make no measurable contribution to our conservation target. We had no way of knowing if these assumptions were correct, of course, but they created boundaries that allowed us to establish a scope and eventually a project plan.

We knew we needed to check the validity of our critical assumptions periodically. We assigned project team members to each assumption and charged them with checking validity prior to each monthly team meeting and reporting their findings during the meeting.

With a logical framework now in place, we proceeded with execution. We installed meters on the incoming header and established a baseline that the city accepted. We also installed meters on every major line within the plant to measure consumption in each part of the facility. The only area that proved difficult to measure was the orange juice facility. As the team member responsible for metering explained, "The orange juice facility uses a lot of water when it runs. The problem is, it runs sporadically and not very often." Eventually, we acquired enough data to determine the average consumption of the facility was a little more than 100,000 gallons per day.

We also studied each of the conservation ideas and developed estimates of the amount of water they would save and the cost of installing them. Eventually, we had a menu of options that would give us some choices about how to achieve the mandated reduction within our budget. We even developed a list of contingencies should some of the conservation ideas deliver less than expected. Oh, and we installed those low-flow toilets!

Our project team meetings settled into a routine. Each began with a review of our critical assumptions. For the first few months, we found no reason to change them. We then reviewed each of the conservation ideas. As new information came to light, some dropped off the list. Others continued to look promising. We adjusted our scope accordingly. Overall, we remained cautiously optimistic.

Some nine months after my initial visit, I traveled back to Oxnard for a project team meeting I had no reason to suspect would be any different. After the usual preliminaries, we began our review of our critical assumptions.

"The new lines are now in production. They are not yet operating at target rate, but they appear to be consuming the amount of water we predicted. This assumption still seems to be valid."

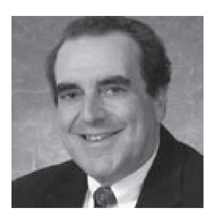
"We have now converted all our restrooms to low-flow toilets. We have not seen any resulting change in total consumption. This assumption remains valid."

Eventually it was time for the team member monitoring the orange juice facility to report. "Please keep this confidential as it has not yet been announced, but the company has decided to exit the orange juice business. The production facility here will close in less than six months." Our jaws dropped. We immediately referred to the consumption data on our spreadsheets and saw that, incredibly, the impact would be just enough to achieve our target. All that remained was to close the project, report the reduction to the city, and return the unused funds to the company.

Not unexpectedly, some project team members disagreed. They argued the company had appropriated funds to install specific equipment and that we were obligated to install it. Others asserted we were obligated to achieve a 10 percent reduction beyond closing the orange juice facility. Some wanted to continue until the facility was in fact closed, in case the company changed its mind. But eventually we decided the project and the project team existed for one purpose only: to satisfy the city's mandate that the plant reduce its water consumption by 10 percent. That mandate had been fulfilled.

So we got a lucky break, but there is no doubt that our decision to establish and monitor critical assumptions was key to our success. Without these assumptions, we would likely have spent months arguing about issues we couldn't definitively understand early on, thereby failing to define a logical project plan. And without our monthly review of their validity, we might have wasted time and money pursuing flawed options. Without that careful monitoring, we would certainly have continued spending money on unnecessary technology for at least another six months, without realizing our job was done.

Fortunately, that was not the case. The plant achieved its water conservation target. The company got most of its money back. The project team learned a new approach to managing projects with high uncertainty. And I traded some dreary Midwest weather for southern California sunshine. All in all, it was a huge success! ●



HUGH WOODWARD practiced project and program management for more than twenty-five years at the Procter & Gamble Company, and he is a former Chair of the Project Management Institute. As President of Macquarie Business Concepts he now helps companies eliminate unproductive effort and unnecessary costs.

ASK Bookshelf

Here is a description of a book that we believe will interest ASK *readers.*

The Ten Faces of Innovation: IDEO's Strategies for Beating the Devil's Advocate and Driving Creativity Throughout Your Organization, by Tom Kelley with Jonathan Littman (New York: Currency/Doubleday, 2005)

As an award-winning innovation and design firm, IDEO creates new products and capabilities through observation-based research. Their successful designs include the first production mouse for Apple's Macintosh computers (1981), the Palm V connected organizer for Palm Computing (1999), and Bank of America's "Keep the Change" banking account service (2006). The design firm attributes its impressive track record to multidisciplinary teams and a collaborative culture combined with a methodology incorporating user observation, creative brainstorming, and prototyping.

IDEO's Tom Kelley and Jonathan Littman describe ten roles, or personas, that they believe nurture innovation and protect against the insidious influences of the devil's advocate. According to the authors, the three "learning personas" continually motivate themselves and others with new ideas. The Anthropologist brings tremendous powers of observation to form unique insights into human factors that solve problems. The Experimenter prototypes new ideas and takes calculated risks to find the next innovative breakthrough. The Cross-Pollinator applies new ideas from seemingly unrelated fields or diverse backgrounds. The authors give the example of escalators originating from a Coney Island amusement ride.

"Organizing personas" help new ideas survive time and budget pressures. The Hurdler overcomes challenges through perseverance and turns obstacles into opportunities (sometimes by bending the rules). The Collaborator's great enthusiasm and diplomatic skills bring interdisciplinary teams together. The Director orchestrates continuous innovation efforts by gathering talented employees into effective teams and serving as a creative catalyst.

The "building personas" help create conditions in which new ideas grow. The Experience Architect creates experiences that motivate and delight. The Set Designer reinvents the work environment to inspire innovation. The Caregiver provides a supportive human-centered setting. The Storyteller makes an emotional connection through myths to convey information and provoke thought.

Kelley and Littman explain that the devil's advocate appears regularly in the project rooms and boardrooms of corporate America, encouraging "the most negative possible perspective, one that sees only the downside, the problems, the disasters-in-waiting." Their view of the devil's advocate differs from other noted authors in the innovation arena, who laud the role as a positive pressure point for guiding new ideas. According to Kelley and Littman, the devil's advocate kills new ideas. The ten nurturing personas counter that negativity with innovative possibilities.

Kelley also notes that individuals may take on multiple roles or switch roles depending on their context. The personas cannot guarantee innovation, and not every successful innovative group will include all ten, but the book provides insight into the sources of innovation that NASA readers can usefully apply to their own groundbreaking work. ●

The Knowledge Notebook

Taking a Knowledge Perspective

BY LAURENCE PRUSAK

In our Western culture, to manage means to control. Especially in organizations, management of traditional resources like land, labor, and capital means being able to count and measure them, move them around, buy and sell them, and, in general, have complete control of them. It's not surprising that many business schools use the word "control" to describe their accounting courses. And "command and control" is an approach, borrowed from the military, that defines the way most large, twentieth-century organizations function.

The control mind-set has always presented a real challenge to what has been called knowledge management. Clearly, knowledge is a very different kind of thing from those other, traditionally recognized sources of wealth. Knowledge is intangible and invisible, and there is rarely agreement within organizations as to exactly what it is. Yet it is what differentiates one organization from another. NASA *knows* how to do some things that no other organization knows how to do. Individual knowledge is aggregated and bundled into capabilities and capacities that allow NASA, for example, to launch the Space Shuttle or design spacecraft to explore the outer planets. The same holds true for countries, firms, and any other social organism that is directed toward a specific goal. Knowledge gets them where they want to go.

But when organizations, recognizing that knowledge is a critical resource, try to *do* something about their knowledge, they run into the control dilemma that is probably inherent in the term knowledge *management*. Managers naturally try to manage it. This is exactly what often happened in the first decade of what came to be called knowledge management. Organizations that came to believe that developing and using knowledge effectively was vital to their success tried to use all the tools at their disposal to manage it—that is, to control it.

Those attempts led to much frustration and wasted effort. You can't manage, in any traditional sense of the word, what you can't see, count, move, or even clearly define. And knowledge—so much of which resides in the heads and hands of individuals and groups and has meaning in particular contexts—is especially resistant to outside control.

But we do need to find ways to increase the efficiency and effectiveness of knowledge work. We need to encourage knowledge seeking and sharing. We need to provide favorable conditions for innovation—that is, the creation of new knowledge. At NASA, successfully turning the new Vision for Space Exploration into a reality will depend on making the most of our knowledge resources and sharing and developing knowledge effectively with contractors. We have to pay attention to knowledge.

But if control doesn't work, what *should* we be doing?

Well, one place to start is to talk more about a knowledge *perspective* and less about knowledge *management*. A knowledge perspective emphasizes appreciating the value of knowledge, using it as best as one can, talking about it, and striving to work with it, while recognizing that it cannot be neatly packaged in databases or made to thrive by executive order. Such a perspective could counteract and, eventually, replace misguided attempts to manage knowledge by using all the wrong tools.

What would this mean in practice? Here are a few recent examples of applying a knowledge perspective that I am aware of:

- Explicitly making knowledge a key input and output of project work. This includes trying to identify what knowledge is needed to accomplish a project, determining how it can be obtained and used, and devising ways of retaining project knowledge and communicating it to other projects that could use it, emphasizing shared experience and direct contact over lessons learned databases.
- Using knowledge in the form of stories and cases to give employees a rich understanding of their organization's values and culture. Both NASA and Petrobras, the Brazilian energy firm, do this well.
- Using organizational design to better develop and exploit knowledge. This includes fostering practice-based or theme-based knowledge communities. Northrup Grumman and Fluor are two firms that invested in community development and support.
- Evaluating workers in terms of their effective use of knowledge and promoting the outstanding performers. Effective knowledge use can mean anything from mentoring, which is often focused on knowledge as to how the organization works, to developing, seeking, and sharing more technical or domain-oriented knowledge.

This list could go on and on, but I think you get the point. Think about the importance of knowledge in any operation you are involved in and how it is being used. Then try to imagine how it could be used better—without worrying about measuring its exact features or attributes or thinking you need to build an elaborate system to capture or control it. Just do it. You will find the effort well worth your time and you will be well on the way to developing your own knowledge perspective and making the most of this essential resource for work. ●

A KNOWLEDGE PERSPECTIVE EMPHASIZES APPRECIATING THE VALUE OF KNOWLEDGE, USING IT AS BEST AS ONE CAN, TALKING ABOUT IT, AND STRIVING TO WORK WITH IT, WHILE RECOGNIZING THAT IT CANNOT BE NEATLY PACKAGED IN DATABASES OR MADE TO THRIVE BY EXECUTIVE ORDER.

ASK interactive

TOP 25

NASA in the News

The Project Management Institute (PMI) recognized NASA as one of "25 Outstanding Organizations in Project Management" in its October 2007 issue of *PM Network* (Volume 21, Number 10). Earlier this year, PMI invited organizations to submit nominations through an online process. They were looking for companies, not-for-profit organizations, and government entities that had achieved the following:

- Developed a project management career path
- Pioneered best practices or demonstrated innovation in project management principles
- Acknowledged project management at the executive level
- Attributed continuous improvement or return on investment to project management practices
- Placed value on project management credentialing

Find out more about PMI and *PM Network* at http://www.pmi.org/Resources/Pages/PM-Network.aspx.

Reminder: PM Challenge 2008

Don't forget to register for NASA's PM Challenge 2008, the Agency's fifth annual project management conference. It will be held February 26 and 27, 2008, in Daytona Beach, Fla., near the Kennedy Space Center. The conference will feature several tracks, including High-Performance Teams, Mission Success Stories, Global Perspectives, Risk Management, and much more. The awards for Software of the Year and Invention of the Year will also be presented at the conference. Registration opens November 14. For more information, and to register, visit http://pmchallenge.gsfc.nasa.gov.

Web of Knowledge

The NASA Engineering and Safety Center, or NESC, provides independent testing, analysis, and assessments of NASA's high-risk projects to ensure safety and mission success. Supported by a team of technical specialists from the ten NASA Centers and from a group of partners and organizations outside the Agency, NESC delivers technical reports and lessons learned that are shared with NASA's leadership. NESC also engages in proactive investigations to identify and address potential concerns before they become major problems. Read more about NESC at http://www.nasa.gov/offices/nesc/home/index.html.

2007 APEX Award for *ASK Magazine*

ASK Magazine won a 2007 Award of Excellence in the Nineteenth Annual Awards for Publication Excellence Competition. The Awards for Publication Excellence (APEX) were based on excellence in graphic design, editorial content, and the success of the entry, in addition to achieving overall communication effectiveness and excellence. Visit http://www.apexawards.com for more information about the awards.

For More on Our Stories

Additional information pertaining to articles featured in this issue can be found by visiting the following Web sites:

- **Cosmic Background Explorer (COBE):** http://lambda.gsfc.nasa.gov/product/cobe/
- **Wallops Flight Facility:** http://www.nasa.gov/centers/wallops/home/
- **Cassini-Huygens:** http://www.nasa.gov/mission_pages/cassini/main/index.html

feedback

We welcome your comments on what you've read in this issue of *ASK* and your suggestions for articles you would like to see in future issues. Share your thoughts with us at http://appel.nasa.gov/ask/about/write.php.

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