ROBOTS vs. HUMANS: Unmanned spacecraft are exploring the solar systems more cheaply and effectively than astronauts are

Francis Slakey**,** *Scientific American Presents*; 1999

Who Should Explore Space?

The National Aeronautics and Space Administration has a difficult task. It must convince U.S. taxpayers that space science is worth $13.6 billion a year. To achieve this goal, the agency conducts an extensive public-relations effort that is similar to the marketing campaigns of America's biggest corporations. NASA has learned a valuable lesson about marketing in the 1990s: to promote its programs, it must provide entertaining visuals and stories with compelling human characters. For this reason, NASA issues a steady stream of press releases and images from its human spaceflight program.

Every launch of the space shuttle is a media event. NASA presents its astronauts as ready-made heroes, even when their accomplishments in space are no longer groundbreaking. Perhaps the best example of NASA's public-relations prowess was the participation of John Glenn, the first American to orbit Earth, in shuttle mission STS-95 last year. Glenn's return to space at the age of 77 made STS-95 the most avidly followed mission since the Apollo moon landings. NASA claimed that Glenn went up for science — he served as a guinea pig in various medical experiments — but it was clear that the main benefit of Glenn's space shuttle ride was publicity, not scientific discovery.

NASA is still conducting grade-A science in space, but it is being done by unmanned probes rather than astronauts. In recent years the Pathfinder rover has scoured the surface of Mars, and the Galileo spacecraft has surveyed Jupiter and its moons. The Hubble Space Telescope and other orbital observatories are bringing back pictures of the early moments of creation. But robots aren't heroes. No one throws a ticker-tape parade for a telescope. Human spaceflight provides the stories that NASA uses to sell its programs to the public. And that's the main reason NASA spends nearly a quarter of its budget to launch the space shuttle about half a dozen times each year.

The space agency has now started building the International Space Station, the long-planned orbiting laboratory. NASA says the station will provide a platform for space research and help determine how people can live and work safely in space. This knowledge could then be used to plan a manned mission to Mars or the construction of a base on the moon. But these justifications for the station are largely myths. Here are the facts, plain as potatoes: The International Space

Station is not a platform for cutting-edge science. Unmanned probes can explore Mars and other planets more cheaply and effectively than manned missions can. And a moon colony is not in our destiny.

The Myth of Science

In 1990 the American Physical Society, an organization of 41,000 physicists, reviewed the experiments then planned for the International Space Station. Many of the studies involved examining materials and fluid mechanics in the station's microgravity environment. Other proposed experiments focused on growing protein crystals and cell cultures on the station. The physical society concluded, however, that these experiments would not provide enough useful scientific knowledge to justify building the station. Thirteen other scientific organizations, including the American Chemical Society and the American Crystallographic Association, drew the same conclusion.

Since then, the station has been redesigned and the list of planned experiments has changed, but the research community remains overwhelmingly opposed. To date, at least 20 scientific organizations from around the world have determined that the experiments in their respective fields are a waste of time and money. All these groups have recommended that space science should instead be done through robotic and telescopic missions.

These scientists have various reasons for their disapproval. For researchers in materials science, the station would simply be too unstable a platform. Vibrations caused by the movements of astronauts and machinery would jar sensitive experiments. The same vibrations would make it difficult for astronomers to observe the heavens and for geologists and climatologists to study Earth's surface as well as they could with unmanned satellites. The cloud of gases vented from the station would interfere with any experiments in space nearby that require near-vacuum conditions. And last, the station would orbit only 400 kilometers (250 miles) overhead, traveling through a region of space that has already been studied extensively.

The Myth of Economic Benefit

Human spaceflight is extremely expensive. A single flight of the space shuttle costs about $420 million. The shuttle's cargo bay can carry up to 23,000 kilograms (51,000 pounds) of payload into orbit and can return 14,500 kilograms back to Earth. Suppose that NASA loaded up the shuttle's cargo bay with confetti before launching it into space. Even if every kilogram of confetti miraculously turned into a kilogram of gold during the trip, the mission would still lose $270 million.

The same miserable economics hold for the International Space Station. Over the past 15 years the station has undergone five major redesigns and has fallen 11 years behind schedule. NASA has already spent nearly twice the $8 billion that the original project was supposed to cost in its entirety. The construction budget is now expected to climb above $40 billion, and the U.S. General Accounting Office estimates that the total outlay over the station's expected 10-year lifetime will exceed $100 billion.

So far the station's only economic beneficiary has been Russia, one of America's partners in the project. Last year NASA announced plans to pay $660 million over four years to the Russian Space Agency so it can finish construction of key modules of the station. The money was needed to make up for funds the Russians could not provide because of their country's economic collapse. U.S. Congressman James Sensenbrenner of Wisconsin, who chairs the House Science Committee, bitterly referred to the cash infusion as "bailout money" for Russia.

But what about long-term economic benefits? NASA has maintained that the ultimate goal of the space station is to serve as a springboard for a manned mission to Mars. Such a mission would probably cost at least as much as the station; even the most optimistic experts estimate that sending astronauts to the Red Planet would cost tens of billions of dollars. Other estimates run as high as $1 trillion. The only plausible economic benefits of a Mars mission would be in the form of technology spin-offs, and history has shown that such spinoffs are a poor justification for big-money space projects.

The Myth of Destiny

In recent years there have been tremendous strides in the capabilities of unmanned spacecraft. NASA's Discovery program has encouraged the design of compact, cost-effective probes that can make precise measurements and transmit high-quality images. Mars Pathfinder, for example, returned a treasure trove of data and pictures for only $265 million. And NASA's New Millennium program is testing advanced technologies with spacecraft such as the Deep Space 2 microprobes. These two-kilogram instruments, now riding piggyback on the Mars Polar Lander spacecraft launched earlier this year, will plunge to the surface of Mars and penetrate up to two meters underground, where they will analyze soil samples and search for subsurface ice.

These spacecraft will still need human direction, of course, from scientists and engineers in control rooms on Earth. Unlike astronauts, mission controllers are usually not celebrated in the press. But if explorers Lewis and Clark were alive today, that's where they would be sitting. They would not be interested in spending their days tightening bolts on a space station.

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By Francis Slakey
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ROBOTS vs. HUMANS: Astronaut explorers can perform science in space that robots cannot

Paul Spudis, *Scientific American Presents*, 1999

Who Should Explore Space?

Criticism of human spaceflight comes from many quarters. Some critics point to the high cost of manned missions. They contend that the National Aeronautics and Space Administration has a full slate of tasks to accomplish and that human spaceflight is draining funds from more important missions. Other critics question the scientific value of sending people into space. Their argument is that human spaceflight is an expensive "stunt" and that scientific goals can be more easily and satisfactorily accomplished by robotic spacecraft.

But the actual experience of astronauts and cosmonauts over the past 38 years has decisively shown the merits of people as explorers of space. Human capability is required in space to install and maintain complex scientific instruments and to conduct field exploration. These tasks take advantage of human flexibility, experience and judgment. They demand skills that are unlikely to be automated within the foreseeable future. A program of purely robotic exploration is inadequate in addressing the important scientific issues that make the planets worthy of detailed study.

Many of the scientific instruments sent into space require careful emplacement and alignment to work properly. Astronauts have successfully deployed instruments in Earth orbit — for example, the Hubble Space Telescope — and on the surface of Earth's moon. In the case of the space telescope, the repair of the originally flawed instrument and its continued maintenance have been ably accomplished by space shuttle crews on servicing missions. From 1969 to 1972 the Apollo astronauts carefully set up and aligned a variety of experiments on the lunar surface, which provided scientists with a detailed picture of the moon's interior by measuring seismic activity and heat flow. These experiments operated flawlessly for eight years until shut down in 1977 for fiscal rather than technical reasons.

The value of humans in space becomes even more apparent when complex equipment breaks down. On several occasions astronauts have been able to repair hardware in space, saving missions and the precious scientific data that they produce. When Skylab was launched in 1973, the lab's thermal heat shield was torn off and one of its solar panels was lost. The other solar panel, bound to the lab by restraining ties, would not release. But the first Skylab crew — astronauts Pete Conrad, Joe Kerwin and Paul Weitz — installed a new thermal shield and deployed the pinned solar panel. Their heroic efforts saved not only their mission but also the entire Skylab program.

Astronauts as Field Scientists

Exploration has two stages: reconnaissance and field study. The goal of reconnaissance is to acquire a broad overview of the compositions, processes and history of a given region or planet. Questions asked during the reconnaissance phase tend to be general — for instance, What's there? Examples of geologic reconnaissance are an orbiting spacecraft mapping the surface of a planet, and an automated lander measuring the chemical composition of the planet's soil.

The goals of field study are more ambitious. The object is to understand planetary processes and histories in detail. This requires observation in the field, the creation of a conceptual model, and the formulation and testing of hypotheses. Repeated visits must be made to the same geographic location. Field study is an open-ended, ongoing activity; some field sites on Earth have been studied continuously for more than 100 years and still provide scientists with important new insights. Field study is not a simple matter of collecting data: it requires the guiding presence of human intelligence. People are needed in the field to analyze the overabundant data and determine what should be collected and what should be ignored.

The transition from reconnaissance to field study is fuzzy. In any exploration, reconnaissance dominates the earliest phases. Because it is based on broad questions and simple, focused tasks, reconnaissance is the type of exploration best suited to robots. Unmanned orbiters can provide general information about the atmosphere, surface features and magnetic fields of a planet. Rovers can traverse the planet's surface, testing the physical and chemical properties of the soil and collecting samples for return to Earth.

But field study is complicated, interpretive and protracted. The method of solving the scientific puzzle is often not apparent immediately but must be formulated, applied and modified during the course of the study. Most important, fieldwork nearly always involves uncovering the unexpected. A surprising discovery may lead scientists to adopt new exploration methods or to make different observations. But an unmanned probe on a distant planet cannot be redesigned to observe unexpected phenomena. Although robots can gather significant amounts of data, conducting science in space requires scientists.

It is true that robotic missions are much less costly than human missions; I contend that they are also much less capable. The unmanned Luna 16, 20 and 24 spacecraft launched by the Soviet Union in the 1970s are often praised for returning soil samples from the moon at little cost. But the results from those missions are virtually incomprehensible without the paradigm provided by the results from the manned Apollo program. During the Apollo missions, the geologically trained astronauts were able to select the most representative samples of a given locality and recognize interesting or exotic rocks and act on such discoveries. In contrast, the Luna samples were scooped up indiscriminately by the robotic probes. We understand the geologic makeup and structure of each Apollo site in much greater detail than those of the Luna sites.

For a more recent example, consider the Mars Pathfinder mission, which was widely touted as a major success. Although Pathfinder discovered an unusual, silica-rich type of rock, because of the probe's limitations we do not know whether this composition represents an igneous rock, an impact breccia or a sedimentary rock. Each mode of origin would have a widely different implication about the history of Mars. Because the geologic context of the sample is unknown, the discovery has negligible scientific value. A trained geologist could have made a field identification of the rock in a few minutes, giving context to the subsequent chemical analyses and making the scientific return substantially greater.

The Melding of Mind and Machine

Human dexterity and intelligence are the prime requirements of field study. But is the physical presence of people really required? Telepresence — the remote projection of human abilities into a machine — may permit field study on other planets without the danger and logistical problems associated with human spaceflight. In telepresence the movements of a human operator on Earth are electronically transmitted to a robot that can reproduce the movements on another planet's surface. Visual and tactile information from the robot's sensors give the human operator the sensation of being present on the planet's surface, "inside" the robot. As a bonus, the robot surrogate can be given enhanced strength, endurance and sensory capabilities.

If telepresence is such a great idea, why do we need humans in space? For one, the technology is not yet available. Vision is the most important sense used in field study, and no real-time imaging system developed to date can match human vision, which provides 20 times more resolution than a video screen. But the most serious obstacle for telepresent systems is not technological but psychological. The process that scientists use to conduct exploration in the field is poorly understood, and one cannot simulate what is not understood.

Finally, there is the critical problem of time delay. Ideally, telepresence requires minimal delays between the operator's command to the robot, the execution of the command and the observation of the effect. The distances in space are so vast that instantaneous response is impossible. A signal would take 2.6 seconds to make a round-trip between Earth and its moon. The round-trip delay between Earth and Mars can be as long as 40 minutes, making true telepresence impossible. Robotic Mars probes must rely on a cumbersome interface, which forces the operator to be more preoccupied with physical manipulation than with exploration.

To answer the question "Humans or robots?" one must first define the task. If space exploration is about going to new worlds and understanding the universe in ever increasing detail, then both robots and humans will be needed. The strengths of each partner make up for the other's weaknesses. To use only one technique is to deprive ourselves of the best of both worlds: the intelligence and flexibility of human participation and the beneficial use of robotic assistance.

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By Paul D. Spudis
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Brain Candy

Is pop culture dumbing us down or smartening us up?

by Malcolm Gladwell, *The New Yorker*, May 16, 2005

In the wonderfully entertaining "Everything Bad Is Good for You" (Riverhead; $23.95), Steven Johnson proposes that what is making us smarter is precisely what we thought was making us dumber: popular culture.

As Johnson points out, television is very different now from what it was thirty years ago. It's harder. A typical episode of "Starsky and Hutch," in the nineteen-seventies, followed an essentially linear path: two characters, engaged in a single story line, moving toward a decisive conclusion. To watch an episode of "Dallas" today is to be stunned by its glacial pace—by the arduous attempts to establish social relationships, by the excruciating simplicity of the plotline, by how *obvious* it was. A single episode of "The Sopranos," by contrast, might follow five narrative threads, involving a dozen characters who weave in and out of the plot. Modern television also requires the viewer to do a lot of what Johnson calls "filling in," as in a "Seinfeld" episode that subtly parodies the Kennedy assassination conspiracists, or a typical "Simpsons" episode, which may contain numerous allusions to politics or cinema or pop culture. The extraordinary amount of money now being made in the television aftermarket—DVD sales and syndication—means that the creators of television shows now have an incentive to make programming that can sustain two or three or four viewings. Even reality shows like "Survivor," Johnson argues, engage the viewer in a way that television rarely has in the past:

When we watch these shows, the part of our brain that monitors the emotional lives of the people around us—the part that tracks subtle shifts in intonation and gesture and facial expression—scrutinizes the action on the screen, looking for clues. . . . The phrase "Monday-morning quarterbacking" was coined to describe the engaged feeling spectators have in relation to games as opposed to stories. We absorb stories, but we second-guess games. Reality programming has brought that second-guessing to prime time, only the game in question revolves around social dexterity rather than the physical kind.

How can the greater cognitive demands that television makes on us now, he wonders, not *matter*?

Johnson develops the same argument about video games. Most of the people who denounce video games, he says, haven't actually played them—at least, not recently. Twenty years ago, games like Tetris or Pac-Man were simple exercises in motor coordination and pattern recognition. Today's games belong to another realm. Johnson points out that one of the "walk-throughs" for "Grand Theft Auto III"—that is, the informal guides that break down the games and help players navigate their complexities—is fifty-three thousand words long, about the length of his book. The contemporary video game involves a fully realized imaginary world, dense with detail and levels of complexity.

Indeed, video games are not games in the sense of those pastimes—like Monopoly or gin rummy or chess—which most of us grew up with. They don't have a set of unambiguous rules that have to be learned and then followed during the course of play. This is why many of us find modern video games baffling: we're not used to being in a situation where we have to figure out what to do. We think we only have to learn how to press the buttons faster. But these games withhold critical information from the player. Players have to explore and sort through hypotheses in order to make sense of the game's environment, which is why a modern video game can take forty hours to complete. Far from being engines of instant gratification, as they are often described, video games are actually, Johnson writes, "all about delayed gratification—sometimes so long delayed that you wonder if the gratification is ever going to show."

At the same time, players are required to manage a dizzying array of information and options. The game presents the player with a series of puzzles, and you can't succeed at the game simply by solving the puzzles one at a time. You have to craft a longer-term strategy, in order to juggle and coordinate competing interests. In denigrating the video game, Johnson argues, we have confused it with other phenomena in teen-age life, like multitasking—simultaneously e-mailing and listening to music and talking on the telephone and surfing the Internet. Playing a video game is, in fact, an exercise in "constructing the proper hierarchy of tasks and moving through the tasks in the correct sequence," he writes. "It's about finding order and meaning in the world, and making decisions that help create that order."