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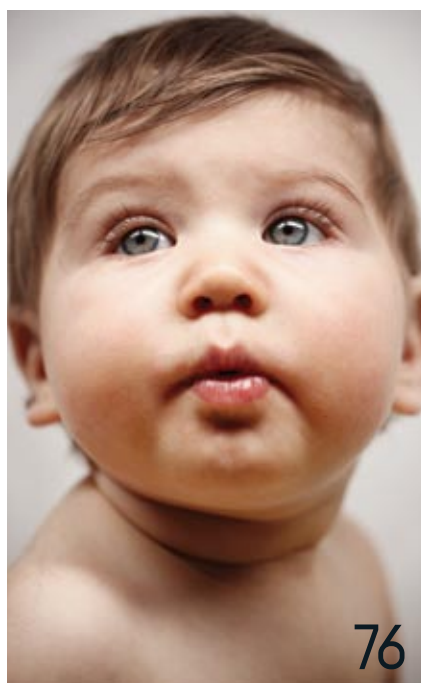
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More at www.ScientificAmerican.com/jul2010



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As I type this letter, I am sitting in a hotel room in Barcelona, Spain, having just completed an important but little-known meeting: the twice-a-year gathering

of editors and other members of *Scientific American's* international editions. Reflecting the scientific enterprise itself, the producers of the 14 local-language editions are spread around the world. Although we are in frequent e-mail and phone contact throughout the year, we also meet in person in various cities, the better to learn from one another.

Around the long table were representatives from Brazil, China, Japan, Kuwait, Russia and essentially every European nation. Our collective readership is a diverse audience that numbers more than one million, but they all share a passion for science and technology. And we, as editors, share a common mission to comb the globe for the science that matters, the better to serve those readers. Members of the editions traded intelligence on best practices and also shared new ideas. One initiative, which I expect to be under way on www.ScientificAmerican.com by the time you read this, is to conduct global surveys about science topics, working together and also in partnership with the journal *Nature* (which is in the same Macmillan corporate family). I will report further in the coming months.

Along with our global reach, we at *Scientific American* take pride in our unique inclusion of scientist authors, who collaborate with us on many of our feature articles and give us a distinctive perspective

BATTLEFIELD ROBOTS are reshaping modern warfare.



More rarefied still are the scientists who have achieved the honor of winning a Nobel Prize, and 143 Nobelists have contributed a collective total of 232 pieces to *Scientific American*, often years before their work was recognized in Stockholm.

Just as those Nobelists have provided their insights in our pages, they have also shared their wisdom and encouragement in lectures and conversations with young scientists at another important but underappreciated assembly, the Nobel Laureate Meetings in Lindau, Germany. This year marks the event's 60th anniversary, and it will include some 60 laureates and more than 600 young scientists. I will also be there, feeling humble among so many brilliant minds but eager to listen, learn—and then to share with readers. Look for my blog posts about the meeting at the end of June on www.ScientificAmerican.com; we will also be posting videos and other coverage from the conference during that time and in subsequent months.

Last, but certainly not least, I direct you to the scientific marvels within this issue. You can explore the strange apparent “lost” energy of the cosmos, in “Is the Universe Leaking Energy?” by Tamara M. Davis, starting on page 38. Learn the latest about promising vaccines and medicines in “DNA Drugs Come of Age,” by Matthew P. Morrow and David B. Weiner, starting on page 48. Watch robots remake the modern battlefield in “War of the Machines,” by P. W. Singer, on page 56. And delve into that most mysterious terrain: the infant mind. Turn to page 76 for “How Babies Think,” by Alison Gopnik. ■

MARIETTE DICHRISTINA
editor in chief

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LETTERS editors@SciAm.com

Math Wars ■ Fusion ■ Toxic Gas



MARCH 2010

■ Reform or Re-reform?

In “Numbers War” [News Scan], Linda Baker’s treatment of our inquiry-based Discovering Mathematics series is filled with errors and naive claims. For instance, there was no “three-year pilot” of our texts, contrary to what Baker reported. The article repeats many unfounded criticisms of reform in mathematics education. For one, Baker describes the National Council of Teachers of Mathematics (NCTM) document as a volley in the war, although it is actually an effort to bring coherence and conceptual clarity to the most important topics in high school mathematics. She claims that NCTM reform “reshaped a generation of instruction,” when, in fact, few students have had a real opportunity to try a fully committed inquiry-based curriculum as envisioned by the NCTM.

Traditional math is the status quo in U.S. schools and predominates in U.S. textbooks. The most egregious distortion is when Baker writes, “Instead of having students memorize formulas and compute problems such as adding fractions, advocates of reform math encouraged students to develop their own visual representations of math concepts and use calculators to solve numerical tasks.”

In my 40 years of interacting with mathematics education professionals, I have never met a single one who does not want students to learn to add fractions. In fact, math education researchers around the world and here in the U.S. agree on the

“Fusion scientists consider their goal to be more tractable and relevant than ever before.”

—Richard Hazeltine, Miklos Porkolab,
Stewart Prager and Ronald Stambaugh

need for an inquiry-based approach that emphasizes conceptual understanding.

Steven Rasmussen

Publisher, Key Curriculum Press

Emeryville, Calif.

BAKER REPLIES: *For this article, I interviewed professional math educators, mathematicians and math teachers, many of whom self-identified as reform math or traditional math advocates—or somewhere in between. Some were off the spectrum entirely. The consensus was that reform math had indeed reshaped a generation of math instruction but that the pendulum had since swung back toward the center, with many educators now advocating both conceptual and skill-based strategies. The article spotlighted a few cases in which various stakeholders felt this balanced approach was missing. Regarding fractions: the issue is not that people “do not want students” to learn to add fractions but whether or not they are actually teaching them to do so.*

■ Plasma Display

Michael Moyer’s “Fusion’s False Dawn” might give the impression that informed scientists have become skeptical about fusion. This impression is incorrect. Fusion scientists consider their goal to be more tractable and relevant than ever before—and every one of several recently commissioned expert review committees has concurred, concluding that fusion energy should be actively pursued. Magnetic fusion devices have already in 1997 produced 16 million watts of fusion power. The challenges of plasma physics have been sufficiently met that we can confidently design

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LETTERS

devices that will make copious fusion reactions. ITER is one such device that will enable study of high-energy-gain plasma physics. Fusion researchers worldwide are discussing facilities from specialized experiments to a demonstration power plant to take on our next issues of materials, power extraction and tritium production in a reliable, continuously operating system.

Richard Hazeltine

Professor of physics, University of Texas at Austin

Miklos Porkolab

Director, Plasma Science and Fusion Center,

Massachusetts Institute of Technology

Stewart Prager

Director, Princeton Plasma Physics Laboratory

Ronald Stambaugh

Vice president, Magnetic Fusion Energy Program,

General Atomics

■ Where Credit Is Due

Having published on the biology of hydrogen sulfide (H_2S) since 1987, we believe that Rui Wang's "Toxic Gas, Lifesaver" had substantial factual inaccuracies and omissions. Studies by our group from as early as 1987 had already described some of the neurochemical effects of $NaHS$, an H_2S precursor. By 1990 we had reported the presence of detectable endogenous levels of H_2S in tissue and discussed the possibility that chronic exposure to sublethal concentrations of $NaHS$ may have biological effects, including the regulation of amino acid neurotransmitter levels. At that time, we had already raised the possibility of neuroprotection by H_2S . Wang was certainly aware of this work, because he cited several of these papers in a review he wrote in 2002. At about the time, another group, led by Sheldon Roth of the University of Calgary, was also studying the effects of H_2S on the respiratory system.

Samuel B. Kombian

Faculty of Pharmacy, Kuwait University

William F. Colmers

Professor of pharmacology,

University of Alberta

Wang suggests that he started the H_2S studies based on his own ideas, which is simply not true. In 1996 Kazuho Abe and I had already published the first paper on the positive biological effects of H_2S and demonstrated that cystathionine beta-synthase

can produce H_2S from cysteine in the brain and that H_2S facilitates the induction of hippocampal long-term potentiation by enhancing receptor activity.

Wang also claims that "we decided to look at an enzyme called cystathionine gamma-lyase (CSE) ... no one knew whether CSE existed in blood vessels." In 1997 Rumiko Hosoki, Norio Matsuki and I had already published our second paper on H_2S , in which we demonstrated that CSE is expressed in the thoracic aorta, the ileum and the portal vein and produces H_2S from cysteine. We also showed that H_2S relaxes these smooth muscles. Wang knew about this work, because he cited our papers in 2001—four years after ours.

Hideo Kimura

National Institute of Neuroscience, Tokyo

WANG REPLIES: *My article was not intended to be a complete academic chronicle of the discovery of the biological effects of H_2S . Many important milestones were not mentioned, but I by no means meant to deny or disregard these contributions, including those of Kimura. Bearing in mind the severe space constraints and general audience of Scientific American, I described how my personal interest in this topic evolved, and the article truthfully reflected that. Nevertheless, some important descriptions were lost during the editing process. For example, shortly before the article went to press, I specifically corrected the text to say [revision in bold], "Some earlier studies by Hideo Kimura in Japan suggested that H_2S is a neuromodulator, making neural circuits more or less responsive to stimuli." Unfortunately, I was told that there was no space for the change to be made.*

As to Kimura's concern about the statement regarding the presence of CSE in blood vessels, in a revision sent to my editor, I wrote, "But no one knew whether **the same** CSE existed in blood vessels. Sure enough, we found the enzyme there **and cloned it.**" These words in bold are important for stating our unique contribution, but they were omitted from the text because of a misunderstanding between the editor and me. Indeed, Kimura and his colleagues showed previously that H_2S relaxes blood vessels, but that did not prevent us or anyone else from reasoning that H_2S might have a similar effect to nitric oxide.

ERRATUM In "Fusion's False Dawn," Michael Moyer referred to William Thompson as the name of the physicist better known as Lord Kelvin. The correct spelling of his name is Thomson.

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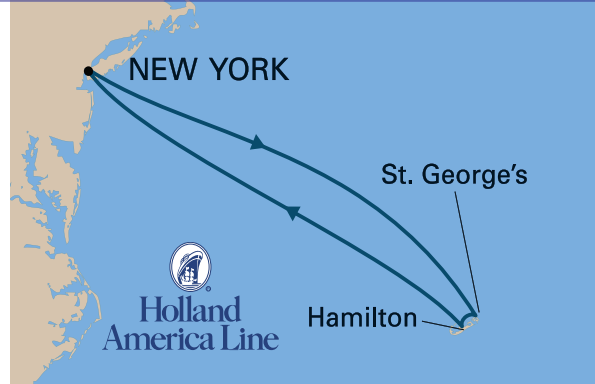
Friday & Saturday, May 6–7 (optional)

Friday, May 6, 2011 — We'll travel to the New York Hall of Science in Queens. Initially a pavilion for the 1964 World's Fair, the Hall of Science is now NYC's science and tech center. We'll speak with resident experts on the emerging field of scientometrics, the science of science.



Scientometrics will permit the forecasting of science developments, and help increase our ability to advocate for science. Then we're off to Manhattan, for a late afternoon social reception with *Scientific American* staffers.

Saturday, May 7, 2011 — Wake up in the city that never sleeps, and we'll meet midday at the Rose Center (left) for Earth and Space at the American Museum of Natural History. Get the inside scoop on research being done at the Rose Center, take a journey to the stars in the Hayden Planetarium, and get a new perspective on space with the Scales of the Universe. After our astronomy sojourn, we'll reconvene in mid-town Manhattan for an early evening social reception.



Cruise prices vary from \$799 for an Inside Stateroom to \$2,899 for a Full Suite, per person. For those attending our program, there is a \$1,275 fee. Government taxes, port fees, and InSight Cruises' service charge are \$169 per person. For more info contact Neil at 650-787-5665 or neil@InSightCruises.com

Listed below are the 15 sessions you can participate in while we're at sea. For a full class descriptions visit www.InSightCruises.com/SciAm-9

VIRTUAL WORLDS

Speaker: **Jeremy Bailenson, Ph.D.**

- Buying and Selling 1's and 0's: How Virtual Reality Changes Marketing
- Virtual Bodies and the Human Identity: The Proteus Effect
- Transformed Social Interaction in Virtual Worlds



BRAIN DIMENSIONS

Speaker: **Nancy C. Andreasen M.D., Ph.D.**

- The Brain's Odyssey through Life: Development and Aging Across the Lifespan
- The Creative Brain: The Neuroscience of Genius
- Venus vs. Mars or the Age of Androgyny? Gender and the Brain

THE INQUIRING PHYSICIST

Speaker: **Lawrence Krauss, Ph.D.**

- Quantum Man: Richard Feynman and Modern Science
- Hiding in the Mirror: The Mysterious Allure of Extra Dimensions
- An Atom from the Caribbean

RATIONAL THOUGHT — AND NOT

Speaker: **Michael Shermer, Ph.D.**

- The Bermuda Triangle and Other Weird Things that People Believe
- Why Darwin Matters: Evolution, Intelligent Design, and the Battle for Science and Religion
- The Mind of the Market: Compassionate Apes, Competitive Humans, and Other Lessons from Evolutionary Economics

ARCHAEOLOGY/ANTHROPOLOGY

Speaker: **Jerald T. Milanich, Ph.D.**

- Belle Glade Cultures — Secrets from 500 BC to AD 1700
- Documenting Florida's Seminoles — Adventure Behind the Scenes
- Archaeology of the Spanish Colonial Southeast U.S. After 1492

CST# 2065380-40



Live Births ■ Dangerous Skies ■ King of Beers

Compiled by Daniel C. Schlenoff

JULY 1960

INFANT MORTALITY—"The death rate of U.S. infants, after a long and precipitous decline, has leveled off in the last few years, according to a study by Iwao M. Moriyama of the National Office of Vital Statistics. In some states it has even risen slightly, after reaching an all-time low of 26 per 1,000 live births in 1956. Most of the reduction in mortality of children under one year of age is attributable to control of infectious diseases, primarily influenza and pneumonia. In 1946, when penicillin became available to the public, the death from infectious diseases dropped about 30 per cent. However, infectious diseases still account for about half of the deaths among infants between one month and one year old. The death rate for younger infants reflects the heavy toll taken by noninfectious conditions such as congenital malformations, birth injuries, postnatal asphyxia and premature births."

JULY 1910

ELEGANT FLIGHT—"The most important fact established by the Rheims aeronautical meet was the unquestionable superiority of the monoplane. Its success must be particularly gratifying to the French people. They seem to have realized that if its inherent fragility, as compared with the strong bridge-like form of the biplane, could be overcome, there were many advantages in the way of simplicity, reduction of head resistance, and small weight. Furthermore, the monoplane is attractive, both because it approximates so closely in appearance the form and structure of the birds, and because its simple and graceful lines give it a decided artistic advantage—this last being a strong recommendation to a people so aesthetic as the French."

THREAT FROM ABOVE—"With the rapid strides made in aerial navigation, it is eminently necessary that the army seriously

consider methods for counteracting the influence such craft will have in future wars. Two 1909 Cadillac '30s' were purchased by the Northwestern Military Academy in the spring of 1910. These automobiles of stock chassis are made to seat four cadets, and mount a Colt automatic rapid fire gun over the engine [see illustration]. The guns of .30 caliber deliver automatically 480 shots a minute, having a sighted range of

thinks that three or four will do twice as much. This is not the case at all. The only English patients I have ever known to refuse tea, have been typhus cases; and the first sign of their getting better was their craving again for tea. —Florence Nightingale"

LAGER BIER—"There are thousands of people in New York who seem to have quite forgotten the use of plain water as a beverage."

MILITARY AUTOMOBILE: A weapon against a fledgling threat from the air, 1910



2,000 yards. Results of experiments clearly demonstrate the rapidity of fire would be such that military automobiles must be reckoned with as weapons against airships and aeroplanes."

JULY 1860

NOTES ON NURSING—"When you see the natural and almost universal craving in English sick for their 'tea,' you cannot but feel that nature knows what she is about. But a little tea or coffee restores them quite as much as a great deal; and a great deal of tea, and especially of coffee, impairs the little power of digestion they have. Yet the nurse, because she sees how one or two cups of tea or coffee restores her patients,

age. In certain quarters of the city, 'lager' is the main staple of life, being for sale in almost every house, and the drink and even the food, of all the men, women and children. Lager is king! Lager is one of our most modern institutions. Ten years ago it was only a vulgar German word of unknown import; then it was looked upon as an insipid Dutch beer; but finally, a majority, perhaps, will vote that it is 'the people's nectar.' Certain witnesses have testified and courts have decided that lager is *not* intoxicating; but in view of the fact that a pint of lager contains as much alcohol as an ordinary glass of brandy, it might be suspected that those witnesses had indeed been indulging in lager just at the time they needed their sober judgment."

It's not the advice you'd expect. Learning a new language seems formidable, as we recall from years of combat with grammar and translations in school. Yet infants begin at birth. They communicate at eighteen months and speak the language fluently before they go to school. And they never battle translations or grammar explanations along the way.

Born into a veritable language jam-boree, children figure out language purely from the sounds, objects and interactions around them.

Their senses fire up neural circuits that send the stimuli to different language areas in the brain. Meanings fuse to words. Words string into structures. And language erupts.

Three characteristics of the child's language-learning process are crucial for success:

First, and most importantly, a child's natural language-learning ability emerges only in a speech-soaked, immersion environment free of translations and explanations of grammar.

Second, a child's language learning is dramatically accelerated by constant feedback from family and friends. Positive correction and persistent reinforcement nurture the child's language and language skills into full communicative expression.

Third, children learn through play, whether it's the arm-waving balancing act that announces their first step or the spluttering preamble to their first words. All the conversational chatter skittering through young children's play with parents and playmates—"...what's this..." "...clap, clap your hands..." "...my ball..."—helps children develop language skills that connect them to the world.

Adults possess this same powerful language-learning ability that orchestrated our language success as children. Sadly, our clashes with vocabulary drills and grammar explanations force us to conclude it's hopeless. We simply don't have "the language learning gene."

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ENERGY & ENVIRONMENT

Lasting Menace

Gulf oil-spill disaster likely to exert environmental harm for decades **BY DAVID BIELLO**

MORE THAN 20 YEARS after the *Exxon Valdez* foundered off the coast of Alaska, sea otters still dig up oil in their hunt for clams in Prince William Sound. Nearly 25 years after an oil storage tank ruptured near mangrove swamps and coral reefs of Bahia Las Minas in Panama, oil slicks still form in the water. And some 40 years after the fuel-oil barge *Florida* ran aground off Cape Cod, the muck beneath the marsh grasses makes the area smell like a gas station.

Similar damage may be in store for the U.S. Gulf coast, given that millions of gallons of light sweet crude spewed from BP's broken well 1,500 meters down and approximately 65 kilometers off the Louisiana coast. Its oil-drilling rig Deepwater Horizon exploded on April 20, and efforts to cap the flow—estimated to be 200,000 to a few million gallons a day during the weeks right after the accident—suffered setbacks and delays. All the oil released, which could ultimately exceed the *Valdez* spill several times over, could compromise wildlife and local livelihoods for years.

The toxic compounds in oil vary, but the most worrisome are polycyclic aromatic hydrocarbons (PAHs), such as naphthalenes, benzene, toluene and xylenes. All can sicken humans, animals and plants. "These hydrocarbons are particularly relevant if inhaled or ingested," says environmental toxicologist Ronald J. Kendall of Texas Tech University. "In the bodies of organisms such as mammals or birds, these aromatic hydrocarbons can be transformed into even more toxic products, which can affect DNA." The mutations that might result could lead to reduced fertility, cancer and other problems.

Not all the PAHs become an environmental threat, though. Thanks to evaporation, oil that reaches the surface loses at least 20 to 40 percent of the original hydrocarbons. "Evaporation is good; it selectively removes a lot of compounds we'd rather not have in the water," says marine chemist Christopher M. Reddy of the Woods Hole Oceanographic Institution. The oil also emulsifies, forming mousse—a frothy mix of hydrocarbons and water—or clumps into so-called tar balls.

But to scientists' surprise, plumes of oil extending several kilometers were floating roughly 1,000 meters beneath the surface, where the toxic compounds are literally washing off the oil and contaminating the water. Those components "can be more pervasive in finding ways to infiltrate a salt marsh" and impact wildlife, Reddy says. And there's a lot of wildlife to impact: some 16,000 species of plants and animals live in the Gulf of Mexico, according to marine biologist Thomas Shirley of Texas A&M University. Many of their habitats "are at risk of being affected, but we don't have any direct way to know which ones or in what amount," remarked marine biologist Jane Lubchenco, director



SEA SICKNESS: Vast oil slicks have formed in the Gulf of Mexico after the explosion of BP's Deepwater Horizon drilling rig. The oil's toxic hydrocarbons could pose environmental health risks for decades.

of the National Oceanic and Atmospheric Administration, at a May 12 press conference on the spill.

In the area by the spill itself, "anything that's in the upper water column is going to be exposed" to oil chemicals, Shirley says. That's bad news for the millions of zooplankton out there, and the contamination could ultimately end up having cascading effects up the food chain. "If you start removing pieces of this big food web out there, what's going to happen?" Shirley asks. "We don't really know, but probably not good things."

In regard to long-term damage, researchers worry most about landfall. "Once the oil, because of high tides or high winds, gets into the coastal wetland, it gets trapped in the sediment," notes

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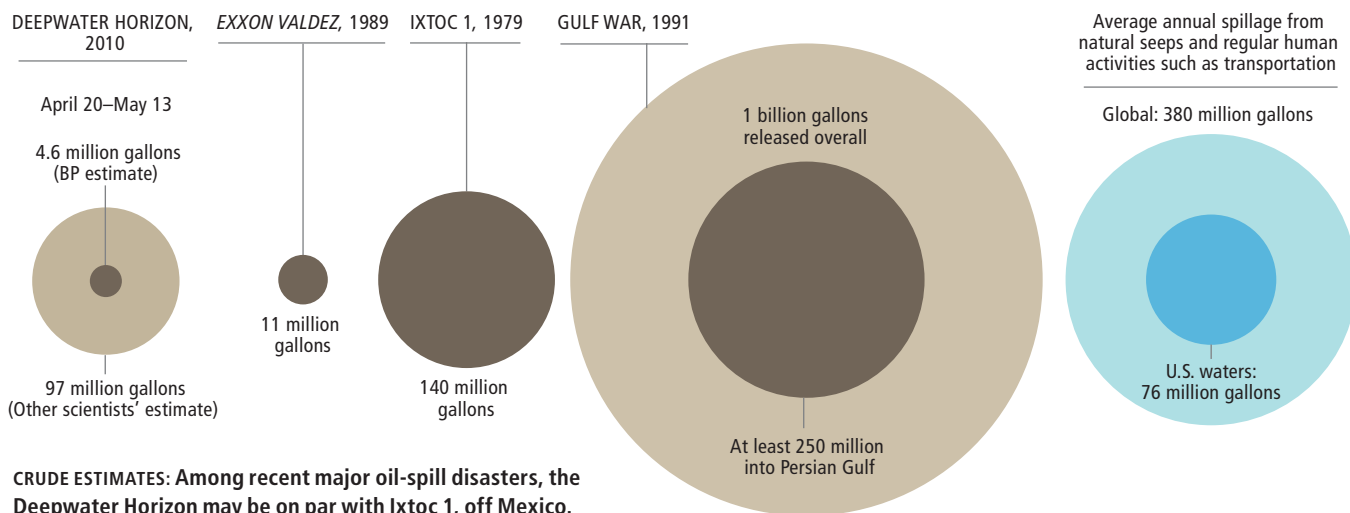
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Héctor M. Guzmán of the Smithsonian Tropical Research Institute in Panama, who studied the effects of the 1986 spill off Panama. “Then for decades you continue to see oil coming back out.” Particularly critical are marshes, which are nurseries for wildlife ranging from fish to birds; contamination there could damage embryos and affect a species for generations.

Whether the oil can be kept out of the wetlands comes down to one thing: the

weather. Rough seas would swamp the booms keeping oil off the coast. “A hurricane or even just a tropical depression could be catastrophic,” Kendall emphasizes. “It will push oil into places that it’s difficult to clean up.”

Of course, everyone hopes that the oil can be removed or dissipated before that happens. Certainly the warmer conditions of the Gulf of Mexico will help bacteria and other natural forces more quickly de-

grade the oil than in the spill at Prince William Sound. And early on workers used hundreds of thousands of gallons of chemical dispersants to help break up the slick. The dispersants themselves carry their own risks and toxicity, which have many environmentalists concerned about their potential impact. Given the choices, NOAA’s Lubchenco probably summed it up best: “When an oil spill occurs, there are no good outcomes.”

RESEARCH & DISCOVERY

Our Inner Neandertal

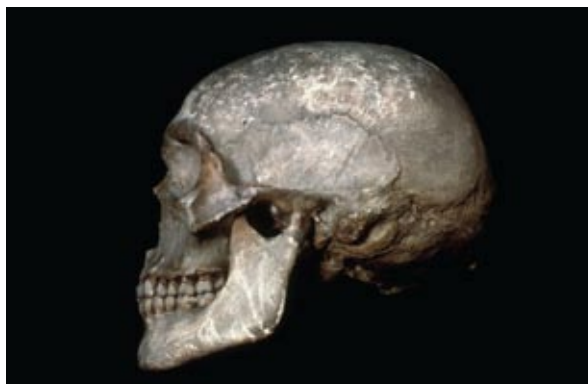
Genome analysis indicates Neandertals and modern humans interbred **BY KATE WONG**

UP TO 4 percent of the DNA of people today who live outside Africa came from Neandertals, the result of interbreeding between Neandertals and early modern humans. That conclusion comes from scientists led by Svante Pääbo of the Max Planck Institute for Evolutionary Anthropology in Leipzig, Germany, who pieced together the first draft of the Neandertal genome—which represents about 60 percent of the entire genome—using DNA obtained from three Neandertal bones that come from Vindija cave in Croatia and are more than 38,000 years old.

The evidence that Neandertals contributed DNA to modern humans came as a shock to the investigators, who published their findings in the May 7 *Science*. “First I thought it was some kind of statistical fluke,” Pääbo remarked during a press teleconference on May 5. The finding contrasts sharply with his previous work. In 1997 he and his colleagues sequenced the first Neandertal mitochondrial DNA. Mitochondria are the cell’s energy-generating organelles, and they have their own DNA,

which is distinct from the much longer DNA sequence that resides in the cell’s nucleus. Their analysis revealed that Neandertals had not made any contributions to modern mitochondrial DNA. Yet because mitochondrial DNA represents only a tiny fraction of an individual’s genetic makeup, the possibility remained that Neandertal nuclear DNA might tell a different story. Still, additional genetic analyses have typically led researchers to conclude that *Homo sapiens* arose in Africa and replaced the archaic humans it encountered as it spread out from its birthplace without mingling with them—the Out of Africa replacement scenario, as it is known.

But mingle they apparently did. When Pääbo’s team looked at patterns of nuclear genome variation in present-day humans, it identified 12 genome regions where non-Africans exhibited variants that were not seen in Africans and that were thus candidates for being derived from the Neandertals, who lived not in Africa but Eurasia. Comparing those regions with the same regions in



FRIENDS AND LOVERS? DNA analysis shows that anatomically modern humans (*top*) mated with Neandertals (*bottom*). Some geneticists suspect that they may have interbred with other archaic humans, such as *Homo erectus*, as well.

the newly assembled Neandertal sequence, the researchers found 10 matches, meaning 10 of these 12 variants in non-Africans came from Neandertals. The contributions do not seem to encode anything particularly important from a functional standpoint, however.

Intriguingly, the researchers failed to detect a special affinity to Europeans—a link that might have been expected given that Neandertals seem to have persisted in Europe longer than anywhere else before disappearing around 28,000 years ago. Rather the Neandertal sequence was equally close to sequences from present-day people from France, Papua New Guinea and China. By way of explanation, the investigators suggest that the interbreeding occurred in the Middle East between 50,000 and 80,000 years ago, before moderns fanned out to other parts of the Old World and split into different groups.

Intermixing does not surprise paleoanthropologists who have long argued on the basis of fossils that archaic humans, such as the Neandertals in Eurasia and *H. erectus* in East Asia, mated with early moderns and can be counted among our ancestors—the so-called multiregional evolution theory of modern human origins. The detection of Neandertal DNA in present-day people thus comes as welcome news to these scientists. “It is important evidence for multiregional evolution,” com-

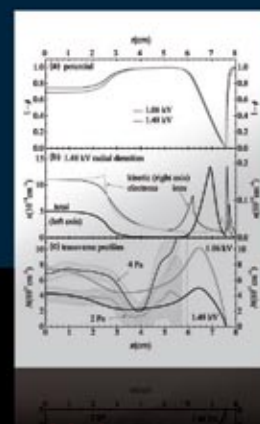
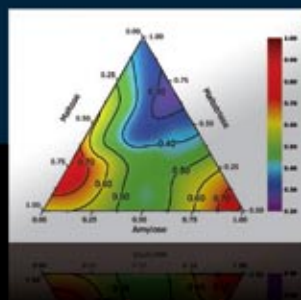
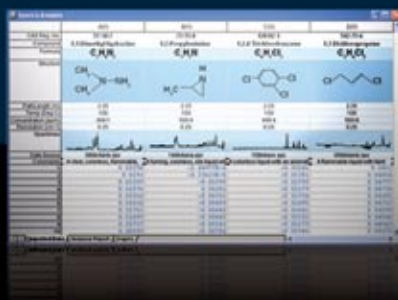
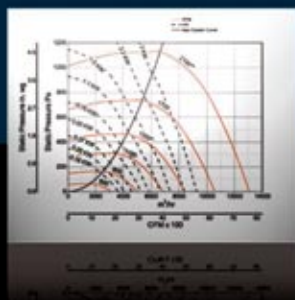
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ments Milford H. Wolpoff of the University of Michigan at Ann Arbor, the leading proponent of the theory.

In a prepared statement, Out of Africa theorist Christopher B. Stringer of the Natural History Museum in London acknowledged that the genome results show that “many of us outside of Africa have some [Neandertal] inheritance.” But Stringer maintains that the origin of our species is mostly an Out of Africa story. Population geneticist Laurent Excoffier of the University of Bern in Switzerland agrees, noting that the alleged admixture did not continue as moderns moved into Europe. “In all scenarios of speciation, there is a time during which two diverging species remain interfertile,” he explains.

In addition to illuminating how early humans interacted, the Neandertal genome is helping to indicate which parts of the modern human genome separate us from all other creatures. Thus far Pääbo’s group has identified a number of modern human genome regions containing sequence variation that is not seen in Neandertals and that may have helped modern humans adapt. Some of these regions are involved in cognitive development, sperm movement and the physiology of the skin. But exactly how these slight changes to the modern human sequence affected the functioning of these genome regions remains to be determined. Says Pääbo: “This is just the beginning of the exploration of human uniqueness that is now possible.”

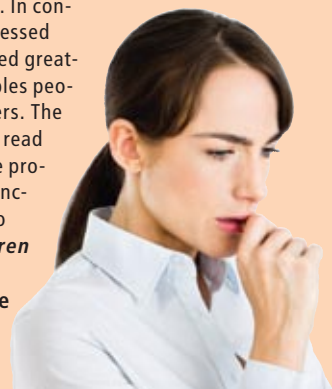
Under Threat, Women Bond and Men Withdraw

Under stress, we fight or flee, or so scientists have long preached. But this response may really be just a guy thing. New evidence shows how, unlike men, women under stress “tend and befriend,” engaging in nurturing and social networking.

At the Cognitive Neuroscience Society 2010 annual meeting in Montreal, psychologist Mara Mather of the University of Southern California and her colleagues asked male and female volunteers to place their hand in ice water, which makes the stress hormone cortisol shoot up. Then they looked at angry or neutral faces while lying inside a brain scanner.

Men showed less activity in a key face-processing region of the brain than the unstressed men did, suggesting that their ability to evaluate facial expressions declined. In contrast, the region was more active in stressed women. Moreover, these women showed greater activity in the brain circuit that enables people to understand the emotions of others. The enhanced ability of stressed women to read faces and empathize could underlie the propensity to bond under trying circumstances, which may have evolved as a way to protect offspring. —*Ingrid Wickelgren*

READY TO BOND? Stressed women have greater activity in the areas of the brain that are involved in empathy.



Damp Rocks from Space

Icy discovery bolsters view that asteroids delivered water to Earth **BY JOHN MATSON**

AN ASTEROID CIRCLING the sun between Mars and Jupiter harbors water ice and organic compounds on its surface—the first time such components have been discovered on asteroids. Those traits had been associated with comets, which spring from colder, more distant reservoirs in the

solar system. The finding supports the notion that asteroids could have provided early Earth with water for its oceans as well as some of the prebiotic compounds that allowed life to develop.

Two teams reported complementary observations of the 200-kilometer-wide asteroid, known as 24 Themis, in the April 29 *Nature*. (SCIENTIFIC AMERICAN is part of Nature Publishing Group.) Both groups saw infrared absorption features indicating a thin coating of frost, along with unidentified organic compounds. “They have found something that a lot of people, including myself, have been chasing in the solar system for a long time,” says Dale Cruikshank, a planetary scien-

tist at the NASA Ames Research Center.

The asteroid is intriguing in part because it occupies a similar orbit to so-called main-belt comets—and likely stems from the same parent body. Main-belt comets reside in the asteroid belt but feature cometlike tails thought to arise from sublimating ice. These newly discovered main-belt comets, and now Themis, “are very interesting objects and potentially one of the sources of Earth’s oceans,” Cruikshank says.

University of Central Florida astronomer Humberto Campins, a co-author of one of the studies, says other asteroids may harbor ice as well. “Or it could be unique to Themis,” Campins says. “We don’t know.”



ICE ON THE ROCK: Artist’s conception depicts asteroid 24 Themis alongside two smaller bodies, one of which is a comet that orbits within the asteroid belt. Measurements indicate that Themis harbors water ice, supporting the idea that asteroids seeded the Earth’s oceans.

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NEWS SCAN

Microscopic Giants

Mat of microbes the size of Greece discovered on seafloor

BY KATHERINE HARMON

FORGET GARGANTUAN WHALES and hefty cephalopods—the real marine mammoths may be the mighty microbes. They constitute at least half, and perhaps up to 90 percent, of the oceans' total biomass, according to data gathered by the decade-long Census of Marine Life project.

The estimate comes courtesy of high-throughput DNA sequencing, which suggests that there might be as many as 100 times more microbe genera than previously assumed. The increase in genus and species also raises the estimate of individual microbes. A single liter of seawater, once thought to contain about 100,000 microbes, can actually hold more than one billion, the census scientists reported in April.



OCEAN'S ABUNDANCE: Microbe called *Culex-iregiloricus trichiscalida* was discovered on the seafloor off the coast of Africa by the ongoing Census of Marine Life project.

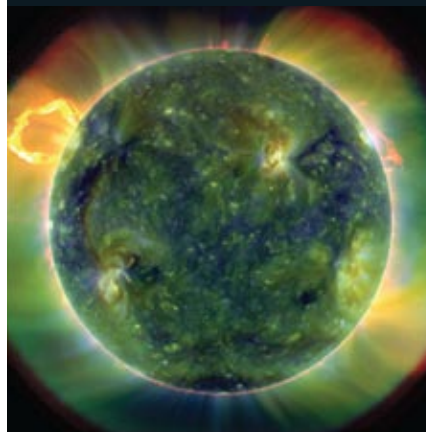
The tiny creatures can join together to create some of the largest masses of life on the planet. Census scientists found one such seafloor mat off the Pacific coast of South America that is roughly the size of Greece.

Despite their small individual size, microbes play a big role in the planet's climate. They help to turn atmospheric carbon dioxide into usable carbon, as well as oxygenating sediment and cy-

cling nutrients in the ocean. But little is known about these creatures' susceptibility to shifts in temperatures, dissolved gases and acidity, which are predicted to occur with climate change. Researchers will present the full census in October in London.

Eye-Candy Solar Science

A new sun-studying satellite had its coming-out party in April, with the release of early imagery and videos. The Solar Dynamics Observatory, launched by NASA in February, returns 16-megapixel images of the sun on a nearly continuous basis, splits the sun's emissions into its individual wavelengths, tracks the propagation of waves across the sun's surface and maps the ever shifting solar magnetic field. The photograph here is an extreme ultraviolet image of the sun taken on March 30. False colors trace different gas temperatures: reds are relatively cool (about 60,000 degrees); blues and greens are hotter (at least one million degrees).



With all that information, scientists think that the observatory could do for heliophysics what the Hubble Space Telescope has done for astrophysics in general.

—John Matson

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MEDICINE & HEALTH

Putting Addiction to Bed

Sleep drugs that block wakefulness may subdue cravings, too

BY CHRISTINE SOARES

A RESTFUL NIGHT'S SLEEP might make a cup of coffee less of a desperate need first thing in the morning. But pharmaceutical companies are looking into whether the latest pills to promise sound, natural sleep could also play an active role in overcoming even the most powerful addictions.

The new sleep aids block the activity of brain peptides called orexins. These tiny proteins keep us wide awake and attentive during the day, and they also gov-

ern some stimulating effects of addictive drugs. Orexins do not cause addiction or relapse directly, but neither happens without the peptides' participation.

The intriguing connection between sleep and addiction has long been observed in people who suffer from narcolepsy—a disorder that causes sudden-onset sleep. Although narcoleptics were sometimes treated with potent amphetamines to help them stay awake, they never became addicted to the drugs. By 1998 genetic detective work had traced the cause of narcolepsy to mutations in the genes for orexins or their receptors—discoveries that revealed both the peptides' existence and their critical role in keeping the brain awake. Efforts to turn those insights into novel insomnia treatments have led to several compounds that are now in late-stage clinical trials.

The same companies developing these sleep aids are also investigating orexins' role in addiction through research in animals. In a recent study Davide Quarta and his co-workers at Glaxo-SmithKline Medicines Research Center in Verona, Italy, confirmed that when the company's experimental orexin blocker SB-334867 was administered to rats along with amphetamine their brains released less dopamine



EYES WIDE OPEN: A target in insomnia studies, peptides called orexins, which keep the brain awake, might also point to new ways to treat addictions.

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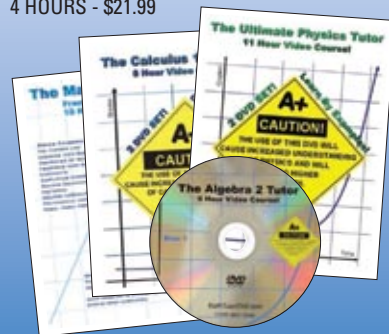
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and they became less sensitized to the stimulant than controls did, even with repeated doses. Sensitized neurons grow extra receptors for the craved drug, demanding more of it to achieve stimulation, thereby fueling a cycle that leads to addiction.

John J. Renger and his colleagues at Merck also showed that a different experimental orexin blocker, administered with amphetamine to rats, prevented sensitization. In the same study, the company's dual orexin-receptor antagonist (DORA), administered along with nicotine to rats that were previously addicted to nicotine, prevented the animals from relapsing.

"What we showed was not that orexins are a target of amphetamine," Renger explains, "because we know amphetamine targets dopamine." The brain's release of orexins in response to the stimulants, however, enhances dopamine's downstream activities that lead to sensitization and addiction. "Orexin sets the tone," Renger says, that enables those brain changes to occur.

As narcolepsy illustrates in the extreme, a lack of orexin removes a barrier to sleep. For that reason, the new orexin-

blocking sleep aids may facilitate more natural slumber than current sleeping pills, which depress brain activity generally and therefore have to fight "wake" signals, including orexin.

Stimulant drugs may produce a similarly unnatural imitation of normal stimuli, Renger speculates, which could explain why orexins play a role in facilitating the dopamine-driven learning and reward processes that lead to addiction. The animal studies indicate that administering orexin blockers with a stimulant drug could facilitate unlearning the addiction, too.

The companies have not announced plans to develop orexin blockers for substance abuse treatment, but Renger notes that once the sleep aids reach the market, they may help toward that end just by facilitating a good night's sleep. "There's evidence out there that one of the major reasons for alcoholics to relapse is insomnia," he explains, "because they relied on it to help them get to sleep." The orexin-blocking sleeping pills might provide a better-quality sleep than alcohol-induced unconsciousness. Whether they are the first sleeping pills guaranteed not to be addictive remains to be seen.

Heartburn Headache

Overuse of a popular acid blocker poses health risks

BY MELINDA WENNER MOYER

IN 2008 AMERICANS spent more than \$14 billion on heartburn treatments called proton pump inhibitors—such as Nexium, Prevacid and Protonix—making them second only to lipid regulators as the best-selling drug class in the country. But recent research suggests that the popularity of these drugs in part results from unnecessary prescriptions that may be putting millions of people at risk. Long-term use has been linked to withdrawal symptoms, an increased risk of bacterial infection, hip fracture and even possibly nutritional deficiencies.

Proton pump inhibitors, or PPIs, work just as their name implies: they block an

enzyme system in the stomach's cells essential for pumping out acid. Although they are meant to treat only gastroesophageal reflux and peptic ulcer disease, "a number of people who have gastrointestinal symptoms that are not due to acid are given PPIs," perhaps because of misdiagnoses or because "the physician didn't have any better alternative," says Colin W. Howden, a gastroenterologist at the Northwestern University School of Medicine.

Doctors also give PPIs to hospital patients who have serious injuries to prevent gastrointestinal bleeding and stress ulcers. But not only are such prescriptions questionable—only one intensive care pa-

tient is saved from serious bleeding for every 900 treated—they are also frequently given to patients who do not need them, despite the fact that the American Society of Health System Pharmacists released guidelines in 1999 delineating who specifically to treat. “This spilled out into, ‘Let’s do this for all or most of our hospitalized patients,’ ” explains Joel Heidelbaugh, an associate professor of family medicine at the University of Michigan at Ann Arbor. He co-authored a 2006 study reporting that his university’s health system annually spends about \$110,000 on unnecessary PPI prescriptions. A more recent 2009 study published in the *American Journal of Medicine* concluded that up to 60 percent of PPI prescriptions for hospitalized patients are unnecessary.

Bizarrely, Heidelbaugh has also found that people admitted to hospitals for gastrointestinal symptoms are less likely to be put on PPIs than people admitted for other problems, such as rheumatological dis-

orders. And approximately one third of patients who start taking the drugs refill their prescriptions without needing to. “We know that people are put on them and left on them; we know it costs something; and we know it’s not without risk,” Heidelbaugh says.

Indeed, multiple studies suggest that long-term use of PPIs can cause problems. A 2006 study in the *Journal of the American Medical Association* reported that people taking long-term, high-dose proton pump inhibitors are 2.65 times as likely as controls to experience hip fractures, possibly because the drugs inhibit calcium absorption. By increasing the pH of the stomach, PPIs also boost the risk of infection: studies published in *JAMA* in 2004 and 2005 reported that subjects on acid-suppressing drugs are nearly twice as likely to develop pneumonia, and nearly three times as likely to acquire a potentially deadly infection from the bacterium *Clostridium difficile*, as unmedicated

subjects (although the overall risk is low). And in March researchers reported in *Clinical Gastroenterology and Hepatology* that half the subjects taking PPIs at an Italian hospital, compared with only 6 percent of healthy subjects not taking the drugs, suffered from an infection of the small intestine caused by bacteria from the colon. The condition can trigger diarrhea and impede nutrient absorption.

Most worrisome, long-term use of PPIs may cause the very symptoms the drugs are designed to treat. In a 2009 study published in *Gastroenterology*, researchers split 120 healthy patients into two groups. Half received a placebo for 12 weeks, while the other half received a PPI for eight weeks, followed by a placebo for the last four weeks. At the end of the trial, 22 percent of subjects who had taken the drugs reported suffering from heartburn and acid reflux, compared with only 2 percent of those who had never taken the drugs.

Howden points out that because the tri-

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al was conducted in healthy subjects, knowing whether PPIs would worsen symptoms in patients with existing acid problems is impossible. But “there is no reason to believe that this should not be the case,” says trial co-author Peter Bytzer, a professor of medicine at the University of Copenhagen in Denmark. “I would even anticipate that the effects might be more pronounced in patients who already suffer

from heartburn.” And if that’s true, then no wonder PPIs are so popular, he says: they may well be addictive.

Currently no national move exists to curb PPI overuse, but “there are many efforts, mostly specific to institutions, to raise awareness about this issue and to try to limit nonjudicious PPI use,” Heidelberg says. The Carolinas Medical Center in Charlotte, N.C., saved about

\$100,000 in annual drug costs after setting such guidelines, and a similar move by St. Paul’s Hospital in Vancouver cut daily medication costs nearly in half without worsening clinical outcomes.

Melinda Wenner Moyer, based in New York City, writes about health and medicine. She described the heart risk from refined carbohydrates in the May issue.

TECHNOLOGY

Manipulation of the Crowd

New concerns about the trustworthiness of online ratings **BY MICHAEL MOYER**

WEB SITES SUCH AS Amazon, TripAdvisor and Yelp have long depended on customers to rate books, hotels and restaurants. The philosophy behind this so-called crowdsourcing strategy holds that the truest and most accurate evaluations will come from aggregating the opinions of a large and diverse group of people. Yet a closer look reveals that the wisdom of crowds may neither be wise nor necessarily made by a crowd. Its judgments are inaccurate at best, fraudulent at worst.

According to Eric K. Clemons, a professor of operations and systems management at the Wharton School of the University of Pennsylvania, online ranking systems suffer from a number of inherent biases. The first is deceptively obvious: people who rate purchases have already made the purchase. Therefore, they are disposed to like the product. “I happen to love Larry Niven novels,” Clemons says. “So whenever Larry Niven has a novel out, I buy it. Other fans do, too, and so the initial reviews are very high—five stars.” The high ratings draw people who would never have considered a science-fiction novel. And if they hate it, their spite could lead to an overcorrection, with a spate of one-star ratings.

Such negativity exposes another, more pernicious bias: people tend not to review things they find merely satisfactory. They evangelize what they love and trash things they hate. These feelings lead to a lot of one- and five-star reviews of the same product.

A controlled offline survey of some of these supposedly polarizing products revealed that individuals’ true opinions fit a bell-shaped curve—ratings cluster around three or four, with fewer scores of two and almost no ones and fives. Self-selected online voting creates an artificial

judgment gap; as in modern politics, only the loudest voices at the furthest ends of the spectrum seem to get heard.

This self-selection process manifests itself in other ways. In a 2009 study of more than 20,000 items on Amazon, Vassilis Kostakos, a computer scientist at the University of Madeira in Portugal, found that a small percentage of users accounted for a huge majority of the reviews. These super-reviewers—often celebrated with “Top Reviewer” badges and ranked against one another to encourage their participation—each contribute thousands of reviews, ultimately drowning out the voices of more typical users (95 percent of Amazon reviewers have rated fewer than eight products). “There is nothing to say that these people are good at what they do,” Kostakos says. “They just do a lot of it.” What appears to be a wise crowd is just an oligarchy of the enthusiastic.

The existence of super-reviewers has one unassailable advantage, though: they are rarely shills. The deliberate manipulation of review sites by people directly involved with a product—the author of the book, say—is one of the oldest and most difficult problems for online-rating communities to solve.

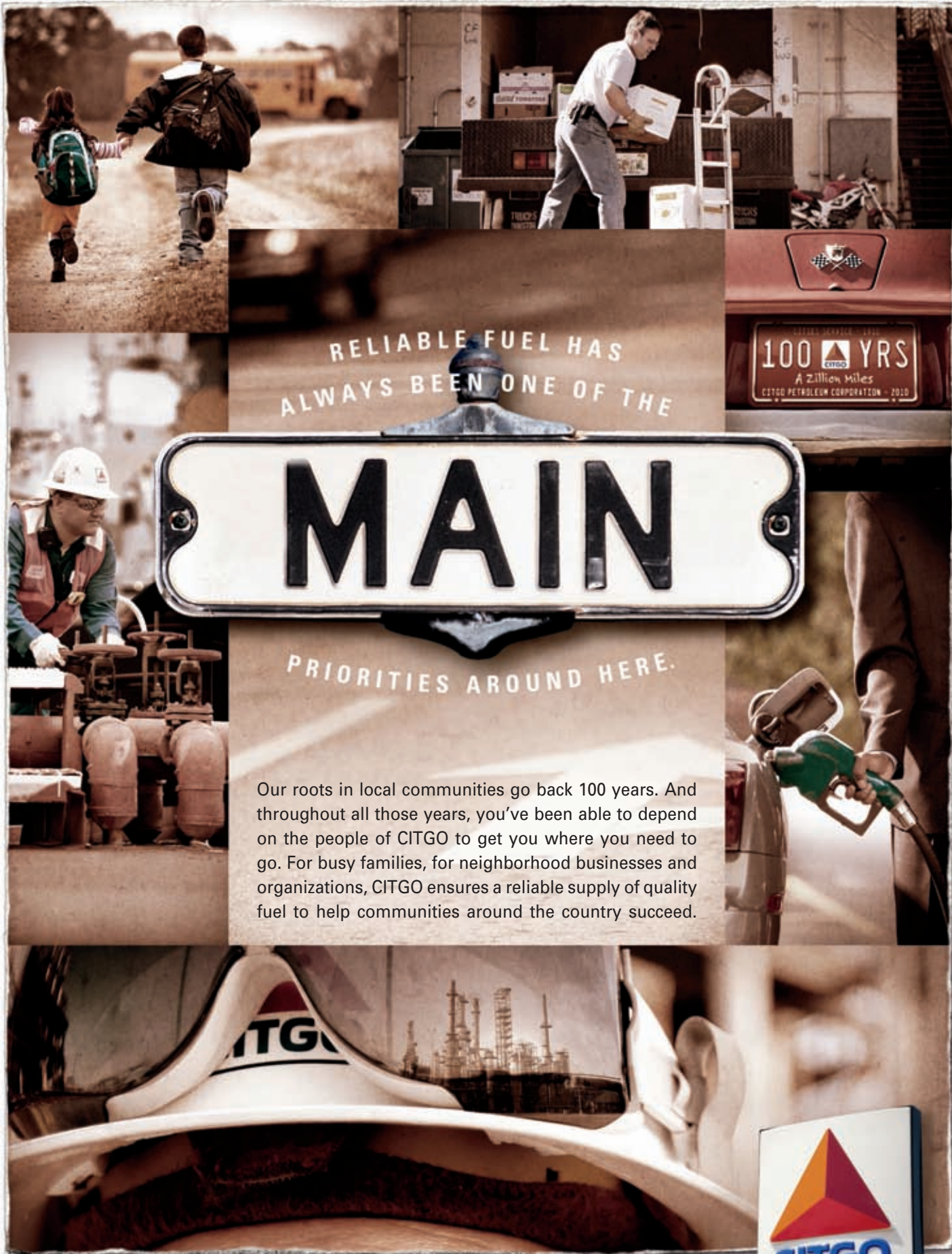
Some sites attempt to remove suspect posts using automated

filters that search for extremely positive or negative language, especially when the review comes from someone with a short résumé. But this lack of transparency can breed mistrust—or worse.

Consider the case of the local-business review site Yelp, which filters out suspect reviews. Its CEO and co-founder Jeremy Stoppelman defends the practice by pointing to classified advertisements placed by business owners offering payment for positive reviews. Yet some businesses suspect more sinister forces at



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work. Earlier this year a coalition of local business owners sued Yelp, accusing the company of running what amounted to a digital extortion racket. The lawsuit claims that sales representatives from Yelp would call businesses and make a simple offer: advertise with us, and we'll make negative reviews disappear.

The company vigorously denies the allegations and claims that any cuts are automated and coincidental. Still, Yelp has

refused to divulge how its filters operate, lest unscrupulous users employ that information to game the system. This lack of transparency has led to the perception that the company itself might be manipulating the playing field.

The system is not beyond repair, however. Clemons points to RateBeer.com, which has attracted some 3,000 members who have rated at least 100 beers each; all but the most obscure beers have been eval-

uated hundreds or thousands of times. The voluminous data set is virtually manipulation-proof, and the site's passionate users tend to post on all beers they try—not just ones they love or hate.

Of course, reviewing 1,000 beers is easier (and cheaper) than rating the same number of restaurants or hotel rooms. Until other sites amass the same amount of quality data, an old truism could be consumers' best advice: buyer beware.

Patent Still Pending

Green tech wilts under Patent Office scrutiny **BY LARRY GREENEMEIER**

LAST DECEMBER the U.S. Patent and Trademark Office began a pilot program to speed the emergence of green technology. The goal was to shave a year off the 40 months it typically took to evaluate a patent application. Yet the agency has approved only about one third of the requests it has received, disappointing inventors and even the Patent Office itself. The program's acceptance rate is "less than I would have expected," says Robert L. Stoll, the agency's commissioner for patents.

As of early May, only 335 of the 943 applications filed under the agency's Green Technology pilot program had qualified to jump to the front of the patent examination line. Applicants have been "aggressive" in their hopes of taking advantage of the fast-track program without necessarily meeting the program's requirements, Stoll explains.

In defining the requirements in the December 8, 2009, Federal Register, the USPTO stated that it is looking for inventions that fit into a number of broad buckets—addressing environmental quality, energy conservation, development of renewable energy, and greenhouse gas emissions reduction. It also listed 79 very specific classifications. Stoll acknowledges, however, that if the office is approving only one third of applications, "maybe we need to eliminate the class and subclass designations to open up the definition for green tech."

But it has been difficult to define what constitutes a patentable invention in this area. Most of the technology being developed to improve (or at least not harm) the environment is little more than an incremental change in devices already in use, says Eric P. Raciti, a partner at the Cambridge, Mass., law firm of Finnegan, Henderson, Farabow, Garrett & Dunner. Whereas anything that creates energy and reduces reliance on fossil fuels could be considered green, the actual technology that does the job often draws on an interdisciplinary set of components from other areas, explains Raciti, who worked for five years as an USPTO patent examiner.

The program to fast-track green patents "won't have a big impact" on the development of green technology, because so many of these technologies have already been patented, agrees Mark Bünger, a research director at Lux Research, a New York-based technology consulting firm. "I wouldn't oversell the importance of the green patent fast track," he states. The technologies that companies are trying to patent as green are typically only a small part of a larger process or project that may cut fossil-fuel consumption or otherwise help the environment, Bünger says, adding that "there will never be something like a killer app in clean technology" that stands completely on its own.

Not all have given up hope, especially start-up companies. "The ability to say



FLOWER POWER UNPLUGGED? A fast-track patent-approval system to encourage green technology is lagging, suggesting that its green-tech definitions may need rethinking.

that we're fast-tracked means that something is interesting here," says Tim Keating, vice president of marketing and field operations at Skyline Solar, a maker of high-gain solar arrays in Mountain View, Calif. "That certainly makes investors more comfortable, which means you get your money for a cheaper price and you spend less of your time raising that money."

Whether the fast-track program continues beyond its yearlong pilot phase will depend on several measures, Stoll says. They include how enthusiastic inventors are about using that program (the number of applications), how often inventors file legitimate green-tech applications, and the public's perception of the program.

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Terminate the Terminators

Robots are now a fact of war, but the prospect of androids that can hunt and kill on their own should give us all pause

BY THE EDITORS

When U.S. forces invaded Iraq in 2003, they fought a traditional war of human on human. Since then, robots have joined the fight. Both there and in Afghanistan, thousands of “unmanned” systems dismantle roadside IEDs, take that first peek around the corner at a sniper’s lair and launch missiles at Taliban hideouts. Robots are pouring onto battlefields as if a new species of mechanotronic alien had just landed on our planet.

It is not the first time that the technology of warfare has advanced more rapidly than the body of international law that seeks to restrain its use. During World War I, cannons shot chemical weapons at and airplanes dropped bombs on unsuspecting cities. Only later did nations reach a verdict on whether it was acceptable to target a munitions factory next to a primary school.

Something similar is happening today with potentially even more profound and disturbing consequences. As Brookings Institution analyst P. W. Singer describes in “War of the Machines,” starting on page 56, the rise of robots leads to the frightening prospect of making obsolete the rule book by which nations go to war. Armed conflict between nation states is brutal, but at least it proceeds according to a set of rules grounded both in international law and in the demands of military discipline. It is not true that anything goes in the heat of battle. “Such rules are certainly not always followed, but their very existence is what separates killing in war from murder and what distinguishes soldiers from criminals,” writes Singer in *Wired for War*, his recent popular book on the military robotic revolution.

Those rules are stretched to their breaking point when robots go to war. The legal and ethical questions abound. Who is accountable when a Predator’s missile hits the wrong target? Missiles from errant drones have already killed as many as 1,000 civilians in Iraq, Afghanistan and Pakistan. Does responsibility reside with a field commander in the Middle East where spotters identified the “target of interest”? Or should blame be apportioned to the “remote pilot” stationed at a military base near Las Vegas who launched the strike from 7,000 miles away? And what about a software engineer who might have committed a programming error that caused a misfire?

Considering rules of engagement for war-at-a-distance raises a surreal set of questions. Does the remote operator in Nevada re-

main a legal combatant—in other words, a legitimate enemy target—on the trip after work to Walmart or to a daughter’s soccer match? Would an increasingly sketchy line between warrior and civilian invite attacks on U.S. soil against homes and schools?

Remote-controlled robots are here to stay, and rules can be worked out to regulate their use. But the more serious threat comes from semiautonomous machines over which humans retain nothing more than last-ditch veto power. These systems are only a software upgrade away from fully self-sufficient operation. The prospect of androids that hunt down and kill on their own accord (shades of Terminator) should give us all pause. An automatic pilot that makes its own calls about whom to shoot violates

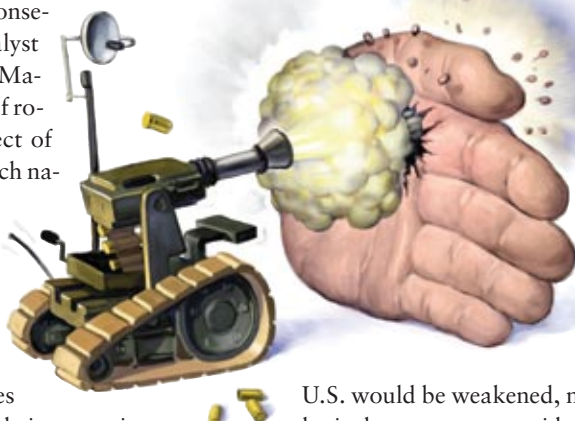
the “human” part of international humanitarian law, the one that recognizes that some weapons are so abhorrent that they just should be eliminated.

Some might call a ban on autonomous robots naive or complain that it would tie the hands of soldiers faced with irregular warfare. But although robots have clear tactical advantages, they carry a heavy strategic price.

The laws of war are an act not of charity but of self-interest; the

U.S. would be weakened, not strengthened, if chemical and biological weapons were widespread, and the same is true of robots. They are a cheap way to offset conventional military strength, and other nations and groups such as Hezbollah in Lebanon are already deploying them. The U.S. may not always be the leader in this technology and would be well advised to negotiate restrictions on their use from a position of strength. We can never put the genie back into the bottle, but putting a hold on further development of this technology could limit the damage.

The organization best placed to work toward a ban is the International Committee of the Red Cross, the guardian of the Geneva Conventions. A good starting point would be to convene a summit to consider armed, autonomous robots in the same framework as chemical and biological agents. The scientific community at large should get involved with this issue much as the Pugwash movement has worked toward nuclear arms control. Now is the time to take steps to ensure that a war of the machines remains nothing more than a science-fiction nightmare. ■





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Get Serious about Budget Deficits

Nations need to curb their public debt to avoid stifling future growth

BY JEFFREY D. SACHS



The continuing economic crisis in the U.S. and Europe is quickly sharpening the debate over public finances. Several countries have budget deficits around 10 percent of national income or larger, and their governments must show their publics and the financial markets that they have a plan for dealing with these unprecedented peacetime imbalances.

In the wake of the financial panic in late 2008, most economies adopted fiscal stimulus packages of spending increases and tax cuts in keeping with Keynesian ideas (which I cautioned about in my March 2009 column). Because consumer spending was falling, offsetting the decline through higher government spending or by stimulating private spending by tax cuts was considered necessary. Keynesian thinking presumes that the financial markets will readily buy government bonds to finance the stimulus.

It proved overoptimistic for many smaller European countries, most recently Greece. Potential investors looked ahead skeptically to governments' ability to service those debts through some combination of higher taxes and lower spending in the future. Consequently, the bond markets slammed the door on new financing by Greece early in 2010 and threatened to do the same for various other European countries, including the U.K.

So far the U.S. has not been similarly touched. Unlike Greece, the U.S. borrows in its own national currency; whereas the Greek government can run out of euros, the U.S. government cannot really run out of dollars as long as the Federal Reserve provides them. Of course, the fear in that case is not bankruptcy but that central bank financing of future deficits will stoke inflation.

Yet even if the markets agree to finance deficit spending, large-scale borrowing might not be wise.

Large deficits today mean that the public debt will rise sharply as a percent of national income. The ratio of U.S. debt to GDP will roughly double between 2007 and

2011, from around 37 percent to 70 percent. Even if the budget deficit is then reduced through spending cuts and tax increases, the costs of servicing the extra debt will remain and will distort the economy. Furthermore, awareness that today's budget deficits will eventually require spending cuts and tax increases at least blunts the short-term stimulus effects of the deficits. Households

may save rather than spend any tax cuts on the grounds that future taxes are rising. And higher interest rates caused by budget deficits may dampen any boost in private investment spending.

America's budget deficit challenge is worsened by the country's deep political division over the role of government. Tax increases are anathema, but contrary to common belief, there are few easy cuts in the budget for removing simple waste.

The biggest waste, I would suggest, lies in the Pentagon budget, which now stands at around 5 percent of GDP and finances two expensive wars, hundreds of overseas military bases, and overpriced service contracts and weapons systems. Yet no public consensus on a sharp reduction of military outlays exists.

Still less will there be an agreement on cutting civilian spending, the bulk of which is on Social Security, Medicare, Medicaid, food stamps and other mandated programs. Many categories of discretionary civilian spending—sustainable energy, R&D, infrastructure, higher education, global development and more—are chronically underfunded rather than laden with waste. The much disparaged earmarks, which do distort the budget, constitute only perhaps 1 percent of total budget spending or even less.

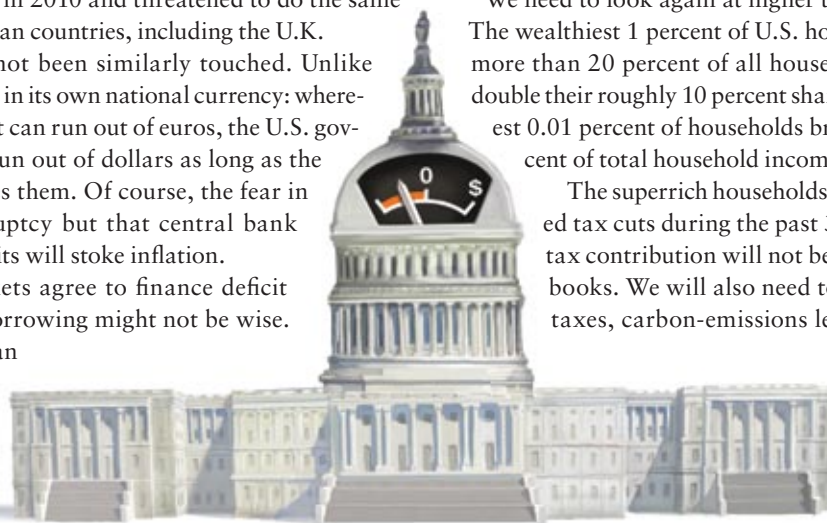
We need to look again at higher taxation of the superrich. The wealthiest 1 percent of U.S. households now take home more than 20 percent of all household income, more than double their roughly 10 percent share around 1980. The richest 0.01 percent of households brings home around 5 percent of total household income.

The superrich households have also enjoyed repeated tax cuts during the past 30 years. Their increased tax contribution will not be sufficient to balance the books. We will also need to look at higher gasoline taxes, carbon-emissions levies and perhaps even a national value-added tax. Yet the superrich households are the right place to begin to get our public finances back in order. ■

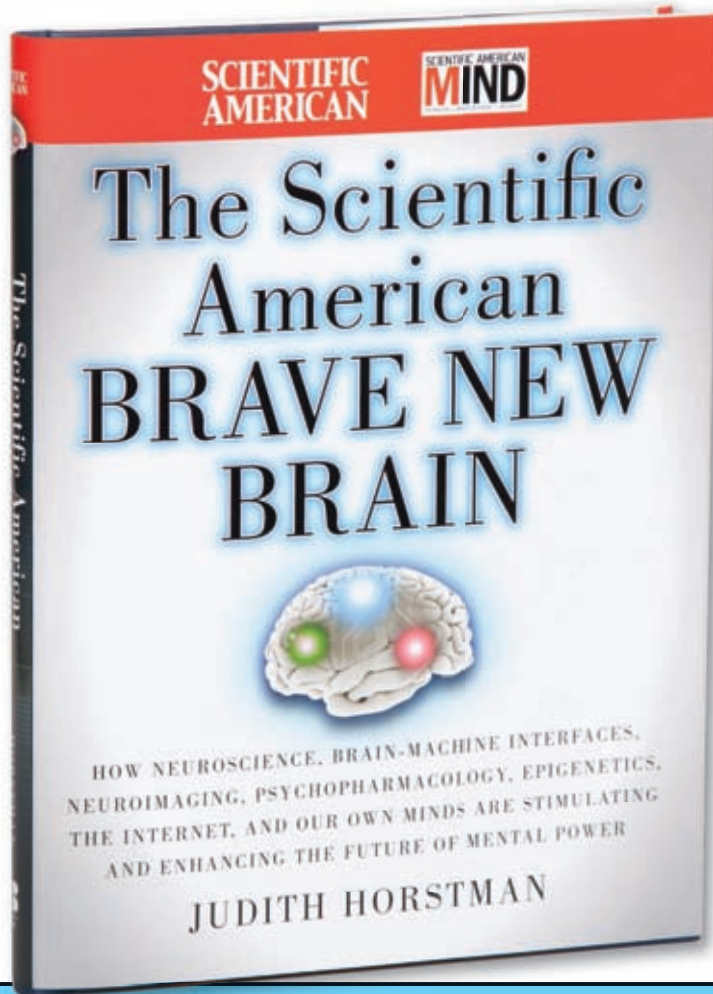
Jeffrey D. Sachs is director of the Earth Institute at Columbia University (www.earth.columbia.edu).



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When Scientists Sin

Fraud, deception and lies in research reveal how science is (mostly) self-correcting

BY MICHAEL SHERMER



In his 1974 commencement speech at the California Institute of Technology, Nobel laureate physicist Richard P. Feynman articulated the foundation of scientific integrity: “The first principle is that you must not fool yourself—and you are the easiest person to fool.... After you’ve not fooled

yourself, it’s easy not to fool other scientists. You just have to be honest in a conventional way after that.”

Unfortunately, says Feynman’s Caltech colleague David Goodstein in his new book *On Fact and Fraud: Cautionary Tales from the Front Lines of Science* (Princeton University Press, 2010), some scientists do try to fool their colleagues, and believing that everyone is conventionally honest may make a person more likely to be duped by deliberate fraud. Nature may be subtle, but she does not intentionally lie. People do. *Why* some scientists lie is what Goodstein wants to understand. He begins by debunking myths about science such as: “A scientist should never be motivated to do science for personal gain, advancement or other rewards.” “Scientists should always be objective and impartial when gathering data.” “Scientists must never believe dogmatically in an idea or use rhetorical exaggeration in promoting it.” “Scientists should never permit their judgments to be affected by authority.” These and many other maxims just do not reflect how science works in practice.

Knowing that scientists are highly motivated by status and rewards, that they are no more objective than professionals in other fields, that they can dogmatically defend an idea no less vehemently than ideologues and that they can fall sway to the pull of authority allows us to understand that, in Goodstein’s assessment, “injecting falsehoods into the body of science is rarely, if ever, the purpose of those who perpetrate fraud. They almost always believe that they are injecting a truth into the scientific record.” Goodstein should know because his job as the vice provost of Caltech was to investigate allegations of scientific misconduct. From his investigations Goodstein found three risk factors present in nearly all cases of scientific fraud. The perpetrators, he writes, “1. Were under career pressure; 2. Knew, or thought they knew, what the answer to the problem they were considering would turn out to be if they went to all the trouble of doing the

work properly; and 3. Were working in a field where individual experiments are not expected to be precisely reproducible.”

To detect fraud, we must first define it, and Goodstein does: “Research misconduct is defined as fabrication, falsification, or plagiarism in proposing, performing, or reviewing research, or in reporting research results.” Next there must “be significant departure from accepted practices of the scientific community.” Then, the misconduct must be “committed intentionally, or knowingly, or in reckless disregard of accepted practices,” and finally, as in any court of law, the fraud charge must be proved by a preponderance of evidence.

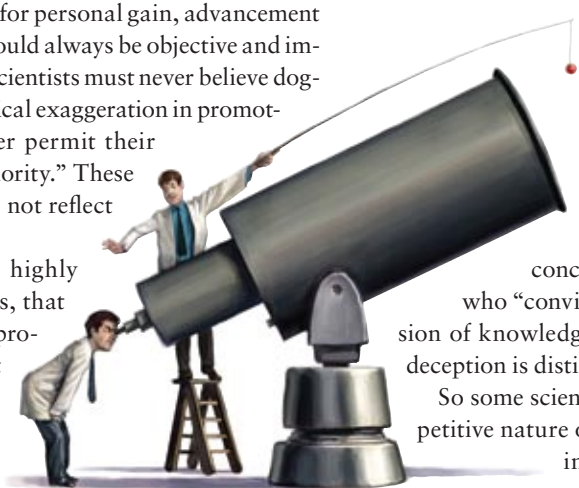
Clear-cut cases of fraud include the twin studies of British psychologist Cyril L. Burt (who faked so many twins that he had to fabricate additional twin researchers), the Sloan-Kettering Institute cancer researcher William Summerlin’s experiments on inducing healthy black skin grafts on white mice (which he was caught enhancing with a black felt-tipped pen), physicist Victor Ninov’s alleged discovery of element 118 (predicted by others so he faked data for its existence), and of course the famous Piltown Man hoax (which turned out to be the jaw of an orangutan dyed to look old). Other cases are not so clear. Martin Fleischmann and Stanley Pons’s “discovery” of cold fusion, Goodstein

concludes, was most likely a case of scientists who “convince themselves that they are in the possession of knowledge that does not in fact exist.” This self-deception is distinctly different from deliberate deception.

So some scientists sin, it’s true. Given the fiercely competitive nature of research funding and the hardscrabble intensity of scientific status seeking, it is surprising that fraud isn’t more rampant.

The reason that it is so rare (compared with, say, corruption in politics) is that science is designed to detect deception (of one’s self and others) through colleague collaboration, graduate student mentoring, peer review, experimental corroboration and results replication. The general environment of openness and honesty, though mythic in its idealized form, nonetheless exists and in the long run weeds out the cheats and exposes frauds and hoaxes, as history has demonstrated. ■

Michael Shermer is publisher of *Skeptic* magazine (www.skeptic.com) and author of *The Mind of the Market*.



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No Country Is an Island

Whether volcanic or nuclear, disasters anywhere in our interconnected world affect us all

BY LAWRENCE M. KRAUSS



This spring I was stranded in Europe for a week, a minor victim of Mother Nature, as most airports on the continent were closed after the eruption of the Eyjafjallajökull volcano in Iceland. This remote natural event did not result in a huge human death toll but still caused hundreds of millions of

dollars of lost revenue for almost all the world's major airlines. More important, it disrupted millions of people's lives.

Such is the nature of our modern interconnected society, where a catastrophe in one corner of the world can nonetheless affect almost immediately the livelihood and well-being of people around the globe.

The Icelandic eruption took on additional significance, following as it did the Nuclear Security Summit that President Barack Obama convened in Washington, D.C., to help begin to secure nuclear materials and to work toward combating global nuclear proliferation. For 40 years the world was focused on the possibility of mutually assured destruction and global annihilation, with literally thousands of nuclear weapons on hair-trigger alert, ready to be launched on the mere warning of an attack.

But the dangers facing the modern world are far more complex. The president has emphasized the devastating global economic and social impact that the explosion of even a single nuclear weapon in a major metropolis would have, beyond of course the tragic loss of human life. Moreover, as more countries in regions with rising geopolitical tensions seek to possess nuclear weapons, the likelihood of both nuclear terrorism and regional nuclear conflicts only continues to increase.

As the event in Iceland makes abundantly clear, "regional" is an illusion in the modern world. A recent set of scientific studies by Alan Robock of Rutgers University, Owen B. Toon of the University of Colorado at Boulder and their colleagues—reported on in journals ranging from *Science* to *Scientific American* (see the January 2010 issue)—demonstrates a more pernicious impact from even a limited nuclear exchange in what, for North Americans, would seem to be

a remote part of the world where natural disasters might be more easily and habitually ignored.

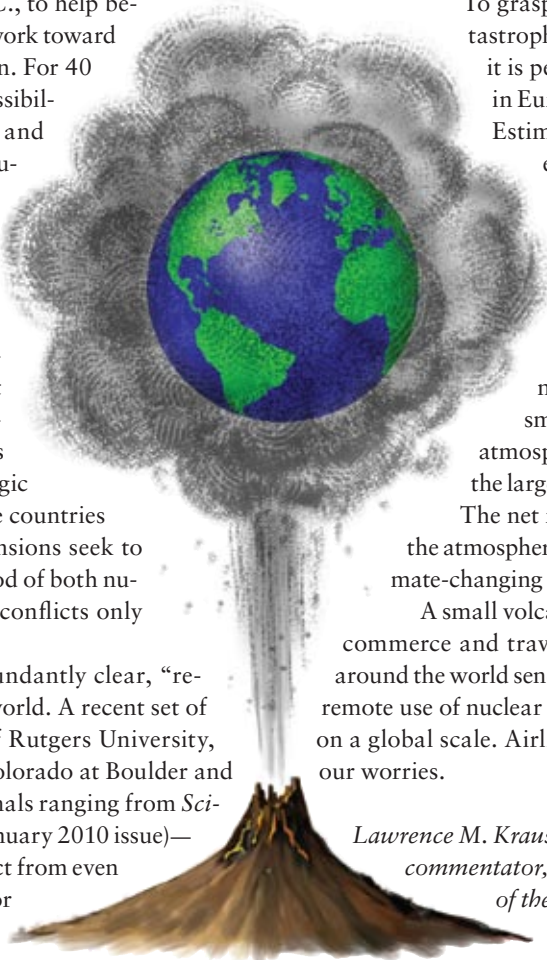
The studies conclude that a regional nuclear conflict between India and Pakistan that detonated merely 100 Hiroshima-size weapons (which are far smaller than many of those in current nuclear arsenals) not only could produce as many fatalities as World War II but also would drastically disrupt the planet's climate for at least a decade. Up to five million tons of smoke would rise above cloud level and within days form a global stratospheric smoke layer, which would for years block 7 to 10 percent of sunlight reaching the earth. Average surface temperatures could drop lower than they have at any time in the past millennium, significantly shortening growing seasons and reducing the average global precipitation.

To grasp the true magnitude of the human catastrophe from such a use of nuclear weapons, it is perhaps easiest to return to the situation in Europe after the Eyjafjallajökull eruption.

Estimates I have gleaned from various sources suggest that the volcano spewed perhaps a million tons of particulate matter into the atmosphere, only slightly smaller in magnitude than the amount predicted to result from a limited nuclear weapons exchange. But the particles of soot from the intense fires ignited by nuclear explosions are much smaller and therefore rise higher into the atmosphere. They also reflect more light than the larger silicon particles emitted by volcanoes. The net result is that this soot would remain in the atmosphere far longer and have a much greater climate-changing effect, affecting agriculture worldwide.

A small volcano in Iceland that was able to paralyze commerce and travel for hundreds of millions of people around the world sends a chilling message: even a limited and remote use of nuclear weapons anywhere will be devastating on a global scale. Airline cancellations would be the least of our worries. ■

Lawrence M. Krauss, a theoretical physicist and science commentator, is Foundation Professor and director of the Origins Initiative at Arizona State University (www.krauss.faculty.asu.edu).



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Is the Universe Leaking Energy?

Total energy must be conserved. Every student of physics learns this fundamental law. The trouble is, it does not apply to the universe as a whole **BY TAMARA M. DAVIS**

ENERGY CAN NEITHER BE CREATED nor destroyed. This principle, called conservation of energy, is one of our most cherished laws of physics. It governs every part of our lives: the heat it takes to warm up a cup of coffee; the chemical reactions that produce oxygen in the leaves of trees; the orbit of Earth around the sun; the food we need to keep our hearts beating. We cannot live without eating, cars do not run without fuel, and perpetual-motion machines are just a mirage. So when an experiment seems to violate the law of energy conservation, we are rightfully suspicious. What happens when our observations seem to contradict one of science's most deeply held notions: that energy is always conserved?

Skip for a moment outside our Earthly sphere and consider the wider universe. Almost all of our information about outer space comes in the

form of light, and one of light's key features is that it gets redshifted—its electromagnetic waves get stretched—as it travels from distant galaxies through our ever expanding universe, in accordance with Albert Einstein's general theory of relativity. But the longer the wavelength, the lower the energy. Thus, inquisitive minds ask: When light is redshifted by the expansion of the universe, where does its energy go? Is it lost, in violation of the conservation principle?

Modern physics has shown that when we move far from the comfort of our everyday lives to explore the extremes of time and space, many of our basic assumptions start to crumble. We know from Einstein that simultaneity is an illusion that changes based on the observer's perspective and that notions of distance and duration are also relative. We now also suspect that the apparent continuity of time and space may be as illusory as the deceptively smooth appear-

KEY CONCEPTS

- As the universe expands and distant galaxies recede from us, their light gets redshifted, thus becoming less energetic.
- This seeming violation of the principle of conservation of energy is actually not in contradiction with accepted physical laws.
- According to the author, the proper interpretation shows that the energy of individual photons is conserved. And phenomena taking place inside the galaxy generally conserve energy.

—The Editors

WHY ENERGY SEEMS TO DISAPPEAR

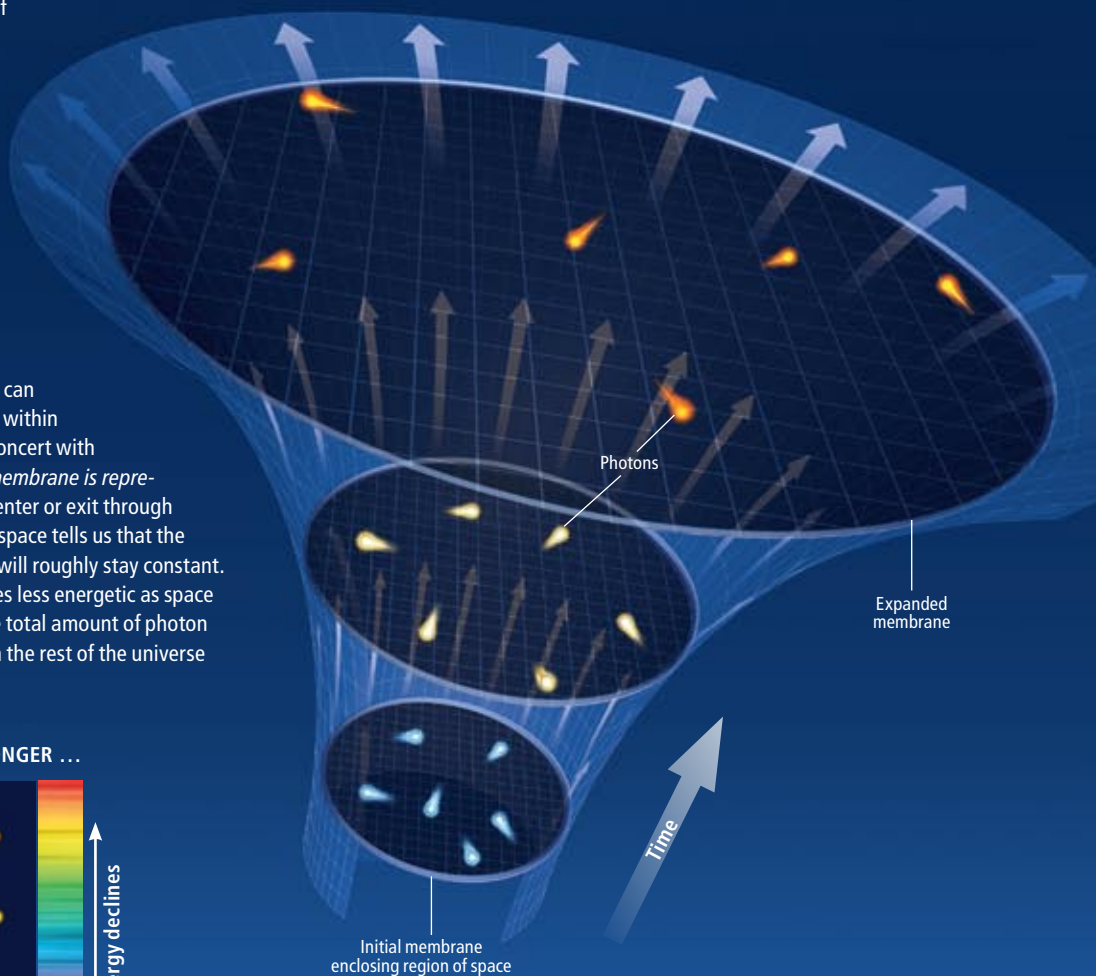
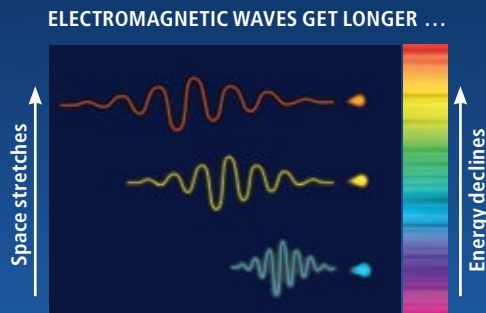
Those who argue that the universe is losing energy base their conclusion in part on the redshift of light.

The universe appears to be expanding, as if space itself were getting stretched out.

In consequence, the electromagnetic waves that compose light get stretched as well, shifting, in the case of visible light, toward the red part of the spectrum (*below*).

Photons of longer wavelength have lower energy, so logic dictates that each photon must become less energetic as it travels toward us.

But does the universe as a whole lose energy? The total energy of the photons in the universe cannot be calculated, but one can in principle calculate the energy contained within an imaginary membrane that expands in concert with the universe (*at right, the region inside a membrane is represented as two-dimensional*). Photons can enter or exit through the membrane, but the uniform density of space tells us that the number of photons in the enclosed region will roughly stay constant. Because each photon in the region becomes less energetic as space expands, this calculation suggests that the total amount of photon energy in the region and, by implication, in the rest of the universe must be going down.



... YET THE NUMBER OF PHOTONS STAYS THE SAME; ENERGY APPEARS TO BE LOST

ance of matter. What *is* there in physics that we can rely on? Which of our deeply held principles is pulling the wool over our mind's eye and blinding us to the deeper truths? We physicists spend our days challenging what is known and striving to discover where our knowledge is inadequate or just plain wrong. And history is littered with the debris of discarded misconceptions. Is conservation of energy one of those misguided ideas?

It is not. On the scale of individual photons, energy is always conserved, even as light gets redshifted. Likewise, for phenomena that take place within our galaxy, violations are virtually impossible and our cherished law remains on a sound foundation. But on a cosmological scale, energy

becomes a subtle concept indeed, and that is where things start to get interesting.

SYMMETRY AND CONSERVATION

NOT ONLY HAS CONSERVATION of energy been empirically validated many times over, but scientists also have good theoretical reasons to believe it. Our confidence comes from German mathematician Emmy Noether, who put conservation of energy on a secure footing nearly 100 years ago, when she discovered that all conservation laws are based on symmetries of nature.

Usually you think of symmetry as something you see in a mirror, a reflection of some kind or a rotation perhaps. An equilateral triangle is

symmetric because you can flip it sideways or rotate it one third of the way around, and you end up with exactly the same shape. A square also has symmetry, but you need rotate it only one fourth of the way around to find an identical configuration. The most symmetric of the two-dimensional objects is the circle, because you can rotate it any amount and reflect it over any axis through its center, and it remains exactly the same—it displays what is called continuous symmetry.

Physical laws, too, can be symmetric. The passage of time does not change the laws of nature; if you repeat an experiment many times—for example, making billiard balls collide at a given angle—the result is always the same. This quality is known as time symmetry. The laws of nature do not change depending on where you are—so we have spatial symmetry. Nor do the laws of nature change depending on the direction in which you look (rotational symmetry). Sure, the scenery may change depending on where you are standing, when you are standing there and the direction you are looking, but the fundamental underlying laws of physics that dictate how that scenery behaves are independent of your location, orientation and time. When a law remains unchanged regardless of the situation, it, like the circle, is said to be continuously symmetric.

What Noether discovered is that whenever nature displays a continuous symmetry, a conservation law comes along for the ride, and vice versa. In particular, spatial symmetry dictates that momentum is conserved; rotational symmetry ensures angular momentum is conserved; and time symmetry means that energy is conserved.

So, saying that energy is conserved is as solid as saying that the laws of physics are the same now as they were in the past and will be in the future. On the other hand, were time symmetry to break down, conservation of energy would fail. As we will see, this is where energy conservation may start to get in trouble in Einstein's universe.

GO WITH THE FLOW

THERE IS NO BETTER WAY to test whether the present matches the past, and thus to see if energy is conserved in the universe, than to watch the past in full live action through an astronomer's telescope. Our telescopes are now so powerful that we are able to see back to when the first galaxies were forming and beyond to the piping-hot afterglow of the big bang itself. The

light we are seeing has been traveling for billions of years, and in all that time, the first thing it has hit is the mirror of our telescope. The wavelengths of that light are our key to assessing conservation.

In the 1920s Edwin Hubble discovered that the light of most galaxies is redshifted: he found that the wavelengths of photons that were emitted or absorbed by atoms (such as by hydrogen) in all but the nearest galaxies to us appear, when they reach us, to be stretched relative to the wavelengths emitted by the same atoms at home—stretching roughly in proportion with the galaxies' distance. In fact, ever since the discovery of this phenomenon, whenever astronomers cannot measure a galaxy's distance more directly they instead give an estimate using its redshift as a proxy.

Redshifts (and blueshifts) also happen all the time here on Earth. **Imagine driving past a police radar.** As your car approached, the electromagnetic waves from the radar would look slightly shrunk to you—if you could see them—when they reached you. But after you passed, the waves would look a bit stretched. This is the Doppler effect: it is the electromagnetic equivalent of the familiar change in acoustical pitch you would hear in a siren as it passes by. (The police officer can tell if you are speeding by measuring a Doppler shift in the reflection of the radar.) Although in this case the waves are not in the visible spectrum, physicists still call the stretching and shrinking of the waves redshift and blueshift, respectively.

Cosmological redshifts, however, are generally considered to be different from the Doppler effect. Doppler shifts are caused by relative motion. In that case, the photons are not losing or gaining energy; they just look different to you than they do to the emitter. In contrast, most general relativity or cosmology textbooks say cosmological redshifts happen because as light travels, the very space it travels in gets stretched like the surface of an inflating rubber balloon.

In fact, cosmological redshifts can happen even when there seems to be no relative motion at all, as the following thought experiment shows. Imagine a galaxy far, far away but connected to ours by a long tether. Relative to us, the galaxy is not moving, even as other galaxies in its vicinity recede from us. Yet standard calculations show that the light reaching us from the tethered galaxy will still be redshifted (though not quite as strongly as the light from the galaxies in its vicinity, which have not been pulled out of the

The metaphor of the universe as an expanding rubber balloon should be taken with a grain of salt.

A MATTER OF CHANGING GEOMETRY

Conservation laws are intimately tied to symmetries of nature. In particular, energy is conserved when the laws of nature have “time symmetry.” Time symmetry is said to occur if any experiment gives the same results regardless of when it is performed. But if experiments can give different results at different times, energy may not be conserved. An example is playing a bank shot on a pool table that has a changing geometry. At cosmological scales, our universe has a changing geometry, which once again implies that energy may not be conserved.

CURVED POOL TABLE

To play on a table that has curved, or “non-Euclidean,” geometry, you have to adjust your shots to the geometry. Still, if the geometry is fixed, the same exact shot will work again in the future. Because of this time symmetry, in a universe with fixed geometry energy would be conserved.

EVOLVING GEOMETRY

If the pool table has a geometry that changes in time, however, the shots that worked in the past may not work again—therefore, time symmetry is broken. Something similar can happen in the universe, because according to general relativity the motion of matter and energy changes the geometry of space. Under these conditions, energy need not be conserved.



[THE AUTHOR]



Tamara M. Davis earned a Ph.D. at the University of New South Wales in 2004 and is a research fellow at the University of Queensland in Brisbane, Australia, and an associate professor at the University of Copenhagen. She works with large astrophysical data sets to discover what cosmology can teach us about fundamental physics—for example, about the nature of dark energy and dark matter. She has won the Astronomical Society of Australia’s early career researcher award and the L’Oréal-UNESCO Women in Science Award for Australia. Davis has also played on Australia’s and on Denmark’s national ultimate Frisbee teams.

flow of the expansion). This redshift is usually attributed to the stretching of the space through which light travels.

PECULIAR PHYSICS

SO PHOTONS TRAVELING in an expanding universe appear to lose energy. What about matter? Does it lose energy, too? When we describe the motion of matter in the universe, we distinguish between two different types. An object can just be receding with the general flow of the universe’s expansion, just like dots painted on our balloon inflates. In cosmology, such an object is called comoving. But an object can also have its own motion on top of the motion caused by the expansion. This second type is called peculiar motion, and it takes place when something is dragged out of the smooth flow of the expansion by local effects, such as the gravitational pull of a nearby galaxy or the thrust of a rocket.

Galaxies themselves always have at least a bit of peculiar motion, but for distant galaxies—which recede faster than near ones do—the pe-

culiar velocity is small compared with their recession. At the largest scales, the distribution of galaxies is uniform, so local effects are negligible and galaxies are essentially comoving. They can be regarded as the dots on the balloon, that is, as flag posts of the expanding fabric of space.

A comoving frame of reference such as that defined by galaxies is very handy: for example, it gives a universal convention for time, so that everyone in every comoving galaxy would agree on how long ago the big bang happened.

If an intergalactic traveler drifts for billions of light-years, he or she will pass many of these flag-post galaxies. But because the universe is expanding, the flag posts are moving away from one another, and our traveler appears to be going slower and slower relative to each subsequent galaxy he or she passes. So the traveler appears to slow down.

Thus, much as light loses energy by increasing in wavelength, matter loses energy by slowing down. At first sight those behaviors appear to be very different. But, interestingly, quantum mechanics unifies the two. In the quantum-

mechanical view of matter, particles that have mass also have wavelike properties. French physicist Louis de Broglie found that the larger the momentum of a particle, the smaller its wavelength and the greater its energy—and he won the Nobel Prize in 1929 for his discovery.

Particles of matter can have high momentum by having high mass or high velocity, or both. That feature explains, for example, why a baseball does not appear to wiggle about in wavelike motions after it leaves the pitcher's glove. Baseballs are enormously massive in quantum terms, and at the typical speed of a major-league fastball pitch (about 145 kilometers an hour) a baseball has a wavelength of 10^{-34} meter—not something a batter will have to worry about. On the other hand, an electron traveling at the same speed has a wavelength of 18 microns: still small, but 29 orders of magnitude larger than a baseball's, and very noticeable when it comes to the behavior of electrons.

When you calculate how much relative velocity massive particles lose as they pass by their receding neighbors, you find that the de Broglie wavelength of the particles increases by exactly the same proportion as a photon's wavelength does. Thus, light and matter seem to behave in exactly the same way when it comes to energy loss in the expanding universe, and in both cases it looks as if energy conservation is being violated. In the case of matter, the paradox is explained by the fact that we are measuring velocity in different frames of reference—that is, relative to the receding galaxies. As we will see, something similar happens with photons.

CREATIVE ACCOUNTING

WERE COSMOLOGICAL ACCOUNTANTS to verify that the universe is losing energy, they might attempt to tally up all the energy in the universe, rather than focusing on one object at a time. They might first add up all the energy contained simply in the mass of the matter in the universe (mass m and energy E are equivalent following Einstein's $E = mc^2$, where c represents the speed of light). Then they would add in the kinetic energy related to the matter's peculiar motion. To that sum, they would have to add the energy of light as well and then get to the complex job of counting the energy in all the gravitational fields around planets, stars and galaxies, plus the energy contained in chemical bonds and in the nuclei of atoms. (Sound and heat are just the motion of particles, so they have already been accounted for.)

A first problem they would face is that the universe may be infinitely large and contain an infinite amount of matter and energy. Thus, the accountants would need to take a shortcut. They would draw an imaginary membrane around a region of the universe and add up the energy inside [see box on page 40]. They then would let the membrane expand as the universe does, so that comoving galaxies stay inside the membrane. Light and matter can pass in and out of the membrane, but because the universe is homogeneous, the same amount leaves as enters, so the amount inside the membrane stays roughly constant. Our accountants know that the whole universe can be constructed from a series of such volumes. If the energy in the universe is to be conserved as a whole, therefore, it is enough to show that the energy in any one of those volumes is conserved.

The calculation is easy to do for matter that is at rest—just chilling out and going with the flow of the expansion. Its only energy in this case comes from its mass, and because no matter leaves or enters the membrane, we know the mass is conserved. But things are a bit more complicated for light, as we have seen, and for matter that has peculiar velocity. Although the number of photons or of matter particles within the membrane does not change, over time photon energy is lowered, as is the kinetic energy of the peculiarly moving matter. Therefore, the total energy in the membrane goes down.

The situation would be even more complicated if the accountants were to count dark energy, which is what is causing the universe's expansion to accelerate. The nature and properties of dark energy are still a complete mystery, but it appears that dark energy does not dilute as the universe expands. Thus, as the volume in our membrane increases, the amount of energy in that volume increases as well, with the additional energy seemingly coming out of nowhere! One might think that the increase in dark energy could balance out the losses in all other forms of energy, but that is not the case. Even if we take dark energy into account, the total energy within the membrane is not conserved.

How do our accountants reconcile these changing energies with Noether's theorem? In fact, they would soon realize that there is no reason why Noether's theorem should apply to our changing universe. According to general relativity, matter and energy curve space, and as matter and energy move (or spread out in an expanding space) the shape of space changes accordingly. In everyday life, these effects are

MORE COSMIC PUZZLES

Is space within our galaxy expanding?

No. Cosmic-scale expansion does not affect the dynamics inside a galaxy. Once local gravitational effects cause a galaxy to form, the expansion has no power to pull the galaxy apart.

Do photons from distant galaxies get redshifted because the universe's density has been decreasing? After all, photons get redshifted when they climb up a gravitational gradient.

True, but at any given time, the universe was uniform, so the density of matter was the same behind a photon as it was in front of it. Thus, photons had no gravitational gradient to climb out of.

Is entropy compatible with time symmetry?

Yes. In complex interactions of particles, such as the breaking of an egg, we can tell which way a movie of the process is being played—the direction in which entropy increases, which is the direction of increasing disorder. Nevertheless, any single one of the interactions between particles could happen forward or backward, as far as the laws of physics are concerned.



**LET'S PASS ENERGY ON TO THE NEXT
LET'S GO.**



GENERATION.

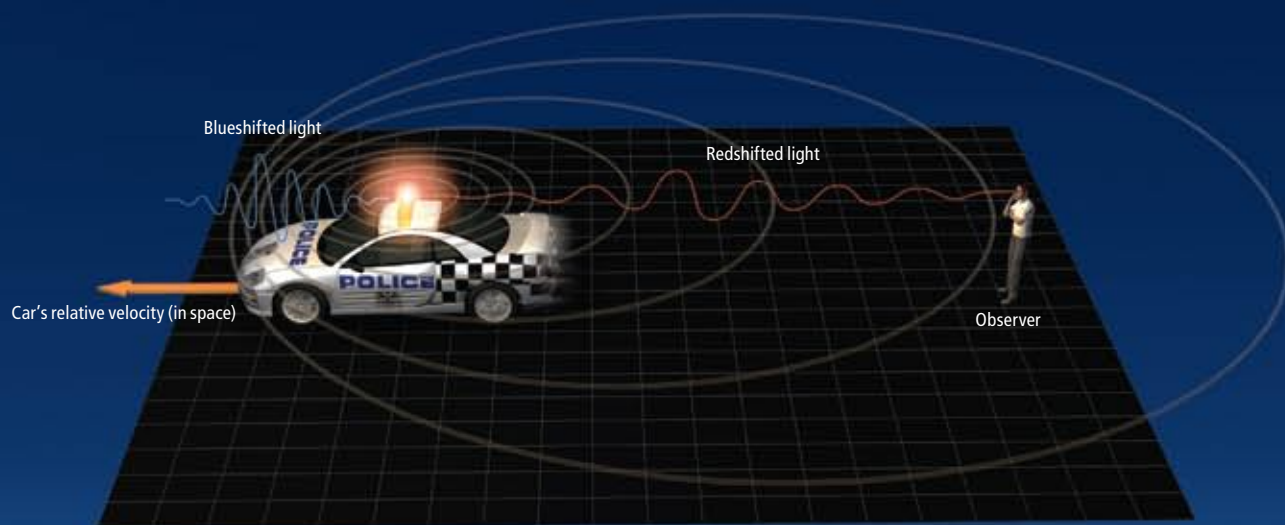
The Yoshida children have a lot of energy. But the country they're growing up in doesn't. Japan, like many other countries, needs a reliable source of energy. That's why Shell is helping to deliver natural gas to more countries than any other energy company. Not just for tonight's bowl of warming noodles, but for years to come, when the children may have children of their own. Let's build a better energy future. Let's go. www.shell.com/letsgo



HOW PHOTON ENERGY IS CONSERVED AFTER ALL

The redshift we see in distant galaxies is usually attributed to the stretching of space, but it can also be interpreted as an effect of the receding motion of the galaxies with respect to the observer. It is therefore similar to the familiar Doppler effect, which one can hear in the siren of a police car that is passing

by but that also affects the wavelengths of photons—for example, those from the car's emergency lights (*below*). In the case of the police car, energy is conserved; similarly, calculating galaxy redshift as a Doppler shift (*opposite page*) shows that photons from a distant galaxy also do not lose energy.



ORDINARY DOPPLER SHIFT

Doppler shifts arise from relative motion. The lights flashing from the top of a police cruiser appear redshifted or blueshifted—though imperceptibly to human eyes—depending on whether the car is moving away from you or toward you. The larger the car's velocity relative to an observer, the

stronger the effect will be. But the occurrence of the Doppler shift does not mean that photons change color (nor that they lose energy) along the way; they just have different colors as seen from an observer's point of view than they have from the car's own point of view.

essentially too small to detect, but at cosmic scales they can be relevant.

This malleability of space implies that the behavior of the universe is not time-symmetric. The easiest way to visualize this fact is to go back to the example of the billiard balls. If we watched several movies of a particular shot being played on a pool table of changing geometry—for example, one that starts flat and warps with time—each movie would look different from the others; you could tell when and in what order each movie was taken. Time symmetry would be broken [see box on page 42].

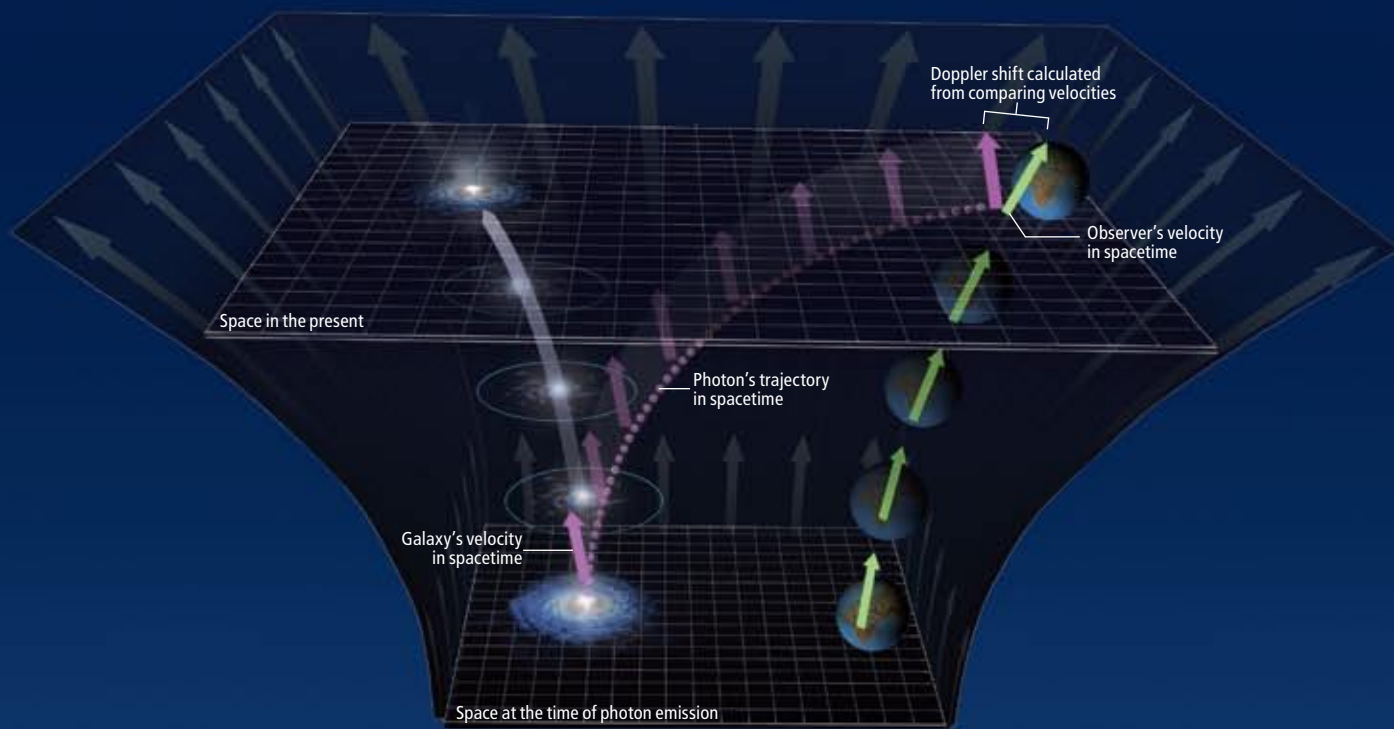
We have come to the limit of our cherished conservation principles: when time and space themselves are mutable, time symmetry is lost, and conservation of energy need no longer hold.

COSMIC SEMANTICS

EVEN IF CURVATURE does not change, however, trying to tally up the energy of the universe is a futile exercise: our accountants' godlike per-

spective does not pertain to any observer in the universe. In particular, they do not take into account the energy of comoving galaxies' motion with respect to one another, so to them, the galaxies appear to have no kinetic energy. Another issue is the gravitational energy associated with the galaxies' mutual attraction. A well-known problem with general relativity is that in the theory one cannot always unambiguously define gravitational energy in a way that applies to the universe as a whole.

Thus, the total energy of the universe is neither conserved nor lost—it is just undefinable. On the other hand, if we abandon the godlike point of view and instead focus on one particle at a time, we can find what many cosmologists believe is a more natural way of thinking of the journey of a photon from a distant galaxy. In this interpretation, the photon does not lose energy after all. The point is that our metaphor of the expanding rubber balloon, though useful to visualize the expansion, should be taken with a



GALAXY REDSHIFT AS A DOPPLER SHIFT

A galaxy's redshift is identical to the Doppler shift an observer would see when watching a police car recede at the same relative velocity as the galaxy—as long as “relative velocity” is interpreted in the appropriate way. First, one must trace the trajectories of the galaxy and of the observer not in space but in spacetime. (In the schematic view here, space is an evolving two-dimensional surface; spacetime trajectories cut through it.) Second, one must compare the velocity of the galaxy at the time when it

emitted the photon (*purple arrow*) with the velocity of the observer at the time when the photon was received (*green arrow*) and then—using the appropriate math derived from general relativity—calculate the relative velocity. The Doppler shift calculated from this relative velocity coincides with the galaxy's redshift, suggesting that the galaxy's redshift can be interpreted as the result of relative motion, rather than of the expansion of space. Therefore, no energy is lost.

grain of salt: empty space does not have a physical reality. As galaxies recede from one another, we are free to consider this relative motion as “expansion of space” or as “movement through space”; the difference is mostly semantics.

Cosmological redshift is usually described as a consequence of the expansion of space. But in Einstein's general relativity, space is relative, and what really matters is a galaxy's history—the trajectory it describes in *spacetime*. Thus, we should calculate the relative velocity of the distant galaxy with respect to us by comparing its trajectory in spacetime and ours. The amount of redshift seen in the galaxy turns out to be identical to the Doppler shift the observer would see in a car that is receding at the same relative velocity [see box above].

This happens because in small enough regions the universe makes a pretty good approximation of flat spacetime. But in flat spacetime there is no gravity and no stretching of waves, and any redshift must just be a Doppler effect.

So we can think of the light as making many tiny little Doppler shifts along its trajectory. And just as in the case of the police car—where it would not even occur to us to think that photons are gaining or losing energy—here, too, the relative motion of the emitter and observer means that they see photons from different perspectives and not that the photons have lost energy along the way.

In the end, therefore, there is no mystery to the energy loss of photons: the energies are being measured by galaxies that are receding from each other, and the drop in energy is just a matter of perspective and relative motion.

Still, when we tried to understand whether the universe as a whole conserves energy we faced a fundamental limitation, because there is no unique value we can ever attribute to something called the energy of the universe.

Thus, the universe does not violate the conservation of energy; rather it lies outside that law's jurisdiction. ■

MORE TO EXPLORE

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Misconceptions about the Big Bang. Charles H. Lineweaver and Tamara M. Davis in *Scientific American*, Vol. 292, No. 3, pages 36–45; March 2005.

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Table 31



FIG. 68.

DNA Drugs Come of Age

After years of false starts, a new generation of vaccines and medicines for HIV, influenza and other stubborn illnesses is now in clinical trials BY MATTHEW P. MORROW AND DAVID B. WEINER

IN A HEAD-TO-HEAD COMPETITION held 10 years ago, scientists at the National Institutes of Health tested two promising new types of vaccine to see which might offer the strongest protection against one of the deadliest viruses on earth, the human immunodeficiency virus (HIV) that causes AIDS. One vaccine consisted of DNA rings called plasmids, each carrying a gene for one of five HIV proteins. Its goal was to get the recipient's own cells to make the viral proteins in the hope they would provoke protective reactions by immune cells. Instead of plasmids, the second vaccine used another virus called an adenovirus as a carrier for a single HIV gene encoding a viral protein. The rationale for this combination was to employ a "safe" virus to catch the attention of immune cells while getting them to direct their responses against the HIV protein.

One of us (Weiner) had already been working on DNA vaccines for eight years and was hoping for a major demonstration of the plasmids' ability to induce immunity against a dreaded pathogen. Instead the test results dealt a major blow to believers in this first generation of DNA vaccines. The DNA recipients displayed only weak immune responses to the five HIV

proteins or no response at all, whereas recipients of the adenovirus-based vaccine had robust reactions. To academic and pharmaceutical company researchers, adenoviruses clearly looked like the stronger candidates to take forward in developing HIV vaccines.

To DNA vaccine investigators, the results were not entirely surprising, because poor responses had been seen in some previous trials. Still, the failures were disappointing because we had good reasons for expecting the plasmid vaccine to be both safe and powerful. Convinced that the original concept was still strong, scientists went back to the drawing board to find ways to boost the effectiveness of the technology. Now these efforts are beginning to pay off. A new generation of plasmid-based vaccines is proving in human and animal trials that it can produce the desired responses while retaining the safety and other benefits that make DNA so appealing. The same DNA-based technology is also now expanding to other forms of immune therapy and the direct delivery of medicines. In their mature form, such DNA-based vaccines and treatments are poised to become a success story by addressing several conditions that now lack effective treatments.

KEY CONCEPTS

- Vaccines and therapies containing DNA rings called plasmids have long held promise for treating and preventing disease, but the plasmids made a weak showing in early tests.
- Improvements to the plasmids and new methods for delivering them have dramatically enhanced their potency.
- DNA vaccines and therapies now used in animals or in late-stage human trials demonstrate that plasmids are reaching their potential.

—The Editors

[BASICS]

HOW DNA DRUGS WORK

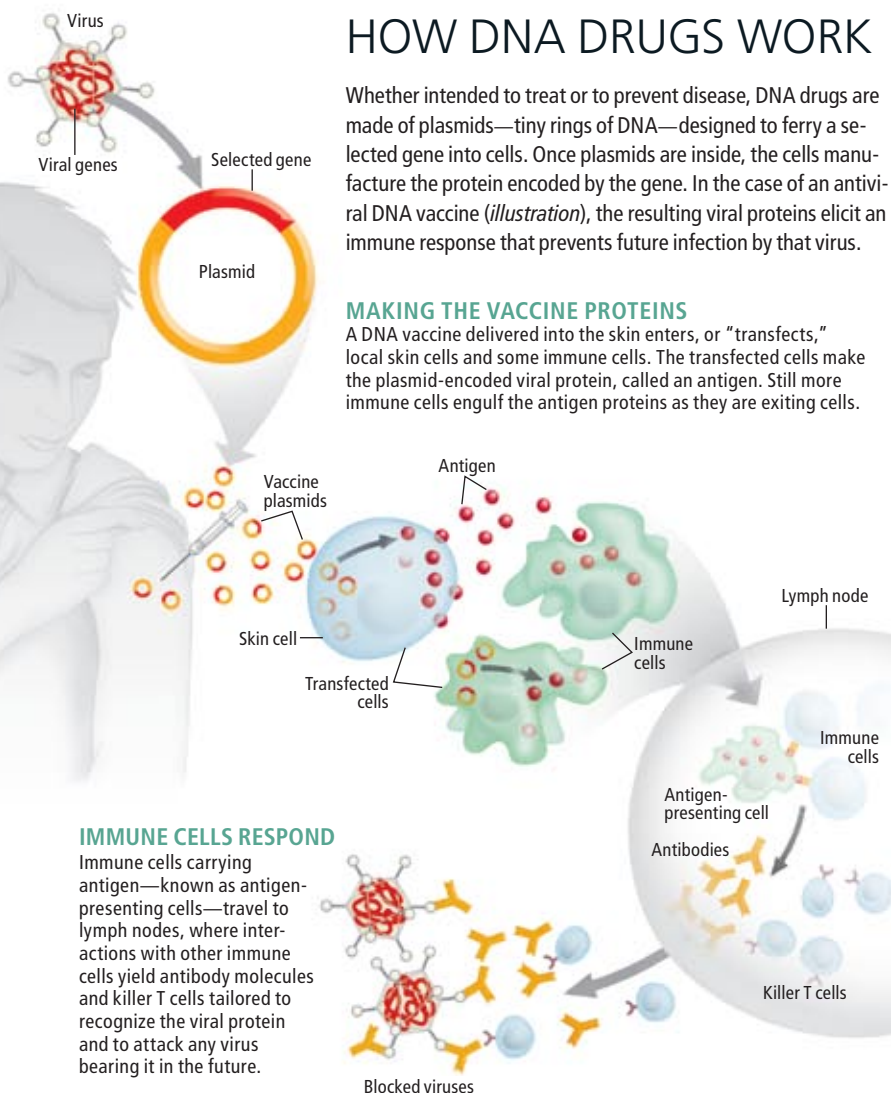
Whether intended to treat or to prevent disease, DNA drugs are made of plasmids—tiny rings of DNA—designed to ferry a selected gene into cells. Once plasmids are inside, the cells manufacture the protein encoded by the gene. In the case of an antiviral DNA vaccine (*illustration*), the resulting viral proteins elicit an immune response that prevents future infection by that virus.

MAKING THE VACCINE PROTEINS

A DNA vaccine delivered into the skin enters, or “transfects,” local skin cells and some immune cells. The transfected cells make the plasmid-encoded viral protein, called an antigen. Still more immune cells engulf the antigen proteins as they are exiting cells.

IMMUNE CELLS RESPOND

Immune cells carrying antigen—known as antigen-presenting cells—travel to lymph nodes, where interactions with other immune cells yield antibody molecules and killer T cells tailored to recognize the viral protein and to attack any virus bearing it in the future.



A GOOD IDEA, THEN AND NOW

WHEN THE CONCEPT of using DNA to immunize people began to gain traction in the early 1990s, its elegant simplicity was immediately apparent. The core components of the vaccine—the plasmids constructed to carry genes encoding one or more proteins from a pathogen—would induce the recipient’s cells to make those proteins but would not carry instructions for making the entire pathogen, so the vaccine could not give rise to the pathogen itself.

When the plasmids enter a host cell, known as transfection, the machinery that normally decodes DNA starts reading the plasmid’s gene and makes the desired protein, which is eventually released from the cell, much the way virus particles would be. Outside the cell the pathogen-specific proteins are recognized by immune cells as foreign to the body. The immune system should thus be tricked into thinking the body is

infected, prompting long-term immune recognition and responses against the foreign protein. Just introducing a DNA ring carrying one gene could thereby induce immunity that protects against an entire pathogen.

In addition to their safety and simplicity, DNA vaccines offer a number of advantages over other types of vaccine. Their manufacture is considerably faster than some traditional vaccines, such as those for influenza that require handling and cultivating “live” viruses and a minimum four-to six-month production process. DNA is inherently stable at room temperature (luckily for our cells), so DNA vaccines should not require constant refrigeration, which is a concern during the transportation and storage of many vaccines.

From the standpoint of a vaccine designer, DNA has another plus, which in recent years played an important role in reopening the door to this technology. The immune system does not perceive the plasmids as foreign material—after all, they are made of DNA—so the vaccine itself technically does not provoke any immune response. Only the protein *encoded* by the plasmid gene, once manufactured by cells, garners the attention of immune sentinels, meaning that plasmids can be used over and over in the same recipient to deliver a variety of genes without fear that the body will develop immunity to the DNA carrier and attack the vaccine itself.

Unfortunately, in the early DNA vaccine tests the problem of weak immune responses was a significant pitfall. The main reasons for those failures seemed to be that vaccine plasmids were not getting into enough cells and, where they did penetrate, the cells were not producing enough of the encoded proteins. As a result, the immune system was not being sufficiently stimulated.

The rival technology would ultimately face a bigger problem, however. In 2007 pharmaceutical company Merck initiated a large trial of an HIV vaccine that used an adenovirus called AdHu5 to deliver HIV viral genes. In light of the potent immune responses seen in previous experiments with adenoviruses, great hope and excitement surrounded the beginning of this test, known as the STEP trial. In all, about 3,000 HIV-negative individuals received the vaccine or a placebo shot.

As the trial progressed, though, a disturbing difference between the two groups began to emerge: people who got the vaccine were no better protected than those who received the placebo, and eventually they appeared to be *more* vulnerable to being infected by HIV. An early

tally found that 49 out of 914 men in the vaccine group became HIV-positive, whereas 33 out of 922 men in the placebo group did. With this realization, in the summer of 2009 the STEP trial was halted. The data are still being analyzed for clues to what happened, but some evidence is pointing to the AdHu5 carrier as one possible confounding factor. In people with preexisting immunity to AdHu5, a common cold virus, the immune system may have attacked the vaccine itself. Why some vaccine recipients seemed more susceptible to HIV infection remains unclear.

THE REBIRTH OF DNA

DURING THE YEARS leading up to the STEP trial, researchers still convinced of the DNA platform's potential had been working hard to develop solutions for the complex issues that handicapped the first generation of plasmid vaccines. These efforts focused on boosting all aspects of the plasmids' activity, including new methods of getting them into cells, new ways of increasing protein production once they were inside, and additions to the vaccines that enhance immune system responses to the vaccine-encoded proteins.

New vaccine delivery methods are among the most significant accomplishments to come out of this work, because they get considerably more cells—including immune cells themselves—to take up the plasmids. For instance, transdermal patches and other needle-free systems, such as Gene Gun and Bioject that use pressurized air to inject vaccine, deliver plasmids into the skin, where immune sentries called antigen-presenting cells are highly concentrated. These methods also physically force plasmids into more cells than needle injection would do. To achieve a similar result with vaccines delivered by needle into muscle or skin, the injection can be followed by electroporation, a series of electrical pulses that cause cell membranes to temporarily open pores that allow plasmids to enter more easily. Electroporation can increase cells' uptake of plasmids by as much as 1,000-fold.

The plasmid-gene constructs themselves have also been improved through several types of refinements to the DNA sequences of the genes they carry. Codon optimization, for instance, involves spelling out the gene's instructions in a way the cell will execute most readily. In the genetic code, the amino acid building blocks of proteins are specified by sets of three DNA "letters" that make up a codon. Certain amino acids are designated by more than one codon, but cells typically favor one of these synonymous codons and trans-

late it more efficiently than the others. Choosing optimal codons thus increases the cell's production of the desired protein. Additional revisions to the gene sequence can improve the stability and accuracy of the messenger RNA gene transcripts that the cell actually reads to make the protein and can speed protein manufacture.

A so-called leader sequence near the start of each gene is the first to be translated by the cell into the beginnings of a protein molecule, and optimizing a gene's leader sequence can improve the stability of the final protein molecules. Certain leader sequences can even mark a protein as one that the cell should secrete, which is desirable because it allows immune cells to encounter the foreign proteins both inside transfected cells and outside them. The two situations provoke slightly different types of immune

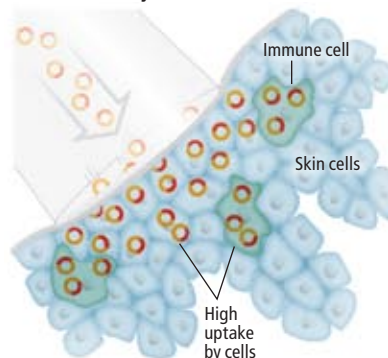
[PROGRESS]

BOOSTING DNA'S POWER

Technologies that increase the effectiveness of plasmid-based vaccines and therapies have renewed hope for the success of the DNA approach. The improvements raise cells' uptake of plasmids, augment their production of plasmid-encoded proteins and intensify immune system responses to those proteins.

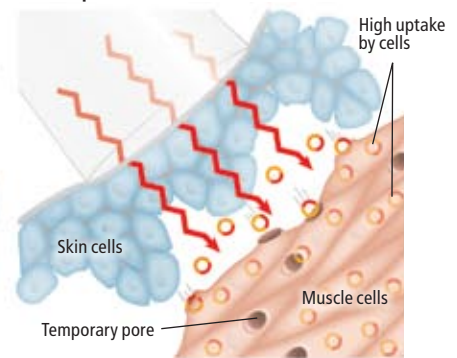
ENHANCED DELIVERY

Needle-free injection



Needle-free injection systems deliver vaccine into the skin, where immune cells are concentrated. The injectors push more plasmids directly into skin and immune cells than needle injections would.

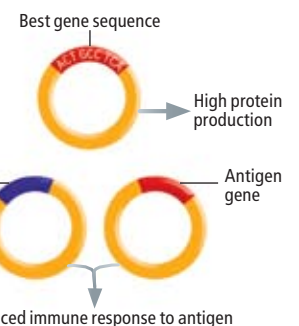
Electroporation device



Mild electrical stimulation called electroporation can boost cells' uptake of plasmids delivered by needle injection. The electrical pulses cause cells to briefly open pores that admit the plasmids.

OPTIMIZED PLASMID DESIGN

Instructions for making a protein encoded by a plasmid gene can be spelled out using various sequences of DNA "letters," but choosing certain sequences can raise the amount of protein a cell generates.



IMPROVED IMMUNE STIMULATION

Immune cell-stimulating substances called adjuvants can be encoded by genes added to plasmids. The adjuvants manufactured alongside the antigens enhance immune responses to the vaccine antigens.

response, and the combination enhances the overall immunity generated by the vaccine.

A final important improvement involves substances called adjuvants, which are typically added to traditional vaccines to boost immune system responses. In some cases, an adjuvant can even steer the immune system toward one form of response over another if desired, for instance, favoring greater production of T cells, which seek out and kill pathogen-infected cells in the body, as opposed to greater production of antibody proteins, which attempt to block pathogens from entering cells. A chemical compound called Vaxfectin, for example, has been shown to increase antibody responses to a DNA vaccine against influenza 200-fold. Another adjuvant—Resiquimod—is used with some DNA vaccines to provoke a strong immune reaction that includes both T cells and antibodies.

Another compelling aspect of the DNA-based technology is that instead of adding adjuvants to the final vaccine formulation, which sometimes creates concerns about maintaining proper emulsification or stability of the formula, designers can incorporate the gene for an adjuvant molecule directly into a vaccine plasmid. Cells that take up the plasmids will then manufacture the encoded adjuvant alongside the vaccine proteins. When gene-encoded adjuvants are added to DNA vaccines, even when the plasmid has already been optimized, as described earlier, the adjuvant can further increase immune responses by fivefold or more.

These designer plasmid vaccines are a far cry from the simple protein-encoding constructs of the early years of the DNA platform. With optimized plasmids and improved delivery methods, the technology was ready to make a comeback by the start of the STEP trial. What is more, the DNA approach has begun to show promise for uses beyond classical vaccination, including plasmid delivery of some medications and of immune therapies targeted at cancers.

A MULTIPURPOSE TECHNOLOGY

THE ABILITY TO SAFELY deliver genes into cells and get those cells to efficiently manufacture the encoded proteins opens avenues to a host of potential treatments. Indeed, many of these DNA-based therapies are ahead of DNA vaccines in the race to widespread clinical use. Unlike classical drugs that often take the form of small chemical molecules, DNA therapies deliver a gene to treat an ailment. Unlike traditional gene therapy, however, the plasmid does not integrate permanently into the recipient's

cellular genome or even remain permanently in cells, which avoids complications that have hampered progress in gene therapies.

As is often the case with new technologies, the earliest successes in plasmid-based therapies have been in animals. One example already licensed for use in pigs is designed to prevent fetal loss. Administered to pregnant sows along with electroporation, the plasmid enters the sow's cells, which then make a hormone (growth hormone–releasing hormone) that supports the gestating fetuses' survival. The success of this treatment is exciting in part because it requires only a single injection to work in such a large animal, which bodes well for human therapies.

Various large clinical trials for human DNA therapies are now under way [see *table on opposite page*], including one that delivers genes for proteins called growth factors that mobilize stem cells to treat congestive heart failure. Another employs a plasmid encoding a growth factor called IGF-1 to treat growth failure in patients with the disorder X-linked severe combined immunodeficiency. A third trial addresses a circulatory problem that can be notoriously hard to treat, called critical limb ischemia. This therapy delivers plasmid-encoded factors that induce new blood vessels to grow, in the hope of preventing the need for amputation.

A different category of treatments, known as DNA biological immunotherapy, combines the best aspects of DNA therapies and vaccines by delivering a gene that induces the body to mount an immune response to an existing disease, such as a tumor or a chronic viral infection. One early trial uses DNA encoding viral proteins to induce immune cell attacks on tumors caused by the human papillomavirus (HPV), for example. Initial results from this trial show that half of recipients muster T cell responses to the HPV proteins and that more than 90 percent generate high levels of antibodies. Another current trial is testing a DNA immunotherapy against the hepatitis C virus. Encouraging preliminary results in both these trials are significant because no effective immune therapies currently exist for either HPV tumors or hepatitis C.

In this arena, veterinary applications are once again even more advanced than human studies, and a successful DNA-based therapy for melanoma in dogs is exciting researchers who study human cancer. The dog melanoma treatment, made by Merial, increases the median survival time of dogs with advanced melanoma by sixfold compared with untreated dogs. This DNA

[THE AUTHORS]



Matthew P. Morrow and David B. Weiner collaborate at the University of Pennsylvania, where Morrow is a post-doctoral research fellow. Investigating HIV for nearly 10 years led to his current focus on DNA vaccines and immune therapies. Weiner, a professor of pathology and medicine, is chair of the university's Gene Therapy and Vaccines graduate program. A pioneer of DNA vaccine technology, he brought the first plasmid-based vaccines to clinical trials and has been a consultant to the FDA and to many vaccine and pharmaceutical companies pursuing plasmid-based drugs.

COURTESY OF MATTHEW P. MORROW (Morrow); COURTESY OF DAVID B. WEINER (Weiner)

DEMONSTRATING THE POTENTIAL OF DNA

Plasmid-based vaccines and therapies are under study in humans for a wide range of disorders, and some are already approved for animals. The table below lists a selection of the disorders targeted by products in human clinical trials or already marketed for animals.

PRODUCT	DISORDER TARGETED IN HUMAN TRIALS	DISORDER TARGETED IN ANIMALS
Vaccines to prevent disease	■ HIV (3 vaccines) ■ Influenza (2 vaccines)	■ West Nile virus (horses) ■ Infectious hematopoietic necrosis virus (farmed salmon)
Immune-stimulating treatments for existing diseases	■ Hepatitis C ■ HIV ■ Human papillomavirus-induced tumors ■ Liver cancer ■ Melanoma	■ Melanoma (dogs)
Therapies that give rise to needed proteins	■ Congestive heart failure ■ Growth failure from X-linked severe combined immunodeficiency disorder ■ Limb circulatory disorders (3 treatments) ■ Melanoma	■ Fetal loss (pigs)

biological immunotherapy attests to the potential of the new-generation DNA platforms to succeed where previous approaches have not.

BACK TO THE FUTURE

DOZENS OF HUMAN clinical trials of DNA therapies and vaccines have been conducted in the past 10 years or are currently ongoing. Plasmid versions of flu vaccines exemplify some of the benefits the DNA approach has already demonstrated. A flu vaccine our research group developed, now in early human trials, was shown in animals to protect against common flu strains and against the highly lethal H5N1 avian flu that has infected several hundred people. The vaccine is able to provide this broad protection because its plasmids contain so-called consensus sequences of flu virus genes, meaning the resulting viral proteins resemble those of many different flu strains. Such vaccines might spell an end to mismatches between seasonal flu vaccines and the flu strains that emerge every year.

Of course, the novel H1N1 flu strain that appeared last year to produce a global pandemic highlights the urgent need for a new vaccine approach. An experimental DNA version of an H1N1 vaccine made by the pharmaceutical company Vical was completed in just two weeks in May 2009. Had it been tested and licensed in advance, such a vaccine could have been manufactured in large amounts at least two months sooner than the standard vaccines became avail-

able. It is now in early human trials with encouraging results.

The potential power of DNA vaccines and therapies to target diseases that have no other effective alternatives has also brought DNA back into the HIV vaccine race. One vaccine now in human trials, Pennvax-B, contains three HIV viral genes plus genes encoding adjuvant molecules and is delivered with electroporation. Two more vaccines are being tested in a strategy that uses plasmids to prime immune cells to recognize the HIV proteins followed by administration of another vaccine type to boost the early immune response to higher levels. One of these, GeoVax, is being given along with a vaccine based on a virus called modified vaccinia Ankara as the boost. And in an amusing irony, the NIH Vaccine Research Center is now testing a different DNA-based HIV vaccine with one of two adenovirus-based HIV vaccines as boosts.

The fact that several DNA vaccines and therapies are already used in animals and are in large, late-stage human trials involving hard-to-treat ailments attests to how far the plasmid technology has come. Dramatic progress in the field over the past decade has brought some of the most creative vaccines and therapeutics yet to clinical testing for human benefit. In this regard, those of us who have nursed this technology since its infancy cannot help but feel proud to see that it has emerged from a difficult childhood and can look forward to a bright future.

MORE TO EXPLORE

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DNA Vaccines: Precision Tools for Activating Effective Immunity against Cancer. Jason Rice et al. in *Nature Reviews Cancer*, Vol. 8, No. 2, pages 108–120; February 2008.

Electroporation of Synthetic DNA Antigens Offers Protection in Nonhuman Primates Challenged with Highly Pathogenic Avian Influenza Virus. Dominick J. Laddy et al. in *Journal of Virology*, Vol. 83, No. 9, pages 4624–4630; May 2009.

The Dirty Truth about PLUG-IN HYBRIDS

How green is that electric car? Depends on where you plug it in

BY MICHAEL MOYER

IN THE MONTHS AFTER Nissan's announcement last year that it would soon introduce the Leaf, the world's first mass-market electric vehicle, the company embarked on a 24-city "zero-emission tour" to show off the technology. The Leaf's electric motor draws its energy from a battery pack that plugs into an outlet in your garage. It has no engine, no gas tank and no tailpipe. And during the time the car is on the road, it is truly a zero-emission machine. But at night, in your garage, that battery pack must refill the energy lost to the day's driving with fresh electrons culled from a nearby power plant. And zero emission it ain't.

The Leaf should be the first all-electric car off the starting grid, but followers are whirring hot behind it. Chevrolet is introducing the Volt, an electric car supplemented with a small internal-combustion engine that keeps the battery charged. Ford will come out with an electric version of its Focus in 2011, followed by models from Toyota, Volvo, Audi and Hyundai.

A true accounting of the environmental consequences of these cars would have to include the emissions of the power plants that supply their energy. When Department of Energy researchers carried out such an analysis, they found that the results vary considerably with geography.

The researchers split the continental U.S. into 13 regions defined by the North American Electric Reliability Corporation and examined the mix of power sources within each region—generally, a combination of coal, natural gas and nuclear energy, with a smattering of renewable energy thrown in. They then looked at how a new fleet of electric cars would alter that supply. Nuclear and renewables, which together account for less than a quarter of the U.S. electricity supply, are "always on" sources. Their energy gets used up quickly for routine tasks, leaving little to no green energy left over to help charge a burgeoning fleet of electric vehicles. In practical terms, this means that even if you live down the street from a wind farm, its energy is already spoken for before you plug in your plug-in.

With nuclear and renewables taken out of the equation, the researchers concluded that power for the fleets will have to come primarily from coal and natural gas. If you live in a place where natural gas is dominant, electric vehicles will reduce carbon dioxide emissions—in some cases by as much as 40 percent below that of an ordinary hybrid. In regions powered mostly by coal—a much dirtier fuel—electric vehicles will lead to an increase in the amount of carbon dioxide released into the atmosphere. The zero-emission tour may have ended this spring, but the controversy over what zero really means is just getting under way.

POWER SOURCES

Where does your electricity come from? The answer depends on the time of day, day of week and where you live. To determine the sources of energy that will power the coming fleet of electric vehicles, researchers modeled the additional strain that a fleet of electric cars would place on the grid. They found that the added demand will likely be met by plants burning fossil fuels. In fact, in the six regions whose numbers are highlighted in yellow, heavy contributions from coal mean that plug-in cars will emit at least as much in the way of greenhouse gases as would an ordinary hybrid.

THE COAL IN YOUR CAR

Here we represent the carbon intensity of the electricity that will power plug-in cars by height and color—dirtier regions are darker and taller. Boxes detail how a plug-in car will compare to an ordinary hybrid in terms of carbon emissions and petroleum consumption.

HOW DIRTY IS YOUR REGION?



In taller and darker regions, the electricity used to power plug-in cars is responsible for higher carbon dioxide emissions.

PER-MILE COMPARISON TO ORDINARY HYBRID:

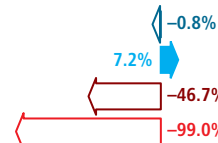


Carbon emitted by ... Gasoline consumed by ...

Carbon emitted by ...	Gasoline consumed by ...
Plug-in hybrid	Plug-in hybrid
All-electric	All-electric

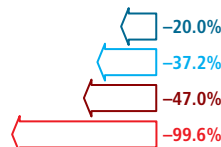
1. UPPER MIDWEST

47.6% NATURAL GAS
46.0% COAL
6.3% RENEWABLE



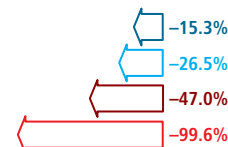
13. NORTHWEST

84.3% NATURAL GAS
15.7% NUCLEAR



12. CALIFORNIA

99.0% NATURAL GAS
1.0% RENEWABLE



◀ The greenest Leafs will be in the Northwest.



THREE FLAVORS OF ELECTRIC CARS



All-Electric

With no gasoline engine, cars such as the **Nissan Leaf** run exclusively on battery power. This limits their range to about 100 miles before they require a charge.



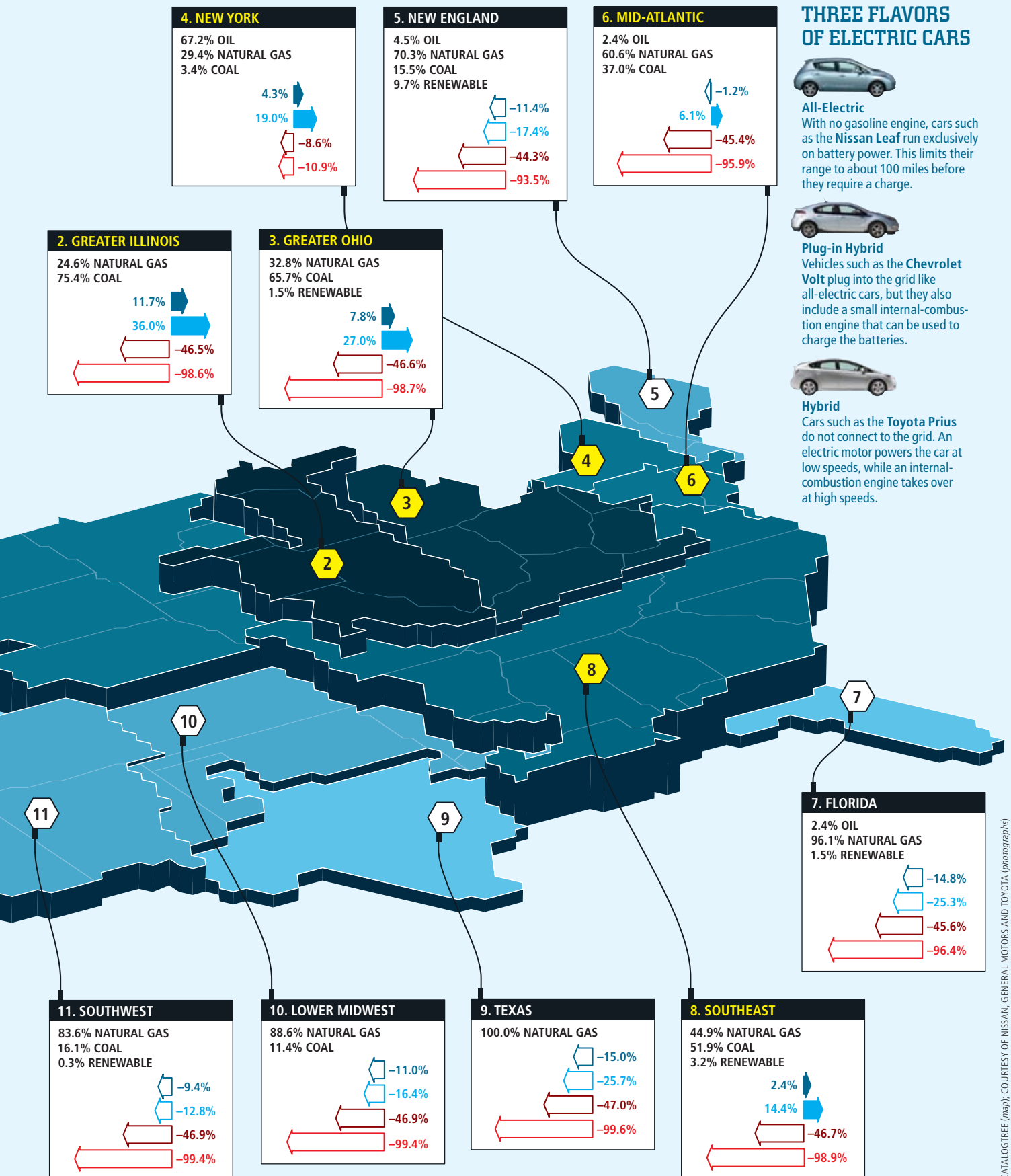
Plug-in Hybrid

Vehicles such as the **Chevrolet Volt** plug into the grid like all-electric cars, but they also include a small internal-combustion engine that can be used to charge the batteries.



Hybrid

Cars such as the **Toyota Prius** do not connect to the grid. An electric motor powers the car at low speeds, while an internal-combustion engine takes over at high speeds.



CATALOGTREE (map); COURTESY OF NISSAN, GENERAL MOTORS AND TOYOTA (photographs)

WAR OF THE MACHINES

Robots on and above the battlefield are bringing about the most profound transformation of warfare since the advent of the atom bomb

BY P. W. SINGER





BACK IN THE EARLY 1970s, a handful of scientists, engineers, defense contractors and U.S. Air Force officers got together to form a professional group. They were essentially trying to solve the same problem: how to build machines that can operate on their own without human control and to figure out ways to convince both the public and a reluctant Pentagon brass that robots on the battlefield are a good idea. For decades they met once or twice a year, in relative obscurity, to talk over technical issues, exchange gossip and renew old friendships. This once cozy group, the Association for Unmanned Systems International, now encompasses more than 1,500 member companies

and organizations from 55 countries. The growth happened so fast, in fact, that it found itself in something of an identity crisis. At one of its meetings in San Diego, it even hired a “master storyteller” to help the group pull together the narrative of the amazing changes in robotic technology. As one attendee summed up, “Where have we come from? Where are we? And where should we—and where do we want to—go?”

What prompted the group’s soul-searching is one of the most profound changes in modern warfare since the advent of gunpowder or the airplane: an astonishingly rapid rise in the use of robots on the battlefield. Not a single robot accompanied the U.S. advance from Kuwait toward Baghdad in 2003.

KEY CONCEPTS

- The U.S. military once shunned robots as obstacles to traditional soldiering.
- “Unmanned” systems have proliferated in conflicts in the Middle East, either helping to negotiate the urban labyrinth of streets and alleyways or acting as scouts in remote villages.
- As robots do more on their own, they continue to raise a host of ethical and legal issues.

—The Editors



REMOTE CONTROL in high-tech warfare has begun to extend to robots involved in surveillance, troop supply and even the firing of powerful weapons.

Robots may keep soldiers out of harm's way, but doing so risks lowering the threshold for the start of a conflict.

Since then, 7,000 “unmanned” aircraft and another 12,000 ground vehicles have entered the U.S. military inventory, entrusted with missions that range from seeking out snipers to bombing the hideouts of al-Qaeda higher-ups in Pakistan. The world's most powerful fighting forces, which once eschewed robots as unbecoming to their warrior culture, have now embraced a war of the machines as a means of combating an irregular enemy that triggers remote explosions with cell phones and then blends back into the crowd. These robotic systems are not only having a big effect on how this new type of warfare is fought, but they also have initiated a set of contentious arguments about the implications of using ever more autonomous and intelligent machines in battle. Moving soldiers out of harm's way may save lives, but the growing use of robots also raises deep political, legal and ethical questions about the fundamental nature of warfare and whether these technologies

could inadvertently make wars easier to start.

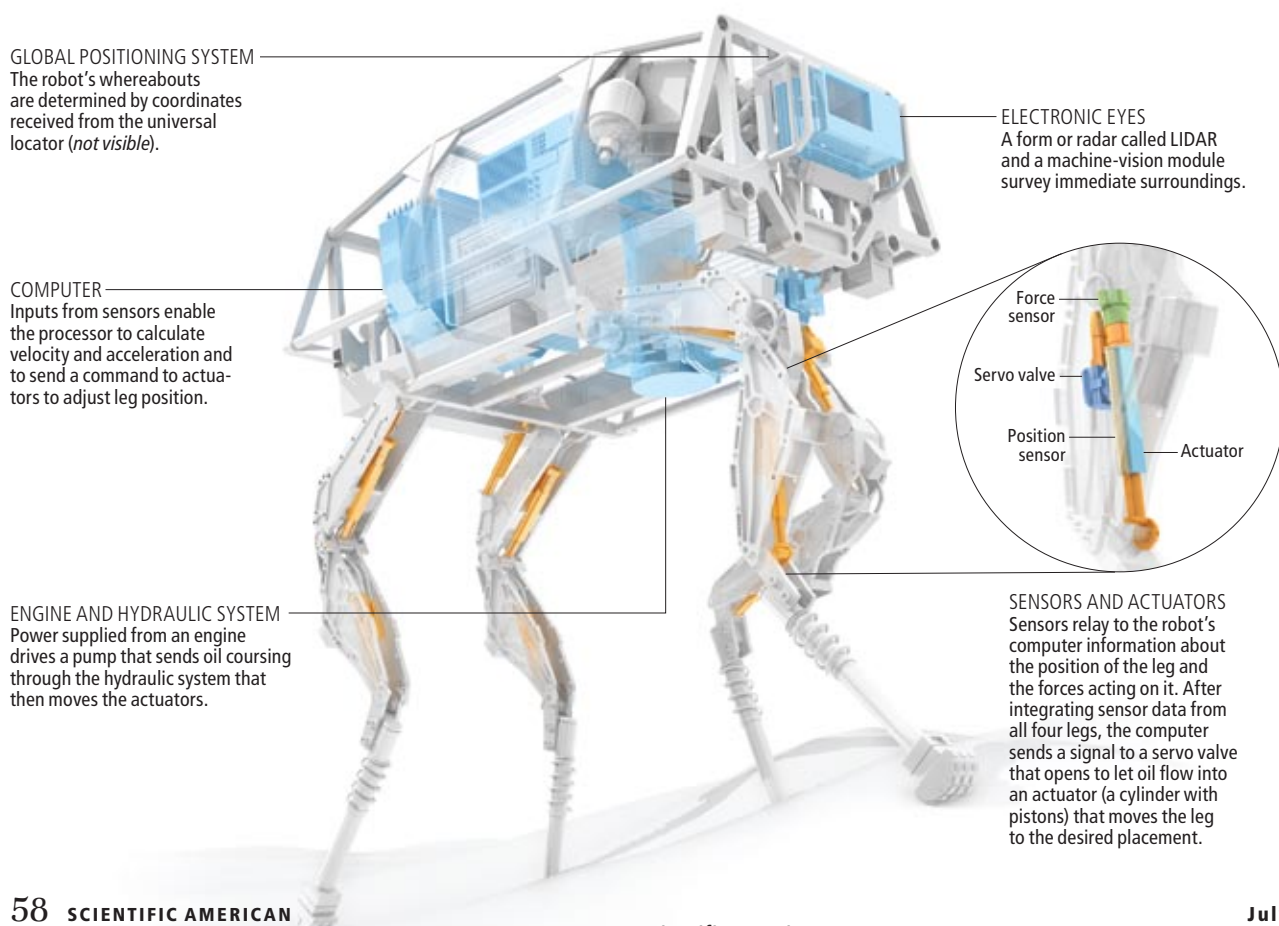
The earliest threads of this story arguably hark back to the 1921 play *R.U.R.*, in which Czech writer Karel Čapek coined the word “robot” to describe mechanical servants that eventually rise up against their human masters. The word was packed with meaning, because it derived from the Czech word for “servitude” and the older Slavic word for “slave,” historically linked to the “robotniks,” peasants who had revolted against rich landowners in the 1800s. This theme of robots taking on the work we don't want to do but then ultimately assuming control is a staple of science fiction that continues today in *The Terminator* and *The Matrix*.

Today roboticists invoke the descriptors “unmanned” or “remote-operated” to avoid Hollywood-fueled visions of machines that are plotting our demise. In the simplest terms, robots are machines built to operate in a “sense-think-act” paradigm. That is, they have sensors that gather

[AN INSIDE LOOK]

ANATOMY OF A NEXT-GENERATION ROBOT

Neither human soldiers nor ordinary machines will match the capabilities of the newest military robots now in development. BigDog, a pack-animal-like quadruped will traverse terrain too steep, rutted, rocky, muddy or snowy for vehicles that move on wheels or tracks, all the while toting ammunition or another supply load weighing hundreds of pounds.



information about the world. Those data are then relayed to computer processors, and perhaps artificial-intelligence software, that use them to make appropriate decisions. Finally, based on that information, mechanical systems known as effectors carry out some physical action on the world around them. Robots do not have to be anthropomorphic, as is the other Hollywood trope of a man in a metal suit. The size and shape of the systems that are beginning to carry out these actions vary widely and rarely evoke the image of C-3PO or the Terminator.

The Global Positioning Satellite system, video-game-like remote controls and a host of other technologies have made robots both useful and usable on the battlefield during the past decade. The increased ability to observe, pinpoint and then attack targets in hostile settings without having to expose the human operator to danger became a priority after the 9/11 attacks, and each new use of the systems on the ground created a success story that had broader repercussions. As an example, in the first few months of the Afghan campaign in 2001, a prototype of the PackBot, now used extensively to defuse bombs, was sent into the field for testing. The soldiers liked it so much that they would not return it to its manufacturer, iRobot, which has since gone on to sell thousands. Similarly, another robotics company executive recounts that before 9/11, he could not get his calls returned by the Pentagon. Afterward, he was told: "Make 'em as fast as you can."

This accelerating acceptance of military robotics became apparent as the Iraq War played out. When U.S. forces went into Iraq in 2003, the ground invasion force had no unmanned systems. By the end of 2004 the number had risen to 150 or so. A year later it had reached 2,400. Today the overall U.S. military inventory is more than 12,000. The same trend occurred with air weaponry: the U.S. military went from having a handful of unmanned aerial vehicles supporting the invasion force to more than 7,000 now. And this progression is just the start. One U.S. Air Force three-star general forecasts that the next major U.S. conflict will involve not the thousands of robots currently in the field but "tens of thousands."

The raw numbers reveal an important shift in attitude by a military that just a few years ago remained dubious of its capabilities and protective of the age-old warrior's prerogative of leading the charge into combat. Today the U.S. Air Force, Army and Navy entice teenage recruits through television advertising that extols how,

as one promotion puts it, the U.S. Navy is "working every day to unman the front lines."

When teens do join the military, exposure to automated systems is integral to their experience, from induction to discharge. They use the latest virtual-training software to learn how to operate a particular weapons system. After training, they may well operate a lawnmower-size PackBot or a TALON ground robot that can defuse bombs or peek over the top of a ridge in the hunt for insurgents in Iraq or Afghanistan.

If they end up at sea, they may well serve on an Aegis-class destroyer or Littoral Combat Ship, which operate as mother ships for a range of systems, from Fire Scout unmanned helicopters to Protector robotic sentry motorboats. If their career takes them into submarines, they could end up controlling unmanned underwater vehicles such as the REMUS (Remote Environmental Monitoring Units, a torpedo-shaped robot sub originally developed by the Woods Hole Oceanographic Institution) to detect mines or to conduct surveillance of unfriendly coastlines. If they become aviators, they may "fly" Predator or Global Hawk drones over Central Asia, while never physically leaving the continental U.S.

THE WAR BOTS OF TOMORROW

SUCH TECHNOLOGIES are billed in a recruiting ad as part of today's military, while "seeming like science fiction." In reality, they are merely the first generation, a suggestion of more to come. That is, today's PackBot robot hunting roadside bombs and the Predator drones flying over Afghanistan represent the equivalent of the Model T Ford and the Wright brothers' Flyer. Prototypes for the next generation reveal three key ways that robots will change how we conduct warfare.

The idea of robots as mere "unmanned systems"—identical to any other machine, except without the presence of a human operator inside—is beginning to fade. The evolution recapitulates the trajectory of automotive history: thinking about cars as mere "horseless carriages" became an artifact as designers started to consider wholly novel forms and sizes. The similar casting off of preconceptions about robots is leading the machines to take on a wide range of shapes. As would be expected, some models take their inspiration from biology. Boston Dynamics's BigDog, for one, is a metallic, equipment-toting quadruped. Others are hybrids, such as a Naval Postgraduate School surveillance bot that has both wings and legs. But other systems in early devel-



BRING YOUR OWN DRONE: The ScanEagle provided an airborne security camera for U.S. Marines in Iraq's Al Anbar province by hovering over remote tracts for hours on end.



HELPING OUT: A soldier chucks a PackBot surveillance robot through a window so that its onboard video cameras can provide an inside view of the premises.

opment have literally no form at all. ChemBot, a creation of the University of Chicago and iRobot, is a bloblike machine that shifts shape, such that it is able to squeeze through a hole in the wall.

With no humans inside, the size of robots can range wildly. Miniaturized robots already measure in millimeters and weigh in grams. Take a surveillance bot made by AeroVironment for urban combat. It mimics a hummingbird in size and in its ability to hover over a target. The next frontier is nanoscale robotics (structures measured in billionths of a meter) that some scientists believe will become commonplace within a few decades. In war these machines might be used for roles that range from “smart dust” that detects the enemy to cellular-level machines inside the human body that repair wounds or, in turn, cause them. At the other end of the scale, the ability to deploy a system that does not have to take into account human bodily needs is leading to gigantic unmanned systems, such as Lockheed Martin’s High-Altitude Airship, an unmanned blimp that carries a radar the length of a football field, designed to fly at above 19,800 meters for more than a month at a time.

Beyond size and shape, a second key change is the widening of roles these machines can perform in warfare. Much like the early “aeroplanes” in World War I, robots started out only for observation and reconnaissance and have now expanded into new tasks. Technology development company QinetiQ North America, maker of the TALON, introduced the MAARS robot in 2007, which is armed with a machine gun and grenade launcher and can take on sentry and sniper duty. In turn, med bots such as the U.S. Army Medical Research and Materiel Command’s Robotic Extraction Vehicle are designed to drag wounded soldiers to safety and then administer care.

The third key change is the robots’ ever growing intelligence and autonomy. The inexorable growth in computing power means that today’s recently enlisted soldiers may end their careers witnessing robots powered by computers literally a billion times more capable than those currently available. The World War II-era military did not differentiate between the B-17 and B-24 bomber by how smart they were, but latter-day weapons systems require just such distinctions. The Predator series of unmanned planes, for example, has evolved from being purely remote-controlled to now being able to take off and land on their own and track 12 targets at once; the target-recognition software can even trace footprints back to their point of origin. Even so, the U.S. military is

already planning to replace these planes, deployed since 1995, with a newer generation.

The expansion of robotic intelligence and autonomy raises profound questions of what roles are appropriate to outsource to machines. These decisions must be weighed on how effective the machines might be in battle but also on what this shift in responsibility would mean for both their human commanders and broader political, ethical and legal responsibility for their conduct. The most likely outcome in the near future is for robots to take on the semblance of “war fighter associates.” In this scenario, mixed teams of humans and robots would work together, each doing what they do best. The human element may well turn out to be akin to the quarterback in a football game, calling plays for robotic teammates, while giving them enough autonomy to react to changing circumstances.

THE REAL STORY

THESE REMARKABLE DEVELOPMENTS may still not fully capture the story of where robotics is headed and what it means for our world and the future of warfare. The full implications cannot be gleaned from describing physical capabilities, just as the significance of gunpowder is not captured by noting that it produced a chemical explosion that allowed a longer trajectory for projectiles.

Robots are one of those rare inventions that literally change the rules of the game. Such a “revolutionary” technology does not give one side a permanent advantage, as some analysts mistakenly believe, because it is quickly adopted by or adapted to by other combatants. Rather it causes shake-ups, not only on the battlefield but in the social structures surrounding it. The long-bow, for example, was not notable simply because it allowed the English to beat the French at the Battle of Agincourt during the Hundred Years’ War; rather it let organized groups of peasants triumph over knights, ending the age of feudalism.

An apt historical parallel to the current period may well turn out to be World War I. Back then, strange, exciting new technologies that had been viewed as merely science fiction just years earlier were introduced and then used in increasing numbers on the battlefield. Indeed, it was H. G. Wells’s 1903 short story “Land Ironclads” that inspired Winston Churchill, then First Lord of the Admiralty, to champion the development of the tank. Another story, by A. A. Milne, creator of the beloved *Winnie-the-Pooh* series, was among the first to raise the idea of using airplanes in war, while Arthur Conan Doyle (in his 1914

[THE AUTHOR]



P. W. Singer directs the 21st Century Defense Initiative at the Brookings Institution and is author of the best-selling 2009 book *Wired for War: The Robotics Revolution and Conflict in the 21st Century* (wiredforwar.pwsinger.com).

COURTESY OF iROBOT (Soldier); COURTESY OF P. W. SINGER (Singer)

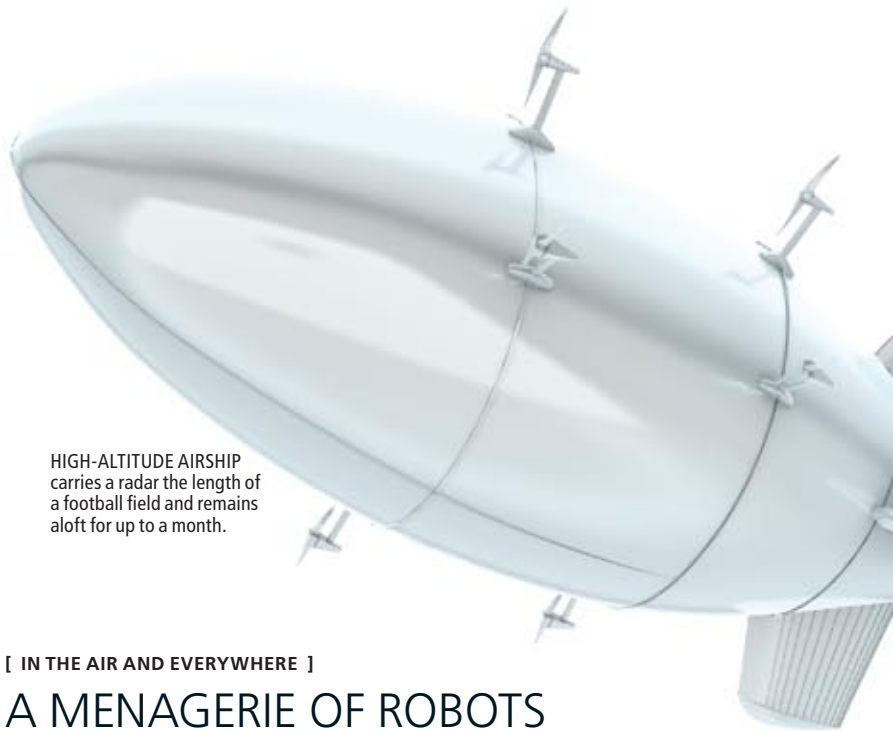
short story “Danger!”) and Jules Verne (in his 1869 novel *20,000 Leagues under the Sea*) pioneered the notion of submarines’ full use in war. First users had an edge, but it was fleeting. British invention and early exploitation of tanks in World War I, for example, was surmounted a mere 20 years later when the Germans proved with their blitzkrieg tactics that they had figured out how to use the new weapon more effectively.

The arrival of tanks, airplanes and submarines was important, however, because they raised a wholly new set of political, moral and legal issues that resulted in dramatic strategic consequences. For instance, differing interpretations between the U.S. and Germany over how submarines were legally allowed to fight (should they be allowed to sink merchant ships without warning?) drew America into the First World War, ultimately leading to its rise to superpower status. Similarly, airplanes proved useful not only at spotting and attacking troops at greater distances, but also at allowing the emergence of aerial bombing that often resulted in bombs raining onto civilian populations, giving an entirely new meaning to the term “home front.”

THE PLOT THICKENS

WE ARE SEEING much the same circumstances today with military robotics. Take the idea of what it once meant to “go to war.” For democratic nations, it long signified a serious commitment that involved currying public favor for an endeavor that jeopardized not just the lives of its citizens’ sons and daughters but the state’s very survival. Unmanned systems (and their ability to carry out remote acts of force) erode the deterrent exerted by public sentiment, a decline already begun by the end of the U.S. military draft in 1979.

This distancing of the human combatant from the theater of conflict may well make wars easier to start and may even change how we view them. For example, the U.S. has carried out more than 130 air strikes into Pakistan using Predator and Reaper unmanned craft. This number is more than triple the total of manned bomber strikes that we launched in the opening round of the Kosovo War a mere decade ago. But unlike that war, robotic air strikes into Pakistan prompted no debate at all in Congress and relatively little reporting in the media. In essence, we are engaging in what we would have previously called a “war,” but without public deliberation. The conflict is not even considered a war, because it comes without any cost in U.S. human lives. By one measure, these strikes have been highly effective. They



HIGH-ALTITUDE AIRSHIP carries a radar the length of a football field and remains aloft for up to a month.

[IN THE AIR AND EVERYWHERE]

A MENAGERIE OF ROBOTS

Machines both big and small on land and in the air have begun to take over tasks typically carried out by human soldiers for centuries.



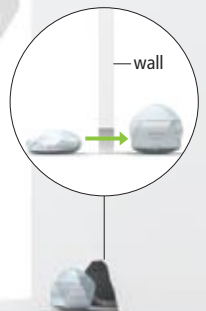
HUMMINGBIRD DRONE measures no more than 7.5 centimeters and flaps its wings frenetically as its cameras observe a scene.



RAVEN, a model-airplane-like spy craft, has proved immensely popular in Iraq.



MAARS serves as a 160-kilogram machine gun—carrying and grenade-launching sentry and sniper.



CHEMBOT, a palm-size blob, morphs to fit through a hole in the wall and then spies on the goings-on in the next room.

AMERICA'S REMOTE-CONTROLLED AIR WAR

An intricate communications network allows soldiers at U.S. domestic and overseas military bases to control unmanned aircraft that fire missiles or gather intelligence from battlefronts in both Iraq and Afghanistan. Each base is responsible for control of one or more types of aircraft (*orange lines*) or for receiving intelligence data (*green lines*). Information moves through two U.S.-based communication centers (*blue cubes*) to and from Iraq and Afghanistan.



have killed as many as 40 leaders of al-Qaeda, the Taliban and allied militant groups without having to send American troops or pilots into harm's way. But the repercussions of these strikes raise questions that are still being answered.

What is, for one, this technology's impact on the "war of ideas" we are fighting against terrorist recruiting and propaganda? That is, how and why is the reality of our painstaking efforts to act with precision emerging on the other side of the globe through a cloud of anger and misperception? Whereas we use adjectives such as "precise" and "costless" to describe the technology in our mass media, a leading newspaper in Pakistan declared the U.S. to be a "principal hate figure" and "all-purpose scapegoat" because of the strikes. Unfortunately, "drone" has become a colloquial word in Urdu, appearing in rock lyrics that accuse America of not fighting with honor. This issue becomes more complex when weighing who should be held accountable when things go wrong. Estimates of civilian casualties range from 200 to 1,000.

But many of these incidents occurred close to some of the most dangerous terrorist leaders around. Where does one draw the line?

The meaning of "going to war" is also changing for the individual warrior in 2010. Setting off to battle has always meant that a soldier might never come home. Achilles and Odysseus sailed off to fight Troy. My grandfather shipped out to fight the Japanese after Pearl Harbor. Remote warfare has changed the enduring truth of the past 5,000 years of war. A growing number of soldiers wake up, drive to work, sit in front of computers and use robotic systems to battle insurgents 11,300 kilometers away. At the end of a day "at war," they get back in their cars, drive home and, as one U.S. Air Force officer put it: "Within 20 minutes you are sitting at the dinner table talking to your kids." The most dangerous part of their day is not the dangers of the battlefield but the commute home.

This disconnection from the battlefield also leads to a demographic change in who does what in war and the issues it provokes about a soldier's identity (young enlisted troops doing jobs once limited to senior officers) or status (the techni-

cian versus the warrior) or the nature of combat stress and fatigue. Remote operators may seem like they are just playing video games, but they experience a psychological burden of fighting day after day after day, with lives on the ground depending on their flawless performance. Their commanders describe the challenges of leading units fighting remotely as being far different and sometimes even more difficult than leading regular units physically in battle.

With each step in the growing lethality and intelligence of robotics, the role of the “man in the loop” of decision making in war has begun to diminish. For example, the pace of war is such that only systems such as the Counter-Rocket Artillery and Mortar, or C-RAM (which looks a bit like the *Star Wars* robot R2-D2, with a 20-millimeter automatic machine gun attached) can react quickly enough to shoot down incoming rockets or missiles. The human is certainly part of the decision making but mainly in the initial programming of the robot. During the actual operation of the machine, the operator really only exercises veto power, and a decision to override a robot’s decision must be made in only half a second, with few willing to challenge what they view as the better judgment of the machine.

Many observers argue that such a trend will lower the likely mistakes in war, as well as ensure that the laws of war are uniformly followed, as if they were software code in a computer processor. Yet this attitude ignores the complex environment of war. An unmanned system may be able to pick out a man carrying an AK-47 rifle from over a kilometer away and tell whether he fired it recently or not (by the weapon’s thermal signature), but knowing whether that man is an insurgent, a member of an allied militia or a simple shopkeeper will be as hard for the machine as it is today for any human soldier.

Nor is the age-old “fog of war” being lifted by technology, as former defense secretary Donald H. Rumsfeld and other advocates for the digital battlefield once believed. For instance, the sophisticated C-RAM technology reportedly once mistook a U.S. Army helicopter for an enemy target because of a programming error. Fortunately, no one was hurt. Unluckily, what an investigative report described as a “software glitch” in a similar anti-aircraft system in South Africa produced a less benign outcome in 2007. Armed with a 35-millimeter cannon, the weapon was supposed to fire into the sky during a training exercise. Instead it leveled and fired in a circle, killing nine soldiers before it ran out of ammunition.

Such incidents, of course, raise immense legal concerns. How should one apportion accountability? What system of law can even be relied on for guidance? These instances demonstrate that technology often moves faster than our social institutions. How do we reconcile our 20th-century laws of war to the new reality?

A NEW BEGINNING

OUR DEFINITIONS and understandings of war, how it is fought and even who should fight are in great flux, driven by a remarkable new technology that delivers immense capability. Humankind has been in this same kind of situation before. We often struggle to integrate and understand new technologies and then eventually look at what was once considered strange and even unacceptable as completely normal. Perhaps the best example can be invoked from the 1400s, when one French nobleman argued that guns were tools of murder a true soldier would not deign to use. Only cowards, he wrote, “would not dare to look in the face of the men they bring down from a distance with their wretched bullets.”

We have “progressed” since then, but the story today is much the same with robotics. Mastery of the technology may turn out to be much easier to address than the policy dilemmas arising from the incredible capabilities of machines that can change the world around them. Indeed, it is for this reason that some scientists invoke a different historic parallel to where we stand now with robotics than the gun or airplane, instead citing the atomic bomb. We are creating an exciting technology that is pushing the frontiers of science but raises such penetrating concerns beyond the scientific realm that we may well come to regret these elaborate engineering creations, as did some designers of early nuclear warheads. Of course, just like those inventors back in the 1940s, today’s robotics developers continue their work because it is militarily useful, highly profitable, as well as the cutting edge of science. As Albert Einstein supposedly said, “If we knew what it was we were doing, it would not be called research, would it?”

The real story is that what was once only fodder for science-fiction conventions has to be discussed seriously and not only at the Pentagon. This narrative is of importance not solely to what takes place at robotic trade group meetings, in the research labs or on the battlefield but to how the overall tale of humanity is playing itself out. Humankind had a 5,000-year monopoly on the fighting of war. That monopoly has ended. ■

Despite the precision of robotic technology, the “fog of war” will surely persist.

MORE TO EXPLORE

Wired for War: The Robotics Revolution and Conflict in the 21st Century. P. W. Singer. Penguin, 2009.

Bombs Away. *The Economist*, Technology Quarterly, page 13; March 4, 2010.

The Regulation of New Warfare. Peter W. Singer. Brookings Institution. Available at www.brookings.edu/opinions/2010/0227_defense_regulations_singer.aspx

An aerial photograph of a geothermal power plant. In the foreground, there are large, dark, cylindrical steam turbines arranged in a row. White steam is rising from the turbines, drifting into the air. The plant is situated on a dry, brownish-yellow hillside. In the background, a dense forest of green trees covers a hillside. The foreground is partially obscured by the branches and needles of a pine tree.

KEY CONCEPTS

- Injecting cleansed municipal wastewater into underground geothermal fields can create sources of steam for generating electricity and reduce wastewater disposal problems.
- Projects in the Santa Rosa, Calif., area are providing lessons in how best to build shallow- and deep-drilled geothermal power plants.
- Small earthquakes can be caused in the area immediately surrounding such plants—a serious complication that municipalities must consider.

—The Editors

CLEAN ENERGY FROM FILTHY WATER

California cities are pumping
their treated wastewater
underground to create
electricity BY JANE BRAXTON LITTLE

VAPOR RISES from cooling towers at a Calpine geothermal power plant in California's Mayacamas Mountains.



RUSSIAN RIVER near Santa Rosa, Calif., is healthier since the city stopped discharging daily wastewater there.

WHEN RESIDENTS of Santa Rosa flip a wall switch, they can take a little credit for the lights that come on. In this California city, yesterday's toilet flush is today's electricity.

Santa Rosa and Calpine Corporation, an energy company, are partners in the world's largest geothermal wastewater-to-power project. They are using urban effluent to generate clean energy, improving life not only for humans but also for fish. For the city, the partnership has eliminated fines it was paying for dumping wastewater into the Russian River and the \$400-million expense of building new wastewater storage facilities. For Calpine, the arrangement has revived geothermal steam fields that were declining from overuse.

Every day the Santa Rosa Geysers Recharge Project pumps some 12 million gallons of treated wastewater through a pipeline to a mountain-top 40 miles from the city and then injects it down into an aquifer a mile and a half underground. There hot rocks boil the water into steam, which is piped to the surface to drive electricity-generating turbines. A sister project in neighboring Lake County recycles eight million gallons of wastewater a day. Together these installations generate 200 megawatts of electricity—equivalent to the output of a modest-size power plant—without discharging any greenhouse gases or pollutants into the atmosphere. Some of the electricity is sent as far as San Francisco, 70 miles to the south.

The Obama administration is touting geothermal as a clean energy source. According to the U.S. Department of Energy, the technique could supply 10 percent of the nation's electricity by 2050, and other estimates go higher. To succeed, plans to expand drilling here and to start elsewhere will have to take into account small earthquakes triggered by extracting steam. Indeed, residents near the Calpine project are complaining of increased ground shaking, and they are worried that an independent geothermal project in the same area could exacerbate the problem.

The benefits to Santa Rosa are many, however, says Dan Carlson, the city's deputy director of operations. And the partnership with Calpine offers a model for developing creative solutions to civic problems that seem overwhelming. Other communities are now exploring various styles of geothermal energy. "Every community has something unique," Carlson says. "The lesson is finding the right fit."

PUMP, DON'T DUMP

FOR SANTA ROSA, that unique something is the Geysers, a misnamed field of fumaroles—vents in rock formations that leak steam. The steam that spews out the side of the Mayacamas Mountains is visible from the city, but until recently it offered little more than a distant backdrop. In 1993 Santa Rosa was facing a cease-and-desist order and the threat of a building moratorium because of the city's illegal wastewater discharges into the Russian River, important spawning grounds for endangered coho salmon and steelhead trout. City officials were scrambling to come up with an affordable storage and disposal system that would meet state environmental requirements. On the other side of the Mayacamas, Lake County officials were under a similar state mandate to halt illegal discharges into Clear Lake, California's largest body of freshwater. Even treated to legal standards, the wastewater still contained nutrients harmful to aquatic life.

High in the hills between the two communities, officials at Calpine's geothermal operation were also in a quandary. Production of electricity was depleting the underground resource faster than it could be naturally replenished: Calpine's power plants were literally running out of steam. Company officials were searching for a source of water to inject into the steam fields to reinvigorate them.

The partnerships Calpine formed with Santa Rosa and Lake County fixed all three problems with one simple solution: moving the wastewater to where it was wanted. Today the world's first recycled-water-to-electricity project, in Lake County, and the largest, in Santa Rosa, are both poised to expand. Lake County plans to extend its pipeline beyond Clear Lake to accept wastewater from Lakeport and other communities. And the neighboring town of Windsor signed a 30-year agreement in November 2008 allowing it to pump 700,000 gallons of effluent a day into the Santa Rosa pipeline.

Officials in both counties are proud of their project's environmental achievements, but they take equal satisfaction in the regulatory and financial stability they have brought. "These were business decisions," Carlson says. "If we could provide a cheaper solution, it would help us and Calpine."

BIRTHPLACE OF AN INDUSTRY

THE STORY OF HOW the Geysers came to lose steam involves years of overexploitation. The Geysers have been hissing for millennia, part of

[THE AUTHOR]



Jane Braxton Little is a freelance writer and photographer based in Plumas County, California. She has written for numerous magazines, including *Audubon*, where she is a contributing editor.

TIMOTHY ARCHIBALD (preceding pages and Russian River); COURTESY OF MARTHA ELYNN (Braxton Little)

a geothermal system east of the San Andreas Fault. A large magma chamber more than five miles below the surface heats a layer of rock. Water trapped in this greywacke sandstone reservoir boils into steam, which fizzes out through hairline fissures in the overlying rock cap.

When William Bell Elliott wandered through in 1847 as a member of a large survey team, he dubbed the steam fields the Geysers. What he found are actually fumaroles, not the spectacular eruptions of geysers shooting hot water into the air. But Elliott's misnomer stuck. Word of the discovery drew a steady stream of tourists that included J. P. Morgan and presidents Ulysses S. Grant and Theodore Roosevelt. But by the 1930s the tourist trade had collapsed in a muddle of hotel fires, landslides and impending war.

While visitors were soaking in the steam that made some feel like "boiled angels," John D.

Grant was building the nation's first geothermal power plant at the Geysers. He completed it in 1921. Pipe blowouts and well failures notwithstanding, Grant eventually produced 250 kilowatts of electricity—enough to light the buildings and streets at the Geysers Resort. By 1960 technical advances made geothermal power commercially viable on a much larger scale. Using pipes drilled through the rock to extract steam from its source, Pacific Gas and Electric Company began operating an 11-megawatt plant. Other companies built additional plants in the 1970s and 1980s. Generation at the Geysers peaked in 1987 at 2,000 megawatts, enough to power two million homes. Calpine entered the geothermal business in 1989 and today operates 19 of the 21 Geysers power plants, spread across 40 square miles of steep slopes pocked with hundreds of steam wells.

Calpine's steam fields were failing. But city wastewater could replenish the resource.

[BIRD'S-EYE VIEW]

THREE PROBLEMS, ONE SOLUTION



Generating 200 megawatts of electricity from wastewater has displaced two billion pounds of greenhouse gas emissions annually.

RUNNING OUT OF STEAM

ALL THAT DRILLING and pumping took a toll on the steam fields. Rainfall could not seep into the sandstone reservoir fast enough to refill the reserves. By 1999 production had dropped significantly, sending Calpine officials looking for water to inject into the ground. The \$250-million Santa Rosa project presented more daunting technical challenges than its eastside counterpart in Lake County, which lies closer to the elevation of the steam fields. To get wastewater from Santa Rosa to the Geysers, a pipeline passes underneath city streets, residential developments and open fields before beginning its 3,000-foot climb into the Mayacamas.

Engineers made the pipeline as inconspicuous as possible. "This is an environmentally conscious community, and we're all stewards of this system," says Mike Sherman, Santa Rosa's operations coordinator for the Geysers. A drive along the 40-mile route from the city's Laguna treatment plant passes wild apple trees that give way to red-barked madrone and majestic valley oaks as the back roads over the pipeline wind upward. Much of the land is operated as a wildlife sanctuary by Audubon California.

A steep single-lane road leads to the pinnacle, which is dominated by a dark-green three-story tank no different from any municipal water tank except for its contents: one million gallons of wastewater. The water has been processed in

three stages along the way: physical treatment in sedimentation tanks to remove grease, oil and other impurities; biological treatment to break down organic matter and remove nutrients and additional compounds; and sand or activated carbon filtration to remove remaining organic matter and parasites. The wastewater is then exposed to ultraviolet light to kill any lingering bacteria.

Calpine uses \$2.5 million worth of its own geothermal electricity annually to pump the water to this peak, where it is stored before being injected into the steam fields east of the Mayacamas crest. Beyond the tank the ground drops through gray pines to a valley laced with pipelines shining silver in the sun. At power plants half a mile away, steam tapped from the ground turns turbines, then condenses into water that is cooled in funnel-shaped towers before it is re-injected into the ground. For the world's largest geothermal power plant, it is a surrealistic, strangely bucolic panorama disturbed only by the faint hum of engines in the breeze.

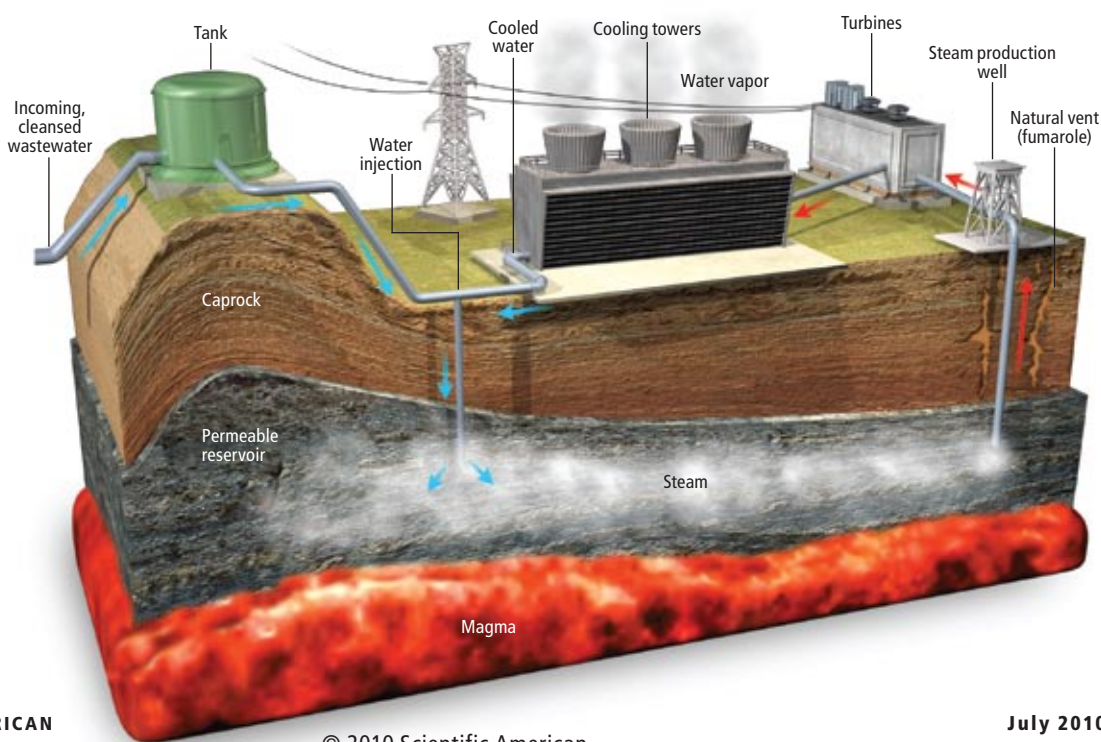
EARTHQUAKES RAISE CONCERN

FOR RESIDENTS WHO LIVE within 20 miles of the production area, however, the scene is anything but pastoral. Since Calpine began injecting effluent into the ground, local residents have experienced a dramatic increase in earthquakes; activity at the Geysers is up by 60 percent since 2003.

[HOW IT WORKS]

INJECTING NEW LIFE INTO GEOTHERMAL POWER

At the Geysers, cleansed wastewater (left) is injected into permeable stone, where heat from magma below converts it to pressurized steam. A well (right) taps the steam, which turns turbines that generate electricity. The steam condenses to water, cools and is then injected back underground.



DON FOLEY

The community of Anderson Springs, less than a mile from the closest installation, has recorded 2,562 separate jolts, including 24 with magnitudes greater than 4.0. Most tremors cause no damage, but others shake items off shelves and even crack building foundations, says Hamilton Hess, a retired University of San Francisco professor who has lived near the Geysers off and on since 1939. Other residents also describe the daily jolts as more than a nuisance: “You can hear the rumbling coming down the canyon. When it hits, it’s like an explosion under the house,” says Jeffrey D. Gospe, president of the Anderson Springs Community Alliance.

In 2009 residents found themselves facing an even greater possibility of earthquakes from an experimental project under construction outside the Geysers steam fields but just two miles from Anderson Springs. Because no surface geothermal activity is present there, AltaRock Energy, a Sausalito-based company, began to drill more than two miles down to fracture the hot bedrock, inject water and tap the resulting steam.

A similar “enhanced geothermal” project in Basel, Switzerland, triggered an earthquake measuring 3.4—modest by some standards but enough to cause more than \$8 million in damage. AltaRock officials said their Lake County project differed in the underlying geology and distance from major faults. They also said they were using technology not available in Basel. But local residents continued to protest, citing errors and exclusions in AltaRock’s environmental analyses.

Scientists have long known that extracting steam from a subterranean magma-heated reservoir cools it, causing the rocks to contract. To accommodate the contraction, the rocks deform through small earthquakes, explains David Oppenheimer, a seismologist with the U.S. Geological Survey. Spaces vacated by the steam can also cave in, causing further jolts.

Officials who planned the Santa Rosa wastewater project predicted increased seismic activity. But the city decided to proceed, citing the overriding benefits of resolving the wastewater disposal crisis and generating clean electricity. That’s small consolation to the 500 year-round residents who live within a 20-mile radius of the Geysers. “It’s Santa Rosa’s wastewater, and they don’t feel the earthquakes,” Hess says.

He and others are troubled by the expansions planned by Santa Rosa and Lake County. Will injecting greater volumes of water in more places eventually trigger “the big one?” Not likely, Oppenheimer says. Expanded production is apt to

increase the number of jolts measuring 2.0 or less, but something large like a magnitude 8.0 earthquake needs a major fault, and the Geysers area has only small fractures. In more than 30 years of monitoring there, the largest earthquake recorded has been 4.5, Oppenheimer says.

The AltaRock plan caused greater concern about more powerful earthquakes, however. In July 2009 federal agencies put the project on hold until a scientific review could better determine the risk for quakes. Facing a dubious future, AltaRock said in December that it was abandoning the effort. In January the DOE announced new safeguard requirements for enhanced geothermal operations.

EXPANDING THE BENEFITS

BY GENERATING 200 megawatts of electricity from wastewater, Santa Rosa and Lake County have effectively reduced greenhouse gas emissions by two billion pounds a year—the amount that a coal-burning power plant of comparable size would spew into the atmosphere. The city and area towns have also stopped pouring effluent into the Russian River and Clear Lake and have eliminated the need to build new storage and treatment facilities. And because Calpine is using wastewater instead of withdrawing water from Russian River tributaries—to which the company has water rights—there is more freshwater in the streams for fish.

For entrepreneurs and scientists hoping to expand the use of geothermal energy nationwide, the Calpine project offers a wealth of experience. But AltaRock’s fate could lessen interest in deep-drilled enhanced geothermal systems at sites with no surface activity, even though they could produce more than 100,000 megawatts of electricity in the U.S., according to a study led by Jefferson W. Tester, professor of sustainable energy systems at Cornell University. In May 2009 the Obama administration made \$350 million available for geothermal development, including \$80 million for enhanced geothermal projects.

For the many potential sites that lack an adequate supply of water to inject into the hot rocks, the power plants at the Geysers still serve as an inspiration. They have demonstrated that treated effluent is a commercially viable alternative to freshwater for steam-generated electricity, Carlson says. Of course, safety issues require more study. But he is optimistic: “Our residents are benefiting, the environment is benefiting and people all over the world can use this model to improve their own communities.” ■



LOCAL RESIDENT Jeffrey D. Gospe and fellow community activists who live near the power plants want geothermal operations changed to reduce potential damage from earthquakes, which have risen in frequency.

MORE TO EXPLORE

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WINGED VICTORY

Modern birds, long thought to have arisen only after the dinosaurs perished, turn out to have lived alongside them **BY GARETH DYKE**

D ECEMBER IN MOSCOW, and the temperature drops under 15 degrees below zero. The radiators in the bar have grown cold, so I sit in a thick coat and gloves drinking vodka while I ponder the fossil birds. The year is 2001, and Evgeny N. Kurochkin of the Russian Academy of Sciences and I have just spent hours at the paleontology museum as part of our effort to survey all the avian fossils ever collected in Mongolia by joint Soviet-Mongolian expeditions. Among the remains is a wing unearthed in the Gobi Desert in 1987. Compared with the spectacularly preserved dinosaur skeletons in the museum's collections, this tiny wing—its delicate bones jumbled and crushed—is decidedly unglamorous. But it offers a strong hint that a widely held view of bird evolution is wrong.

More than 10,000 species of birds populate the earth today. Some are adapted to living far out on the open ocean, others eke out a living in arid deserts, and

KEY CONCEPTS

- The descent of birds from small, meat-eating dinosaurs is by now established. Far less clear is the origin of anatomically modern birds.
- The conventional fossil-based thinking is that modern birds arose only after the asteroid impact that claimed the dinosaurs and many other creatures 65 million years ago.
- But molecular studies and a smattering of equivocal fossil finds have hinted that modern birds might have deeper roots.
- Recently analyzed fossils of ancient modern birds confirm this earlier origin, raising the question of why these birds, but not the archaic ones, survived the mass extinction.

—The Editors

SIDE BY SIDE: Based on fossil evidence from Antarctica, this artist's conception depicts *Vegavis*, an early modern bird, foraging alongside duck-billed dinosaurs in a marine estuary some 67 million years ago.

KAZUHIKO SANO

still others dwell atop snow-capped mountains. Indeed, of all the classes of land vertebrates, the one comprising birds is easily the most diverse. Evolutionary biologists long assumed that the ancestors of today's birds owed their success to the asteroid impact that wiped out the dinosaurs and many other land vertebrates around 65 million years ago. Their reasoning was simple: although birds had evolved before that catastrophe, anatomically modern varieties appeared in the fossil record only after that event. The dawning of ducks, cuckoos, hummingbirds and other modern forms—which together make up the neornithine (“new birds”) lineage—seemed to be a classic case of an evolutionary radiation in response to the clearing out of ecological niches by an extinction event. In this case, the niches were those occupied by dinosaurs, the flying reptiles known as pterosaurs and archaic birds.

Over the past decade, however, mounting evidence from the fossil record—including that crushed wing—and from analyses of the DNA of living birds has revealed that neornithine birds probably diversified earlier than 65 million years ago. The findings have upended the traditional view of bird evolution—and sparked important new questions about how these animals soared to evolutionary heights.

EARLY BIRDS

BIRDS ARE ONE of just three groups of vertebrates ever to have evolved active, flapping flight. The other two are the ill-fated pterosaurs and the bats, which appeared much later and share the skies with birds to this day. For years paleontologists debated the origin of the earliest birds. One side argued that they evolved from small, meat-eating dinosaurs called theropods; the other contended that they evolved from earlier reptiles. But the discoveries over the past two decades of birdlike dinosaurs, including many with downy coats, have convinced most scientists that birds evolved from theropod dinosaurs.

Connecting the dots between ancestral avians and modern birds has proved far trickier, however. Consider *Archaeopteryx*, the 145-million-year-old creature from Germany that is the oldest known bird. *Archaeopteryx* preserves the earliest definitive evidence for wings with asymmetric feathers capable of generating the lift required for flight—one defining characteristic of the group. Yet it more closely resembles small-bodied dinosaurs such as *Velociraptor*,

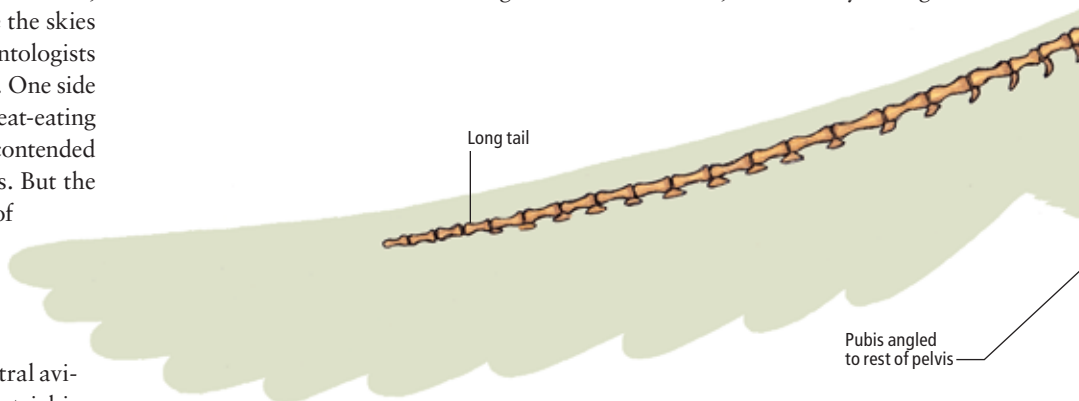
[THE AUTHOR]



Gareth Dyke prefers dry bones and flattened fossils to living birds. A paleontologist at University College Dublin, he became interested in animal flight when he was an undergraduate student in England. In conducting his research on the evolution of birds and their flight, he has studied and described fossils from all over the world. When not traveling to visit museums or to do fieldwork in the middle of deserts, Dyke enjoys learning about 19th-century European history. He is writing a book about a Transylvanian dinosaur collector who was also a spy for Austria-Hungary.

Deinonychus, *Anchiornis* and *Troodon* than modern birds. Like those dinosaurs, early birds such as *Archaeopteryx* and the more recently discovered *Jeholornis* from China and *Rahonavis* from Madagascar possessed long, bony tails, and some had sharp teeth, among other primitive traits. Neornithines, in contrast, lack those characteristics and exhibit a suite of advanced ones. These features include fully fused toe bones and fingerless wings, which reduce the weight of the skeleton, allowing more efficient flight, and highly flexible wrists and wings, which enhance maneuverability in the air. How and when the neornithines acquired these traits were impossible to determine, however, thanks to an absence of fossils documenting the transition.

This is not to say the fossil record lacked avian remains intermediate in age between the first birds and the postextinction neornithines. Clearly by the early Cretaceous, more than 100 million years ago, birds representing a wide range of flight adaptations and ecological specializations had evolved. Some flew on wings that were broad and wide; others had wings that were long and thin. Some lived in forests eating insects and fruit; others made their home along lakeshores or in the water and subsisted on fish. This incredible diversity persisted through the latest stages of the Cretaceous, 65 million years ago.



BIRDS EVOLVED FROM small, carnivorous dinosaurs. Accordingly, some of the oldest known fossil birds, such as the 145-million-year-old *Archaeopteryx*, retain a number of primitive characteristics linking them to this so-called theropod group—teeth and long tails, for instance. Modern birds shed these features and evolved fingerless wings and highly flexible wrists, among other traits that enhanced their flying ability.

PATRICIA J. WYNNE

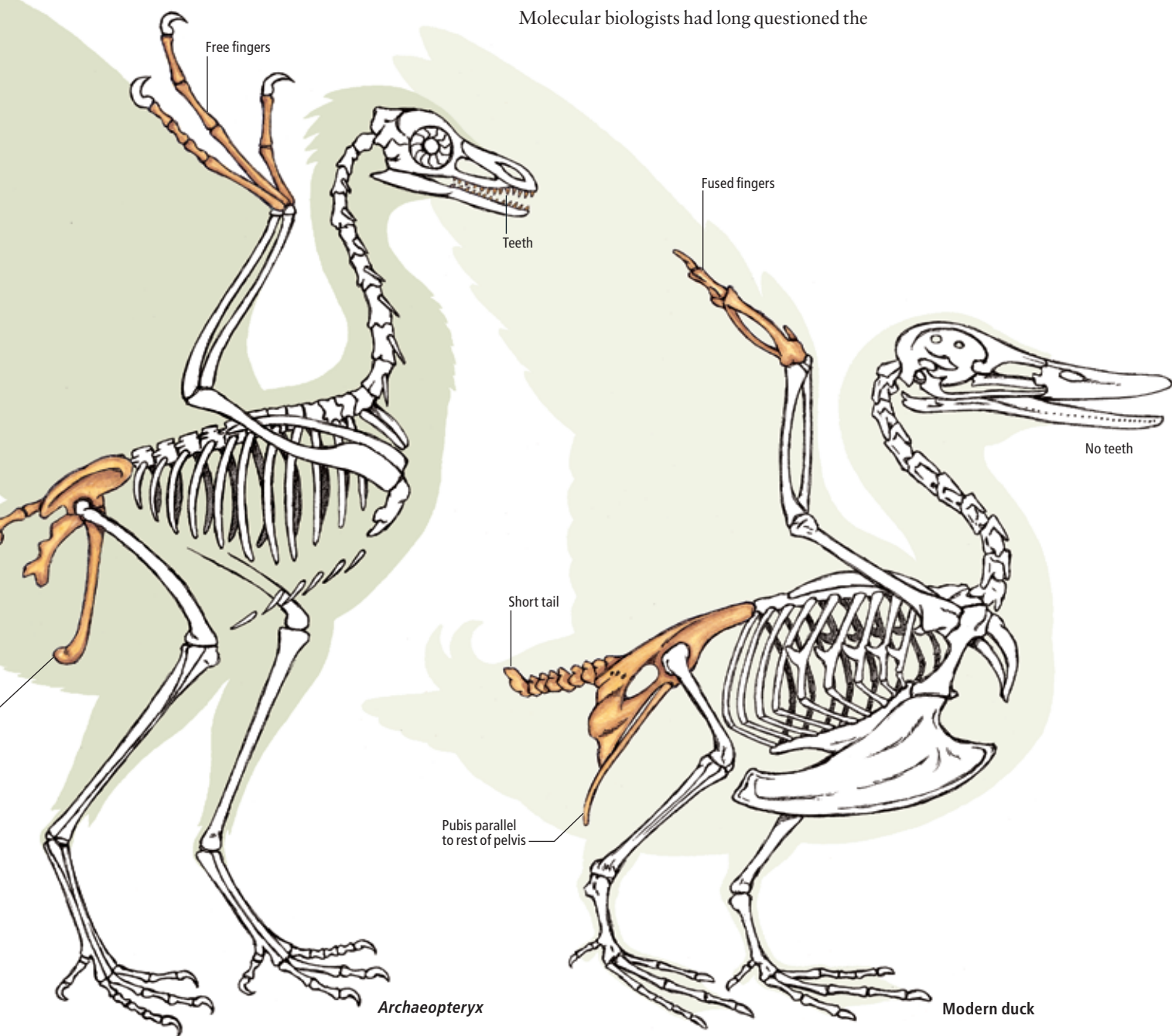
In fact, along with my Dutch colleagues at the Natural History Museum in Maastricht, I have described remains of toothed birds found just below the geologic horizon that marks the end-Cretaceous extinction event. But all the Cretaceous birds complete enough to classify belonged to lineages more ancient than neornithines, and these lineages did not survive the catastrophe—which is why, until recently, the available evidence implied that the simplest explanation for the rise of modern birds was that they originated and radiated after the extinction event.

MOLECULAR CLUES

BY THE 1990s, while paleontologists were still looking for ancestral neornithines in the Cretaceous and coming up empty-handed, another method of reconstructing the evolutionary history of organisms—one that did not involve the fossil record—was gaining traction. Molecular biologists were sequencing the DNA of living organisms and comparing those sequences to estimate when two groups split from each other. They can make such estimates because certain parts of the genome mutate at a more or less constant rate, constituting the “ticking” of the so-called molecular clock.

Molecular biologists had long questioned the

It is funny to think of a robin perched on the back of a *Velociraptor* or a duck paddling alongside a *Spinosaurus*.



Why were modern birds able to survive the asteroid impact and its attendant ecological changes when their more primitive avian cousins and their fellow fliers, the pterosaurs, were not?

classical, fossil-based view of modern bird evolution. So they tackled the problem using their clock technique to estimate the divergence dates for major lineages of modern birds. Among the most significant splits is the one that occurred between the large, mostly flightless paleognaths (ostriches and emu and their kin) and the Galloanserae (which includes chickens and other members of the Galliformes group, as well as ducks and other members of the Anseriformes group). The DNA studies concluded that these two lineages—the most primitive of the living neornithines—split from each other deep in the Cretaceous. And researchers obtained similarly ancient divergence dates for other lineages.

The findings implied that, contrary to conventional paleontological wisdom, neornithines lived alongside dinosaurs. It is funny to think of a robin perched on the back of a *Velociraptor* or a duck paddling alongside a *Spinosaurus*. But the molecular evidence for the contemporaneity of modern birds and dinosaurs was so compelling that even the paleontologists—who have typically viewed with skepticism those DNA findings that conflict with the fossil record—began to embrace it. Still, those of us who study ancient skeletons urgently wanted fossil confirmation of this new view of bird evolution.

DUCKS IN A ROW

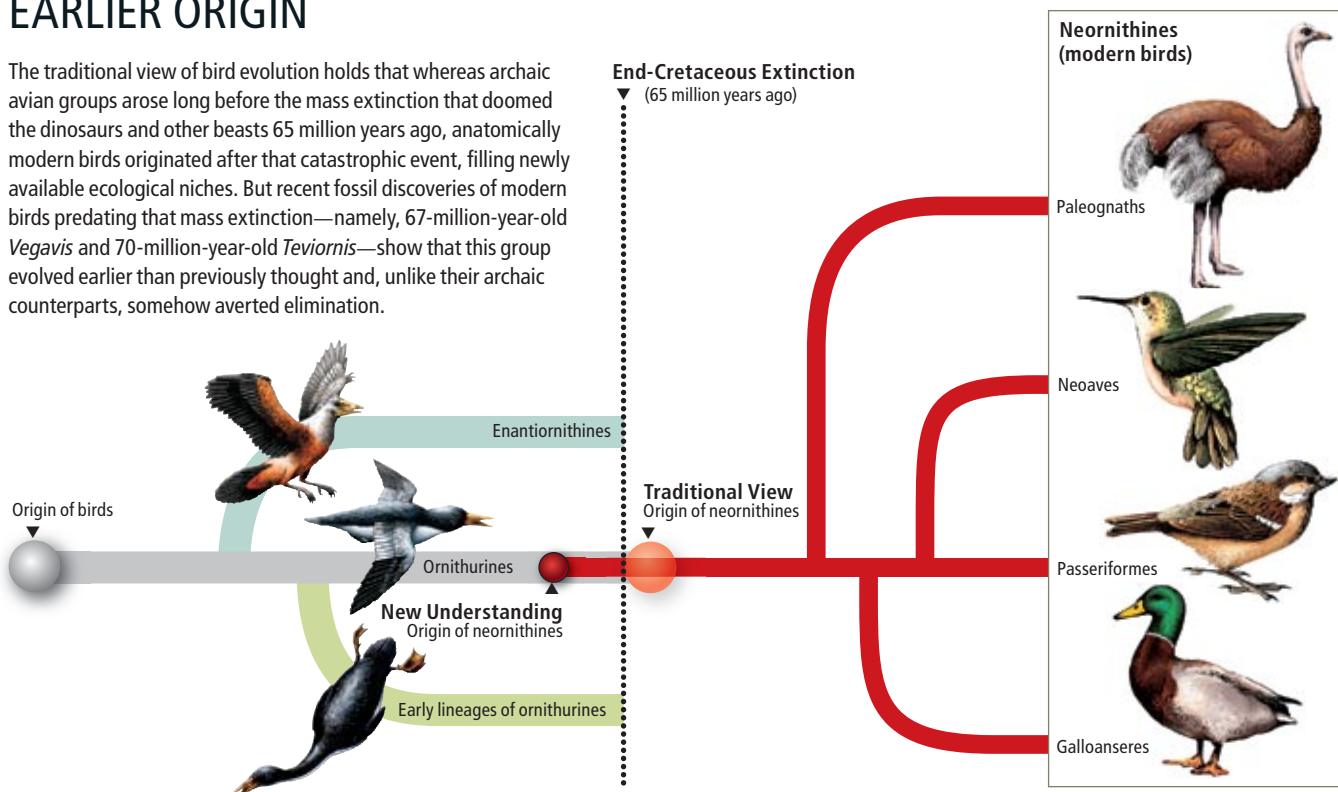
AT LAST, after the new millennium, paleontologists' luck began to change for the better, starting with the tiny Mongolian wing that Evgeny and I focused on in Moscow. Back when Evgeny first saw the fossil in 1987, he told me that he thought it looked like a member of the presbyornithids, a group of now extinct ducklike birds related to modern ducks and geese. But at 70 million years old, it was a Cretaceous bird, and everyone knew—or thought they did—that there was no definitive evidence for presbyornithids in the Cretaceous. Yet our comparisons in the museum that cold winter in 2001 demonstrated conclusively that the wing—with its straight carpo-metacarpus (the bone formed by the fusion of the hand bones) and details of canals, ridges and muscle scars—did indeed belong to a presbyornithid, which, moreover, was the oldest unequivocal representative of any neornithine group. Our finding fit the predictions of the molecular biologists perfectly. In a 2002 paper that formally described the animal, we gave it the name *Teviornis*.

Before long, *Teviornis* was joined by a second confirmed early neornithine, *Vegavis*, from Antarctica's Vega Island. *Vegavis* had been found in the 1990s only to languish in relative anonymity

[FINDING]

EARLIER ORIGIN

The traditional view of bird evolution holds that whereas archaic avian groups arose long before the mass extinction that doomed the dinosaurs and other beasts 65 million years ago, anatomically modern birds originated after that catastrophic event, filling newly available ecological niches. But recent fossil discoveries of modern birds predating that mass extinction—namely, 67-million-year-old *Vegavis* and 70-million-year-old *Teviornis*—show that this group evolved earlier than previously thought and, unlike their archaic counterparts, somehow averted elimination.



SHAWN GOULD (fossil birds and sparrow); JEN CHRISTIANSEN (ostrich, hummingbird and duck)

for years before its true significance came to light. In 2005 Julia A. Clarke, now at the University of Texas at Austin, and her colleagues published a paper showing that *Vegavis* was another bird from the Cretaceous that exhibits a number of features found in modern ducks, particularly in its broad shoulder girdle, pelvis, wing bones and lower legs. At 66 million to 68 million years old, *Vegavis* is a little younger than *Teviornis* but still clearly predates the mass extinction. And it is a much more complete fossil, preserving the better part of a skeleton.

For most paleontologists, *Vegavis* clinched the case for Cretaceous neornithines. Thus enlightened, researchers have begun reexamining fossil collections from this time period, looking for additional examples of early modern birds. One investigator, Sylvia Hope of the California Academy of Sciences in San Francisco, had been arguing for years that bird species she has identified from fossils found in New Jersey and Wyoming that date to between 80 million and 100 million years ago are modern. But the finds—mostly single bones—had been considered by other researchers as too scrappy to identify conclusively. The revelations about *Vegavis* and *Teviornis* suggest that she was right all along. Comparisons of Hope's bones with more complete remains should prove illuminating in this regard.

FLYING THE COOP

ROOTING MODERN BIRDS in the Cretaceous neatly aligned the fossil record with the DNA-based divergence dates. But it raised a vexing new question, namely, Why were modern birds able to survive the asteroid impact and its attendant ecological changes when their more primitive avian cousins and their fellow fliers, the pterosaurs, were not? To my mind, this constitutes the single biggest remaining mystery of bird evolution. The answer is still very much up for grabs, and I am devoting much of my research at the moment to trying to get at it.

With only a couple of confirmed Cretaceous neornithines on record, there is not much in the way of fossil clues to go on. Insights have come from studies of living birds, however. Using a huge data set of measurements of living birds, my colleagues in the U.K. and I have shown, for example, that the wing-bone proportions of primitive modern birds, including *Teviornis* and *Vegavis*, are no different from those of the extinct enantiornithines. Comparing the fossil wing-bone proportions with those of living birds allows us to infer some aspects of wing shape

and hence gain information about the aerodynamic capabilities of fossil birds. But so far as we can tell, the wing shapes of the two groups of fossil birds do not differ; in other words, we do not think that early neornithines were any better at flying than were the enantiornithines (although both these groups were most likely better in the air than earlier theropodlike birds such as *Archaeopteryx*).

If flight ability did not give the neornithines an advantage over their Cretaceous counterparts, what did? A number of paleontologists, including me, have posited that differences in foraging habits might have conferred a competitive edge. In support of that theory, I have shown in a series of papers published over the past few years that modern birds preserved in the immediate aftermath of the mass extinction, in rocks 60 million years old and younger, probably lived mostly in wet environments: coastlines, lakes, the edges of rivers and the deep ocean, for example. Many of the birds that inhabit such environments today—ducks among them—are typically generalists, able to subsist on a wide variety of foods. And ducklike birds are currently the one confirmed lineage of modern birds we have found in the Cretaceous. The groups of Cretaceous birds that did not survive the disaster, in contrast, have been collected from rocks that were formed in many different kinds of environments—including seashores, inland areas, deserts and forests. This ecological diversity may indicate that the archaic birds had evolved specializations for feeding in each of these niches. Perhaps, then, the secret of early modern birds' success was simply the fact that they were less specialized than the other groups.

Such flexibility might have enabled the neornithines to adapt more easily to the changing conditions that followed the asteroid impact. It is an appealing idea, but these are early days. Only with the discovery of more fossils—whether in the ground or in museum drawers—will we be able to determine how modern birds eluded elimination and took wing.

HARD EVIDENCE

Partial skeleton of *Vegavis* from Antarctica's Vega Island reveals a 67-million-year-old bird with distinctly modern features, including a broad shoulder girdle and fused wing bones.



MORE TO EXPLORE

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Survival in the First Hours of the Cenozoic. Douglas S. Robertson et al. in *Geological Society of America Bulletin*, Vol. 116, Nos. 5–6, pages 760–768; May 2004.

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The Beginnings of Birds: Recent Discoveries, Ongoing Arguments and New Directions. Luis M. Chiappe and Gareth J. Dyke in *Major Transitions in Vertebrate Evolution*. Edited by J. S. Anderson and H.-D. Sues. Indiana University Press, 2007.

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How Babies Think

Even the youngest children know, experience and learn far more than scientists ever thought possible

BY ALISON GOPNIK

Photographs by Timothy Archibald

KEY CONCEPTS

- Babies' and young children's cognitive abilities far surpass those that psychologists long attributed to them. They can, for instance, imagine another person's experiences and grasp cause and effect.
- Children learn about the world much as scientists do—in effect, conducting experiments, analyzing statistics and forming theories to account for their observations.
- The long helplessness of babies may be an evolutionary trade-off, a necessary consequence of having brains wired for prodigious feats of learning and creativity.

—The Editors

THIRTY YEARS AGO most psychologists, philosophers and psychiatrists thought that babies and young children were irrational, egocentric and amoral. They believed children were locked in the concrete here and now—unable to understand cause and effect, imagine the experiences of other people, or appreciate the difference between reality and fantasy. People still often think of children as defective adults.

But in the past three decades scientists have discovered that even the youngest children know more than we would ever have thought possible. Moreover, studies suggest that children learn about the world in much the same way that scientists do—by conducting experiments, analyzing statistics, and forming intuitive theories of the physical, biological and psychological realms. Since about 2000, researchers have started to understand the underlying computational, evolutionary and neurological mechanisms that underpin these remarkable early abilities. These revolutionary findings not only change our ideas about babies, they give us a fresh perspective on human nature itself.

PHYSICS FOR BABIES

WHY WERE WE so wrong about babies for so long? If you look cursorily at children who are four years old and younger (the age range I will

discuss in this article), you might indeed conclude that not much is going on. Babies, after all, cannot talk. And even preschoolers are not good at reporting what they think. Ask your average three-year-old an open-ended question, and you are likely to get a beautiful but incomprehensible stream-of-consciousness monologue. Earlier researchers, such as the pioneering Swiss psychologist Jean Piaget, concluded that children's thought itself was irrational and illogical, egocentric and "precausal"—with no concept of cause and effect.

The new science that began in the late 1970s depends on techniques that look at what babies and young children do instead of just what they say. Babies look longer at novel or unexpected events than at more predictable ones, and experimenters can use this behavior to figure out what babies expect to happen. The strongest results, however, come from studies that observe actions as well: Which objects do babies reach for or crawl to? How do babies and young children imitate the actions of people around them?

Although very young children have a hard time telling us what they think, we can use language in more subtle ways to tease out what they know. For example, Henry Wellman of the University of Michigan at Ann Arbor has analyzed recordings of children's spontaneous conversations for clues to their thinking. We can give chil-



Babies look longer at novel or unexpected events than at more predictable ones, and experimenters can use this behavior to figure out what babies expect to happen.

dren very focused questions—for instance, asking them to choose between just two alternatives, rather than asking an open-ended question.

In the mid-1980s and through the 1990s, scientists using these techniques discovered that babies already know a great deal about the world around them. That knowledge goes well beyond concrete, here-and-now sensations. Researchers such as Renée Baillargeon of the University of Illinois and Elizabeth S. Spelke of Harvard University found that infants understand fundamental physical relations such as movement trajectories, gravity and containment. They look longer at a toy car appearing to pass through a solid wall than at events that fit basic principles of everyday physics.

By the time they are three or four, children have elementary ideas about biology and a first understanding of growth, inheritance and illness. This early biological understanding reveals that children go beyond superficial perceptual appearances when they reason about objects. Susan A. Gelman, also at Michigan, found that young children believe that animals and plants have an “essence”—an invisible core that stays the same even if outside appearances change.

For babies and young children, the most important knowledge of all is knowledge of other people. Andrew N. Meltzoff of the University of Washington showed that newborns already understand that people are special and will imitate their facial expressions.

In 1996 Betty Repacholi (now at Washington) and I found that 18-month-olds can understand that I might want one thing, whereas you want another. An experimenter showed 14- and 18-month-olds a bowl of raw broccoli and a bowl of goldfish crackers and then tasted some of each, making either a disgusted face or a happy face. Then she put her hand out and asked, “Could you give me some?” The 18-month-olds gave her broccoli when she acted as if she liked it, even though they would not choose it for themselves. (The 14-month-olds always gave her crackers.) So even at this very young age, children are not completely egocentric—they can take the perspective of another person, at least in a simple way. By age four, their understanding of everyday psychology is even more refined. They can explain, for instance, if a person is acting oddly because he believes something that is not true.

By the end of the 20th century experiments had thus charted impressively abstract and sophisticated knowledge in babies and the equally impressive growth of that knowledge as children

get older. Some scientists have argued that babies must be born knowing much of what adults know about how objects and people behave. Undoubtedly, newborns are far from being blank slates, but the changes in children’s knowledge also suggest that they are learning about the world from their experiences.

One of the greatest mysteries of psychology and philosophy is how human beings learn about the world from a confusing mess of sensory data. Over the past decade researchers have begun to understand much more about how babies and young children can learn so much so quickly and accurately. In particular, we have discovered that babies and young children have an extraordinary ability to learn from statistical patterns.

THE STATISTICS OF BLICKETS

IN 1996 Jenny R. Saffran, Richard N. Aslin and Elissa L. Newport, all then at the University of Rochester, first demonstrated this ability in studies of the sound patterns of language. They played sequences of syllables with statistical regularities to some eight-month-old babies. For example, “bi” might follow “ro” only one third of the time, whereas “da” might always follow “bi.” Then they played the babies new strings of sounds that either followed these patterns or broke them. Babies listened longer to the statistically unusual strings. More recent studies show that babies can detect statistical patterns of musical tones and visual scenes and also more abstract grammatical patterns.

Babies can even understand the relation between a statistical sample and a population. In a 2008 study my University of California, Berkeley, colleague Fei Xu showed eight-month-old babies a box full of mixed-up Ping-Pong balls: for instance, 80 percent white and 20 percent red. The experimenter would then take out five balls, seemingly at random. The babies were more surprised (that is, they looked longer and more intently at the scene) when the experimenter pulled four red balls and one white one out of the box—an improbable outcome—than when she pulled out four white balls and one red one.

Detecting statistical patterns is just the first step in scientific discovery. Even more impressively, children (like scientists) use those statistics to draw conclusions about the world. In a version of the Ping-Pong ball study with 20-month-old babies using toy green frogs and yellow ducks, the experimenter would take five toys from the box and then ask the child to give her a toy from some that were on the table. The children showed

[THE AUTHOR]



Alison Gopnik is professor of psychology and affiliate professor of philosophy at the University of California, Berkeley. She has done groundbreaking research into how children develop a “theory of mind,” the ability to understand that other people have minds and may believe or want different things than they do. She helped to formulate the “theory theory,” the idea that children learn in the same way that scientists do. Investigations of children’s minds, she argues, could help us resolve deep philosophical questions such as the mystery of consciousness.

no preference between the colors if the experimenter had taken mostly green frogs from the box of mostly green toys. Yet they specifically gave her a duck if she had taken mostly ducks from the box—apparently the children thought her statistically unlikely selection meant that she was not acting randomly and that she must prefer ducks.

In my laboratory we have been investigating how young children use statistical evidence and experimentation to figure out cause and effect, and we find their thinking is far from being “pre-causal.” We introduce them to a device we call “the blinket detector,” a machine that lights up and plays music when you put some things on it but not others. Then we can give children patterns of evidence about the detector and see what causal conclusions they draw. Which objects are the blinkets?

In 2007 Tamar Kushnir, now at Cornell University, and I discovered that preschoolers can use probabilities to learn how the machine works. We repeatedly put one of two blocks on the machine. The machine lit up two out of three times with the yellow block but only two out of six times for the blue one. Then we gave the children the blocks and asked them to light up the machine. These children, who could not yet add or subtract, were more likely to put the high-probability yellow block on the machine.

They still chose correctly when we waved the high-probability block over the machine, activating it without touching it. Although they thought this kind of “action at a distance” was unlikely at the start of the experiment (we asked them), these children could use probability to discover brand-new and surprising facts about the world.

In another experiment Laura Schulz, now at the Massachusetts Institute of Technology, and I showed four-year-olds a toy with a switch and two gears, one blue and one yellow, on top. The gears turn when you flip the switch. This simple toy can work in many ways. Perhaps the switch makes both gears turn at once, or perhaps the switch turns the blue gear, which turns the yellow one, and so on. We showed the children pictures illustrating each of these possibilities—the yellow gear would be depicted pushing the blue one, for instance. Then we showed them toys that worked in one or the other of these ways and gave them rather complex evidence about how each toy worked. For example, the children who got the “causal chain toy” saw that if you removed the blue gear and turned the switch, the yellow gear would still turn but that if you re-



moved the yellow gear and turned the switch, nothing happened. We asked the children to pick the picture that matched how the toy worked. Four-year-olds were amazingly good at ascertaining how the toy worked based on the pattern of evidence that we presented to them. Moreover, when other children were just left alone with the machine, they played with the gears in ways that helped them learn how it worked—as if they were experimenting.

Another study by Schulz used a toy that had two levers and a duck and a puppet that popped up. One group of preschoolers was shown that the duck appeared when you pressed one lever and that the puppet popped up when you pressed the other one. The second group saw that when you pressed both levers at once, both toys popped up, but they never got a chance to see what the levers did separately. Then the experimenter had the children play with the toy. Children from the first group played with the toy much less than those from the second group. They already knew how it worked and were less interested in exploring it. The second group faced a mystery, and they spontaneously played with the toy, soon uncovering which lever did what.

These studies suggested that when children play spontaneously (“getting into everything”)

STATISTICIAN AT WORK

Babies are skillful statistical analysts. Experiments showed that eight-month-olds notice if an improbable number of red Ping-Pong balls are taken out of a collection that is mostly white. Variations of the experiments (such as swapping the role of red and white) control against alternative explanations (such as having a greater interest in red objects). Twenty-month-olds tested with green and yellow toys inferred that a person taking an unusually large number of the rare color would prefer to be given a toy of that color. Thus, babies and young children learn about the world like scientists—by detecting statistical patterns and drawing conclusions from them.

NATURAL EXPERIMENTERS

Four-year-olds are adept at interpreting evidence to learn about cause and effect, such as determining if one cog on a machine is turning another (below). Some even carried out the correct experiments (and drew the right conclusion) while freely “playing” with the toy. Research involving a “blicket detector” (opposite page), which is more likely to light up for some combinations of blocks than for others, found that four-year-olds could use statistics to learn how the machine worked, even when it showed new, unexpected behavior. Indeed, they were more open-minded than adults when faced with evidence that the machine responded to blocks in an unusual way.

they are also exploring cause and effect and doing experiments—the most effective way to discover how the world works.

THE BABY COMPUTER

OBVIOUSLY CHILDREN ARE NOT doing experiments or analyzing statistics in the self-conscious way that adult scientists do. The children’s brains, however, must be unconsciously processing information in a way that parallels the methods of scientific discovery. The central idea of cognitive science is that the brain is a kind of computer designed by evolution and programmed by experience.

Computer scientists and philosophers have begun to use mathematical ideas about probability to understand the powerful learning abilities of scientists—and children. A whole new approach to developing computer programs for machine learning uses what are called probabilistic models, also known as Bayesian models or Bayes nets. The programs can unravel complex gene expression problems or help understand climate change. The approach has also led to new ideas about how

the computers in children’s heads might work.

Probabilistic models combine two basic ideas. First, they use mathematics to describe the hypotheses that children might have about things, people or words. For example, we can represent a child’s causal knowledge as a map of the causal relations between events. An arrow could point from “press blue lever” to “duck pops up” to represent that hypothesis.

Second, the programs systematically relate the hypotheses to the probability of different patterns of events—the kind of patterns that emerge from experimentation and statistical analysis in science. Hypotheses that fit the data better become more likely. I have argued that children’s brains may relate hypotheses about the world to patterns of probability in a similar way. Children reason in complex and subtle ways that cannot be explained by simple associations or rules.

Furthermore, when children unconsciously use this Bayesian statistical analysis, they may actually be better than adults at considering unusual possibilities. In a study to be presented at a conference later this year, my colleagues and I showed four-year-olds and adults a blicket detector that worked in an odd way, requiring two blocks on it together to make it go. The four-year-olds were better than the adults at grasping this unusual causal structure. The adults seemed to rely more on their prior knowledge that things usually do not work that way, even though the evidence implied otherwise for the machine in front of them.

In other recent research my group found that young children who think they are being instructed modify their statistical analysis and may become less creative as a result. The experimenter showed four-year-olds a toy that would play music if you performed the right sequence of actions on it, such as pulling a handle and then squeezing a bulb. For some children, the experimenter said, “I don’t know how this toy works—let’s figure it out.” She proceeded to try out various longer action sequences for the children, some that ended with the short sequence and made music and some that did not. When she asked the children to make the toy work, many of them tried the correct short sequence, astutely omitting actions that were probably superfluous based on the statistics of what they had seen.

With other children, the experimenter said that she would teach them how the toy worked by showing them sequences that did and did not produce music, and then she acted on the toy in exactly the same way. When asked to make the



toy work, these children never tried a shortcut. Instead they mimicked the entire sequence of actions. Were these children ignoring the statistics of what they saw? Perhaps not—their behavior is accurately described by a Bayesian model in which the “teacher” is expected to choose the most instructive sequences. In simple terms: if she knew shorter sequences worked, she would not have shown them the unnecessary actions.

EVOLUTION AND NEUROLOGY

IF THE BRAIN is a computer designed by evolution, we can also ask about the evolutionary justification and neurological basis for the extraordinary learning abilities we see in very young children. Recent biological thinking is in close accord with what we see in the psychology lab.

From an evolutionary perspective, one of the most striking things about human beings is our long period of immaturity. We have a much longer childhood than any other species. Why make babies so helpless for so long and thus require adults to put so much work and care into keeping their babies alive?

Across the animal kingdom, the intelligence and flexibility of adults are correlated with the immaturity of babies. “Precocial” species such as chickens rely on highly specific innate capacities adapted to one particular environmental niche, and so they mature quickly. “Altricial” species (those whose offspring need care and feeding by parents) rely on learning instead. Crows, for instance, can take a new object, such as a piece of wire, and work out how to turn it into a tool, but young crows depend on their parents for much longer than chickens.

A learning strategy has many advantages, but until learning takes place, you are helpless. Evolution solves this problem with a division of labor between babies and adults. Babies get a protected time to learn about their environment, without having to actually do anything. When they grow up, they can use what they have learned to be better at surviving and reproducing—and taking care of the next generation. Fundamentally, babies are designed to learn.

Neuroscientists have started to understand some of the brain mechanisms that allow all this learning to occur. Baby brains are more flexible than adult brains. They have far more connections between neurons, none of them particularly efficient, but over time they prune out unused connections and strengthen useful ones. Baby brains also have a high level of the chemicals that make brains change connections easily.



The brain region called the prefrontal cortex is distinctive to humans and takes an especially long time to mature. The adult capacities for focus, planning and efficient action that are governed by this brain area depend on the long learning that occurs in childhood. This area’s wiring may not be complete until the mid-20s.

The lack of prefrontal control in young children naturally seems like a huge handicap, but it may actually be tremendously helpful for learning. The prefrontal area inhibits irrelevant thoughts or actions. But being uninhibited may help babies and young children to explore freely. There is a trade-off between the ability to explore creatively and learn flexibly, like a child, and the ability to plan and act effectively, like an adult. The very qualities needed to act efficiently—such as swift automatic processing and a highly pruned brain network—may be intrinsically antithetical to the qualities that are useful for learning, such as flexibility.

A new picture of childhood and human nature emerges from the research of the past decade. Far from being mere unfinished adults, babies and young children are exquisitely designed by evolution to change and create, to learn and explore. Those capacities, so intrinsic to what it means to be human, appear in their purest forms in the earliest years of our lives. Our most valuable human accomplishments are possible because we were once helpless dependent children and not in spite of it. Childhood, and caregiving, is fundamental to our humanity. ■

MORE TO EXPLORE

The Scientist in the Crib: Minds, Brains, and How Children Learn. Alison Gopnik, Andrew N. Meltzoff and Patricia K. Kuhl. William Morrow and Company, 1999.

Bayesian Networks, Bayesian Learning and Cognitive Development. Special section in *Developmental Science*, Vol. 10, No. 3, pages 281–364; May 2007.

Causal Learning: Psychology, Philosophy, and Computation. Edited by Alison Gopnik and Laura Schulz. Oxford University Press, 2007.

The Philosophical Baby: What Children’s Minds Tell Us about Truth, Love, and the Meaning of Life. Alison Gopnik. Farrar, Straus and Giroux, 2009.

Alison Gopnik’s Web site:
alisongopnik.com

The Drillers Are Coming

Companies and regulators are squaring off over a controversial technique that yields natural gas but threatens to pollute water supplies **BY MARK FISCHETTI**

ASINGLE, VAST SHALE DEPOSIT—the Marcellus formation, stretching from Tennessee to New York—might contain enough natural gas to supply the U.S. for more than 40 years at today’s consumption rates, according to recent estimates. Thousands of vertical wells have exploited the shale’s easy-to-reach deposits. But newer technology and improved procedures are making horizontal drilling cost-effective, greatly expanding the amount of gas that can be extracted economically.

Political pressure is increasing to achieve energy independence from overseas suppliers and to use cleaner sources such as natural gas to create electricity, which emits 40 percent less carbon dioxide than burning coal. In response, the

rush is on to capture as much Marcellus gas as possible. Drilling is expanding fastest in Pennsylvania’s extensive reserve. Only two Marcellus wells were drilled in that state in 2005, but 210 were drilled in 2008, and 768 were drilled in 2009, according to the Pennsylvania Department of Environmental Protection (DEP). And every year the portion of drilling permits for horizontal wells has increased significantly, accounting for 75 percent in 2009 and 87 percent so far in 2010. Fewer than 3,000 Marcellus drilling permits were approved from 2005 through 2009, yet “we expect about 5,000 applications in 2010,” says John Hanger, secretary of the DEP. Horizontal drilling is spreading rapidly across Europe as well.

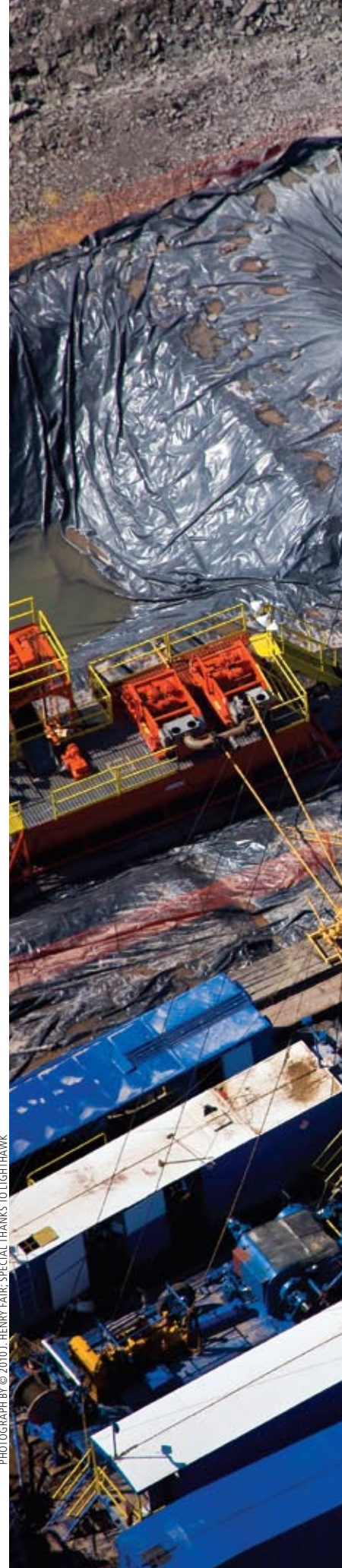
Concern is growing, too: scientists, politicians and public advocates are claiming with increasing urgency that the horizontal process—known as slickwater hydraulic fracturing, or fracking—poses a threat to the environment and people’s health. Enormous volumes of freshwater and chemicals are forced down the wells to break the rock and free the gas, and large quantities of fouled water flow back up.

Residents in states where fracking has been practiced for years have charged that gas production has contaminated air and drinking water. Investigations by state or federal agencies in

KEY CONCEPTS

- The Marcellus shale could potentially supply the country’s natural gas needs for 40 years.
- Critics claim the hydraulic fracturing process that taps the gas can contaminate drinking water supplies, prompting regulators to propose tough controls.
- Full disclosure of chemicals injected into the earth during the fracking process could ease tensions.

—The Editors



PHOTOGRAPH BY © 2010 J. HENRY FAIR; SPECIAL THANKS TO LIGHTHAWK



DRILL RIG bores a hole down to the Marcellus shale under Dimock, Pa. Drilling fluid and cuttings are sprayed into a retention pond.

Texas, Colorado and Wyoming have raised anxiety. An August 2009 air-quality study in Dish, Tex., by the state's Commission on Environmental Quality found that benzene, xylene and other toxins exceeded legal limits. Isolated incidents do not constitute scientific proof that gas production is systemically perilous. On the other hand, the recent oil disaster in the Gulf of Mexico makes an eloquent case for caution. Does fracking pose too big of a threat? The answer is not clear.

HEIGHTENED SCRUTINY

SAFETY DISAGREEMENTS between industry and citizen groups boiled over into national news earlier this year. Because the Marcellus formation underlies the watersheds that supply more than nine million people in the New York City area and another 200,000 upstate in Syracuse, the New York Department of Environmental Conservation announced in April that it would require drilling applicants to meet tough, site-specific environmental reviews—procedures that would be so time-consuming and costly that industry would walk away. “We’re not going to go to New York because of that,” acknowledges Mark D. Whitley, a senior vice president at Range Resources in Fort Worth, Tex., one of the biggest Marcellus drillers.

A month before the New York announcement was made, the U.S. Environmental Protection Agency had begun a two-year study of the horizontal drilling process, from site selection to the disposal of fracking fluids. In e-mail responses to questions from *SCIENTIFIC AMERICAN*, the agency writes that anecdotal evidence indicates potential adverse impacts on drinking water, but “there is a lack of scientific information to verify these concerns.” The study, the EPA notes, is intended “to resolve the scientific uncertainties.”

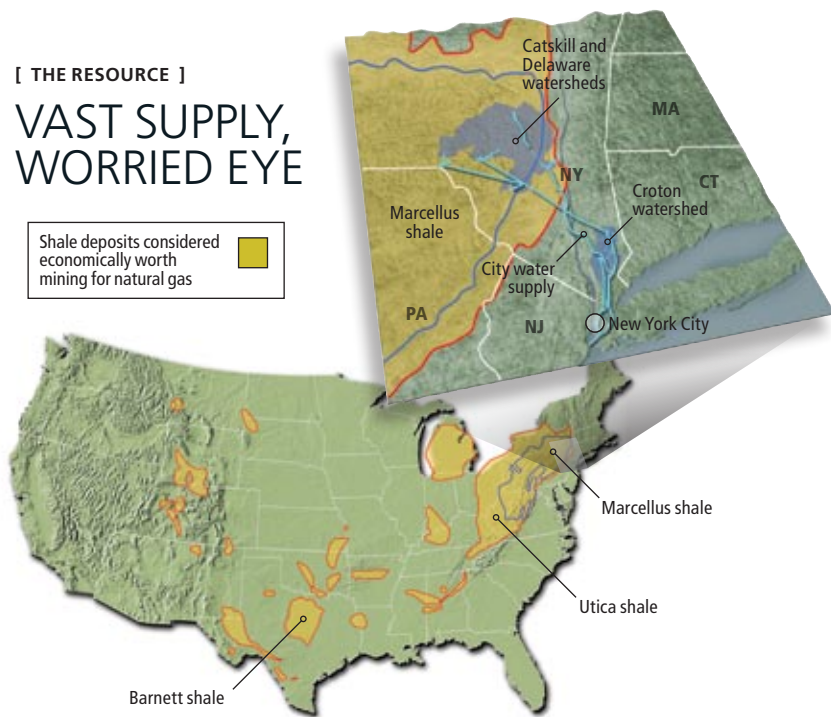
Some legislators have said the pace of land leasing and drilling should slow down until such examinations are completed. But Kathryn Z. Klaber, president of the Marcellus Shale Coalition, an industry group in Pennsylvania, says drillers will not ease up, other than possibly in New York. Whitley adds, “I don’t see the EPA study having any impact” on expansion plans.

DOWN THE HOLE

CONCERNS STEM LARGELY from chemicals used in the fracking process. After four or five acres of land are cleared, a well is drilled to the shale layer, typically 3,000 to 8,000 feet below the surface. The layer is usually only a few hundred feet

[THE RESOURCE]

VAST SUPPLY, WORRIED EYE



Huge underground shale formations (*gold*) could provide the U.S. with natural gas for years. But concerns that drilling into deposits could contaminate freshwater sources has prompted New York to fight extraction in regions of the Marcellus that underlie drinking water supplies.

thick, so the drill bit gradually turns about 90 degrees and continues horizontally through the layer for up to a mile. Steel pipe is then inserted the length of the bore and encased in cement.

Shale is fracked in stages of about 1,000 feet each, beginning at the far end of the pipe. For each stage, huge pumps force a million or more gallons of fluid through holes in the pipe at up to 6,000 pounds per square inch, fracturing the shale. Subterranean pressure pushes the fracking mixture back up the pipe; this “flowback fluid” picks up other compounds from the shale, including salts, heavy metals and naturally radioactive materials. The fluid is stored in a holding pond or tanks. Gas later rises through the pipe.

Going down, the fluid is about 99.5 percent freshwater and sand and 0.5 percent chemicals. The sand props open the fractures so gas can escape. Drilling companies use a proprietary mix of up to 10 or 12 chemicals in a well, including a friction reducer to help the mixture flow, a scale inhibitor to prevent rust, acid to clean the perforations, bactericides to kill microorganisms that can inhibit some chemical actions, and more. Among the dozen “fracturing solutions” used by Halliburton, one of the nation’s largest fracking companies, are hydrochloric acid, ethylene glycol and the bacteria killer glutaraldehyde. BJ Services’s list includes methanol and petroleum distillate blend. Although 0.5 percent

sounds small, that fraction of one million gallons is 5,000 gallons of chemicals.

Over time, five frackings would be done across the mile stretch. And up to 12 horizontal bores may be drilled from one well over several years. Ten bores, each with five stages, would require 50 million gallons of freshwater and 250,000 gallons of chemicals.

Geologists say it is highly unlikely that the chemicals could find their way up to groundwater, which typically lies a few hundred feet below the surface, because the shale is below impermeable rock. But the flowback fluid can leak at the wellhead. “The high pressures can cause malfunctions at the surface,” Pennsylvania’s Hanger says. Although the pipe is encased in cement to prevent such leaks, “the space between the wider bore and the narrower pipe is not uniform,” notes Anthony R. Ingraffea, a professor of engineering at Cornell University who has a Ph.D. in rock fracture mechanics and whose research has at times been supported by the gas industry. The bore intersects voids, fractures and cracks, “and sometimes cement doesn’t fill those features.”

It is also unclear how long the cement will last. And the drilling may cross pockets of methane, allowing the gas to rise up the borehole to groundwater. Another problem may involve leaks from poorly built or lined holding ponds. Up to 40 percent of the water and chemicals sent down the hole returns in the briny flowback fluid. “The companies are trying to do it right,” says J. Scott Roberts, deputy secretary for mineral resources management at the DEP. “But we do find the occasional individual who forgets what the priorities should be. Or a company runs short of money and does dumb things.”

CHEMICAL TRANSPARENCY

WARINESS ABOUT which chemicals are used where stems in part from a legal maneuver that excludes fracking from having to meet the “underground injection control” provisions of the Safe Drinking Water Act, which protect underground drinking water sources from contamination. The exemption, written into the 2005 Energy Policy Act, was dubbed the Halliburton loophole because it was supported by then vice president Dick Cheney, former CEO of Halliburton. In 2009 New York State Representative Maurice Hinchey introduced the FRAC Act to repeal the exemption. As of May, the act was in committee, with no timetable for action. Klaber says the legislation is pointless, “a solution that doesn’t have a problem.”

[HOW IT WORKS]

FRACK, BABY, FRACK

Hydraulic fracturing, or fracking, releases natural gas from shales. A borehole is drilled down to and through the shale, a pipe is inserted and a cement slurry is injected around the pipe to encase it. The drill rig is then removed, and rock is fractured in several stages (one of which is shown, bottom right).

The Occupational Safety and Health Administration requires a company to list on-site chemicals on a “material safety data sheet” that must be available to first responders, so if an accident occurs they can evaluate possible injuries. But Josh Fox, who produced the 2010 documentary *Gasland*, about potential health problems experienced by residents across the U.S., says in the film that gas companies refused to tell him, and abutting homeowners, which chemicals were used at particular sites.

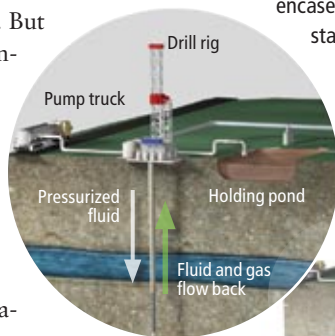
Klaber says local regulators can obtain the data sheets and can disclose that information to the public. The sheets do not list the concentrations of the chemicals, which the EPA notes “are necessary to determine toxicity.” The DEP’s Roberts says the sheets do not disclose “the recipe” of how chemicals are mixed or used: “That’s considered intellectual property.” One issue is whether mixing of chemicals or their reactions with compounds down in the shale create other compounds that could be harmful.

Even unmixed, the chemicals may be toxic. The River Reporter, an advocacy group in Narrowsburg, N.Y., sent a list of 54 data-sheet chemicals to the Endocrine Disruption Exchange for analysis. The exchange, led by Theo Colborn, a former EPA science adviser, determined that the chemicals fell into 14 categories of potential health concerns, including possible damage to the lungs, liver, kidneys, blood and brain.

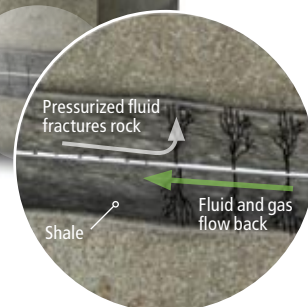
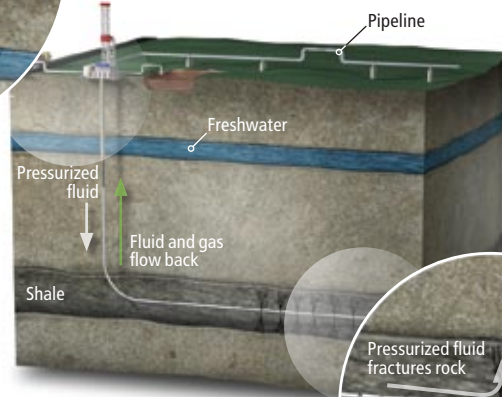
GROUNDWATER CONTAMINATION

INDUSTRY LEADERS, including Range Resources’s Whitley, point out that no cases of groundwater contamination due to the fracking process have ever been documented. Some regulators agree. Critics say that phrasing refers only to injected fluids rising back to groundwater level. They note that when the entire fracking operation is considered, including wastewater holding ponds, hundreds of contamination incidents have been documented. In Dimock, Pa., for example, the DEP cited Houston-based Cabot Oil & Gas for spilling fracking fluid and diesel.

Most violations cited by regulators do not involve fracking chemicals, however. Both the industry and the critics “are being a bit disingenuous” in their statements, says Terry Engelder, professor of geosciences at Pennsylvania State University, whose research is also in part supported by the gas industry. “New York, in particular, is being hypocritical; they are happy to heat with natural gas drilled around the water



After the rig is removed, fracking fluid is pumped down the pipe; when it returns, it is stored in a holding pond or tanks. Later, gas will flow through a well-head (not shown) into a pipeline.



For each stage, a gun blasts perforations through the cement-encased pipe. A mixture of water, sand and chemicals is forced through the holes at high pressure, breaking the rock. The fluid, and later the gas, flows back up the well.

supplies for Pittsburgh.” Hanger concurs: “Both sides are trying to win a position, and truth can be a casualty.”

The EPA study, due in 2012, could add scientific clarity. Also, in July the EPA plans to announce results of an investigation into contamination of residential wells in Pavillion, Wyo.

GOING FULL BORE

REGARDLESS OF WHAT the EPA reports say, fracking seems destined to increase. In May, for instance, Statoil Natural Gas signed an agreement to send up to 113 billion cubic feet of Marcellus gas a year, for 20 years, from Ellisburg, Pa., to Toronto. Ironically, in March, Statoil also agreed to pipe gas to New York City.

Tension over fracking will likely continue. At a May 3 forum at Duquesne University, Hanger called for a severance tax on producers to cover the cost of sealing wells that might be abandoned and to remediate other damage. Operators pay severance taxes in 28 states. Klaber warned that too many impediments could discourage more drilling in Pennsylvania, which she said created 107,000 jobs in the prior year. The industry, she says, does not want to “miss an opportunity as a country to reap the benefits that come with domestic natural gas.” The country certainly needs energy. It also needs drinking water. Whether it can have both remains an open question. ■

MORE TO EXPLORE

Riverkeeper’s watchdog Industrial Gas Drilling Reporters, covering action in New York State and Pennsylvania, can be downloaded at www.riverkeeper.org/campaigns/safeguard/gas-drilling

Information from the Marcellus Shale Coalition is available at www.pamarcellus.com

A video of Anthony R. Ingraffea explaining fracking can be seen at www.mefedia.com/watch/28577813

To track the documentary *Gasland*, go to www.gaslandthemovie.com

Earth sans Ice Caps ■ Biomimetics ■ Immortality

BY KATE WONG

➔ BULLETPROOF FEATHERS: HOW SCIENCE USES NATURE'S SECRETS TO DESIGN CUTTING-EDGE TECHNOLOGY

edited by Robert Allen. University of Chicago Press, 2010 (\$35)

Researchers are increasingly turning to nature for design inspiration. This book surveys examples from the field of biomimetics—from self-cleaning surfaces based on the lotus leaf to fishery echo sounders that aim to simulate dolphin sonar (right).



EXCERPT

➔ THE FLOODED EARTH: OUR FUTURE IN A WORLD WITHOUT ICE CAPS

by Peter D. Ward. Basic Books, 2010 (\$25.95)

Earth scientist Peter D. Ward of the University of Washington imagines how Earth and its inhabitants will change in the next 1,000 years as the ice caps melt and the seas rise. Here he describes northern California in the year 2135.

"The [Great Valley of California] had once been one of the richest agricultural areas on the planet. It had been divided roughly in half by the Sacramento River Delta and the low marshes west of Sacramento. Its northern half had been farmed for fruit, olives, nuts, cotton, and especially rice, while the southern valley was once the largest vegetable-producing area on the planet. Now the Great Valley was bisected by the long extension of San Francisco Bay, which stretched all the way to Sacramento. Salt water from that enormous extension of the sea had gradually worked its way into the many aquifers that had once been necessary for irrigation, and every year the sea encroached both north and south into the major rivers of the Valley. Now, despite the intense engineering efforts Californians had put forth, most of those aquifers contained salt. But even that would not have been so bad had the climate continued to allow snow to fall prodigiously on the Sierras. Because the precipitation now came entirely as rain, there was no snowpack to melt and provide spring runoff just in time for sowing and watering new crops, or give budding trees a good drink in the first spell of hot weather.

"That heat used to arrive in April, but now there was no winter here at all. In one respect it was a blessing—no longer did the characteristic and deadly early-morning fogs cause numerous fatal accidents on Interstate 5, the major north-south freeway through California, as drivers rear-ended others in the pea soup. There was no fog at all now, because the tropical temperatures of the Valley never rose to the dew point. But the lack of fog was of little importance to drivers, because there were none on the freeway except for trucks. Personal automobiles had been outlawed some decades before, in a vain effort to save some of the world's oil. Yet goods still needed to be moved from place to place, and people needed to travel as well, thus swelling the freeways with buses and trucks."



ALSO NOTABLE

NONFICTION

- ➔ **Long for This World: The Strange Science of Immortality**
by Jonathan Weiner. Ecco, 2010 (\$27.99)
- ➔ **Colossus: Hoover Dam and the Making of the American Century**
by Michael Hiltzik. Free Press, 2010 (\$30)
- ➔ **Spider Silk: Evolution and 400 Million Years of Spinning, Waiting, Snagging, and Mating**
by Leslie Brunetta and Catherine L. Craig. Yale University Press, 2010 (\$30)
- ➔ **Drawing the Map of Life: Inside the Human Genome Project**
by Victor K. McElheny. Basic Books, 2010 (\$28)
- ➔ **The Last Tortoise: A Tale of Extinction in Our Lifetime**
by Craig B. Stanford. Harvard University Press, 2010 (\$23.95)
- ➔ **What's Luck Got to Do with It?: The History, Mathematics, and Psychology of the Gambler's Illusion**
by Joseph Mazur. Princeton University Press, 2010 (\$29.95)
- ➔ **A Little Book of Language**
by David Crystal. Yale University Press, 2010 (\$25)
- ➔ **Parasites: Tales of Humanity's Most Unwelcome Guests**
by Rosemary Drisdelle. University of California Press, 2010 (\$27.50)
- ➔ **Leonardo's Legacy: How Da Vinci Reimagined the World**
by Stefan Klein. Da Capo Press, 2010 (\$26)



FICTION

- ➔ **The Bradbury Report**
by Steven Polansky. Weinstein Books, 2010 (\$24.95)
- ➔ **Ancestor**
by Scott Sigler. Crown, 2010 (\$24.99)

KID-FRIENDLY

- ➔ **Honey Bees: Letters from the Hive**
by Stephen Buchmann. Delacorte Press, 2010 (\$16.99)
- ➔ **The Bumper Book of Nature: A User's Guide to the Great Outdoors**
by Stephen Moss. Harmony, 2010 (\$29.99)



Abraham Lincoln once said, “Let us have faith that right makes might.” Do you have that kind of faith? Or do you think that idealistic principles are outdated and impossible to achieve?

Read Richard W. Wetherill’s book *RIGHT IS MIGHT* to discover why *right* really is *might*, and how the natural laws of the universe make it so.



Richard W. Wetherill
1906-1989

During his lifetime, Wetherill was often described as a person who was scores of years ahead of his time. Now former members of his research and study group think that his day has finally come. Increasingly, more and more people understand that to succeed they must be rational and honest.

In 1929, Wetherill identified a *natural law* controlling people’s personal and interpersonal behavior. ***The law states that people are required to think, say, and do what is right in order to get a right result.*** It further states that when people have personal problems or trouble, something is wrong about their thinking, conversation, and behavior.

In his book Wetherill explains the outcome that results from attempted violation or disregard for nature’s behavioral law. As with all natural laws, this law is also self-enforcing. Persons who deviate from what is right install in the recesses of their minds the wrong thinking that was used to justify such behavior.

While Wetherill’s book *RIGHT IS MIGHT* was written in 1950, its contents are as applicable in 2010 as they were sixty years ago—perhaps even more so—and because Wetherill could not find a publisher willing to go out on a limb for honesty and right action in 1950, the manuscript was simply filed.

After his death in 1989, the manuscript was found among his papers, and it was carefully edited to delete some dated material, but the principles of right behavior that he put into words are ageless. They are all preserved.

RIGHT IS MIGHT tells the reader how honesty and rightness are achieved in a person’s private and public life. It also describes the exciting developments in the lives of persons who had applied the formula for successful living

A reader might ask, “What did they do?”

Following Wetherill’s suggestions they recognized the challenges of life and met life head on; squared themselves with their consciences; did what could be done to improve conditions; and made sure that every personal decision was completely honest.

People who do that do not fear the future. They know that the key to every virtue is honesty, so they wage an intentional campaign of unwavering honesty.

Adopting that dynamic formula for success benefits everybody on earth. It will benefit posterity. Before it benefits others, the person who adopts it is the first to benefit. Rational, honest thoughts and behavior is a formula not open to abuse. Nobody can cause trouble for others or for himself by using it. Not using that formula causes trouble for everybody.

The last paragraph of *RIGHT IS MIGHT* reminds us, ***“It is helpful to recognize that what is wrong in life is based on emotional unreality and is temporary. What is right in life is part of the reality that unfailingly endures, establishing the principle that RIGHT IS MIGHT.”***

Visit our Website www.alphapub.com where essays and books (including *Right Is Might*) describe changes called for by whoever or whatever created natural laws. Read, download, and/or print the material free! Press a button to hear site pages read aloud, except for the texts of the seven books.

This message is from a self-financed, nonprofit group of former students of the late Richard W. Wetherill. By May of 2010 our Website had over 50,000 American and worldwide visitors. We invite your help to direct others to alphapub.com to learn how to find the *examined* life that is well worth living.

An Apple a Day for a Week

Shipping out with people who love a certain kind of Machine

BY STEVE MIRSKY



The classroom gently rocked as the speaker approached the lectern. I sat quietly, holding one talisman in my left hand—an iPhone—while balancing another sign of fealty in my lap—a MacBook. The computer was brand-new, purchased for this very purpose. Otherwise, the assembled might have scoped me out for what I truly was—a quarter-of-a-century adherent to PCs that ran DOS and Windows—and thrown me overboard. For I was attending a weeklong gathering at sea of the faithful, called MacMania 10.

One hundred two Macphiles and I were onboard the Holland America cruise ship *Veendam*, heading southeast from New York to Bermuda in the first week of May. In 2008 and 2009 I also sailed, but as a speaker in the Scientific American Bright Horizons series produced by Insight Cruises. Insight also puts together the MacMania outings, as well as sojourns featuring opera, astronomy and quilting. Hence their URL: geekcruises.com.

When my regular old cell-phone—that-just-calls-people-and-takes-cruddy-photos died last summer after being soaked in a thunderstorm, I bought my first Apple product, the iPhone. Which has since become permanently attached to my left hand. So when the cruise curriculum featured numerous talks on maximizing the iPhone experience, I decided to sail—on my own dime this time and with the new MacBook, so that the talks about that device wouldn't be lost on me.

My classmates were so devoted to Apple that some three quarters, based on a show of hands, already owned an iPad. Although, in truth, their presence on the ship was proof enough. As speaker David Pogue, tech columnist for the *New York Times*, categorized them: “You who are enough nuts about your Apple stuff to pay for an expensive cruise just to hobnob with other oppressed minority members.”

Despite their love of pomology, some could admit to certain issues. Sal Soghoian, AppleScript product manager, acknowledged the iPad screen's glare and reflection: “I'm tired of looking at my nostrils while watching a video.” To which some wag in the audience shouted, “It's easy to get rid of the glare with the fingerprints.”



The fingerprint issue is real, but as Pogue explained of the iPhone, “It has this oleophobic coating. Oleophobic, of course, meaning afraid of yodelers. No, meaning repels oil.” He then showed his messy screen to the audience. “You can see how greasy this is. I do one wipe on a piece of clothing,” at which he drew the phone across his pant leg, “and it is spotless. All the oil is gone.” The same is true for the iPad, although, as Pogue said, “You have to have bigger pants.”

Trifles with fingerprints aside, the audience's true zealotry was revealed when Andy Ihnatko, *Chicago Sun-Times* tech columnist and inventor of the Macquarium (a real aquarium made from the chassis of an old Mac computer), had a brief prob-

lem getting his MacBook to interface with the ship's audiovisual system. He muttered, “Tip one, get a Windows 7 machine—they give you less trouble than a Mac.” Lusty boos erupted, and some might have rushed the stage had Ihnatko not made it clear he was, of course, just joshing.

Another example of the true love of the MacManiacs was their desire for logoed apparel. *Macworld* magazine's editorial director Jason Snell offered a golf shirt featuring the Apple logo to anybody who could reasonably wear a XXXL, which Soghoian called simply “programmer-sized.” Greedy

for the same-style shirt that Steve Jobs, hallowed be his name, wears at presentations, one attendee yelled out, “I'm willing to gain the weight.” Which would also lead to pants suitable for iPad wipes.

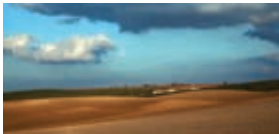
It is easy to gain weight on a cruise ship, but between the six meals a day I learned many useful things. For example, how to copy movies from DVDs. You see, according to Snell, the Digital Millennium Copyright Act says that writing software to copy movies is illegal. And the Motion Picture Association of America, an industry group, says that using the software is illegal. Although some legal scholars think that if you have purchased a DVD of the movie *And Justice for All* or *12 Angry Men* or *The Firm*, and you have copied said movie and put the party of the first part on your iPhone strictly for your own personal use, then *prima facie res ipso loquitur sic semper tyrannis* you're within the law. Especially if you do it in international waters.

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