CYBERSECURITY
3-Part Plan for Big Data

NEUROSCIENCE
Accidental Genius

EDUCATION
The Science of Learning

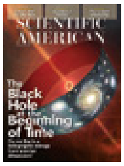
SCIENTIFIC AMERICAN

ScientificAmerican.com
AUGUST 2014

The Black Hole at the Beginning of Time

Do we live in a holographic mirage from another dimension?

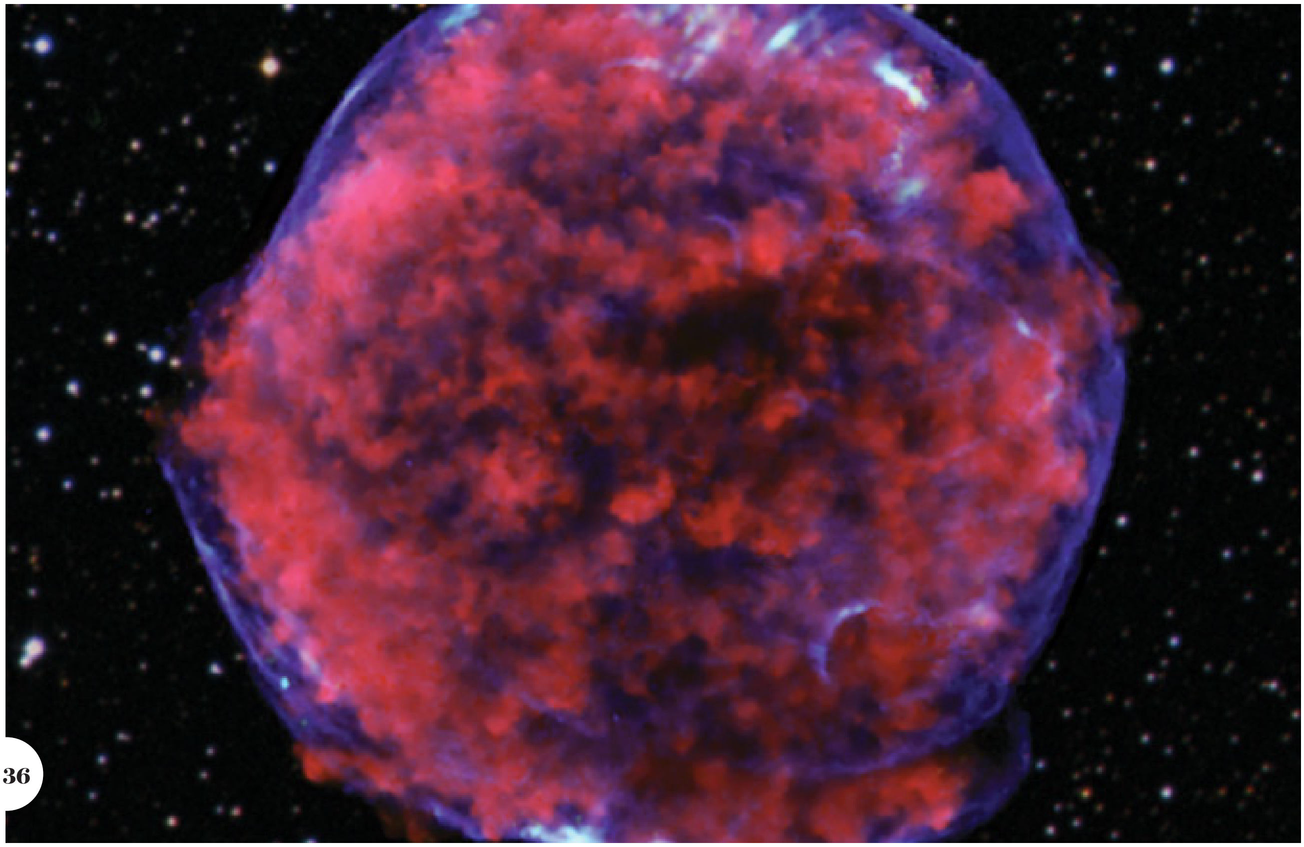
ON THE COVER



Modern cosmology holds that the universe came from an infinitely dense singularity at the beginning of time. Perhaps this singularity came from another cosmic cataclysm—the collapse of a star to form a black hole in a predecessor universe with four dimensions of space. The black hole's three-dimensional event horizon would protect our universe from cosmic uncertainties. Image by Kenn Brown, Mondolithic Studios.

SCIENTIFIC AMERICAN

August 2014 Volume 311, Number 2



COURTESY OF NASA/CXC/RUTGERS/K. ERIKSEN ET AL. AND DSS (*Tycho's supernova remnant*)

FEATURES

13

17

80

SCIENTIFIC AMERICAN

DEPARTMENTS

ON THE WEB

64th Annual Lindau Nobel Laureate Meeting
Our in-depth report covers a gathering that featured 37 Nobel laureates and about 600 young researchers from nearly 80 countries. The scientists met June 29–July 4 to share the latest ideas on the cutting edge of physiology and medicine.
Go to www.ScientificAmerican.com/aug2014/lindau

Scientific American (ISSN 0036-8733), Volume 311, Number 2, August 2014, published monthly by Scientific American, a division of Nature America, Inc., 75 Varick Street, 9th Floor, New York, N.Y. 10013-1917. Periodicals postage paid at New York, N.Y., and at additional mailing offices. Canada Post International Publications Mail (Canadian Distribution) Sales Agreement No. 40012504. Canadian BN No. 127387652RT; TVQ1218059275 TQ0001. Publication Mail Agreement #40012504. Return undeliverable mail to Scientific American, P.O. Box 819, Stn Main, Markham, ON L3P 8A2. **Individual Subscription rates:** 1 year $39.97 (USD), Canada $49.97 (USD), International $61 (USD). **Institutional Subscription rates:** Schools and Public Libraries: 1 year $72 (USD), Canada $77 (USD), International $84 (USD). Businesses and Colleges/Universities: 1 year $330 (USD), Canada $335 (USD), International $342 (USD). Postmaster: Send address changes to Scientific American, Box 3187, Harlan, Iowa 51537. **Reprints available:** write Reprint Department, Scientific American, 75 Varick Street, 9th Floor, New York, N.Y. 10013-1917; fax: 646-563-7138; reprints@SciAm.com. **Subscription inquiries: U.S. and Canada (800) 333-1199; other (515) 248-7684. Send e-mail to scacustserv@cdsfulfillment.com.** Printed in U.S.A.

Mariette DiChristina is editor in chief of *Scientific American*. Follow her on Twitter @mdichristina

The Shadow Universe and Other Marvels

COULD OUR UNIVERSE HAVE COME into being as a three-dimensional shell around a four-dimensional black hole? In the current issue's cover story, "The Black Hole at the Beginning of Time," authors Niayesh Afshordi, Robert B. Mann and Razieh Pourhasan suggest a revision to the idea that the universe originated from an infinitely dense point. It sounds fantastic, but the result is the outcome of calculations that use the mathematics of space and time. Turn to page 36 for the beginning of a story about the beginning.

If humankind has invented a better tool than science to help us learn about the world (and universe) around us, I haven't heard of it. And if I may be meta for a moment, one of the things we can learn about is how we can best learn. How can we make teaching truly "scientific"—that is, efficacious? What really matters, and what is the evidence that can show us what works?

In "The Science of Learning," starting on page 68, Barbara Kantrowitz details new efforts, including hundreds of studies, to bring more rigorous science to American classrooms. The research is uncovering when our intuitions about education may be wrong. For instance, "tell and practice," in which students first receive instruction and then conduct an exploratory activity, has been the rule because it has seemed like a sound idea. But the opposite actually is true: students absorb the information better if they try the activity first. Applying the findings of research to classrooms, however, has proved challenging.

The link between science and learning is one that SCIENTIFIC AMERICAN has sought to foster from its first issue, dated August 28, 1845: "As a family newspaper," wrote founding editor Rufus Porter of his new weekly broadsheet, "it will convey more useful intelligence to children and young people, than five times its cost in school instruction." Feel free to check our math. SA

SCIENCE IN ACTION

And the Winner Is

On August 6 we will announce the winner of the $50,000 *Scientific American* Science in Action Award, which honors a project that can make a practical difference by addressing an environmental, health or resources challenge. The winning entry will be innovative, easy to put into action and reproducible in other communities. The third annual prize, open for students from ages 13 to 18, is part of the Google Science Fair competition, now in its fourth year; *Scientific American* is a founding partner. *—M.D.*

Illustration by Nick Higgins


Hamamatsu City
CMS

editors@sciam.com

April 2014

DARK MATTER AND STARS

“The First Starlight,” by Michael D. Lemonick, discusses the formation of the first stars and galaxies in the universe.

Slight mention was made in the article of the role dark matter may have played in the process. Because dark matter will also have been drawn into the gravitational collapse that formed the first stars, these stars may have been bloated with this nonfusible dark matter, delaying star formation until the masses became enormous. Perhaps million-solar-mass black holes could have been formed directly from dark matter without a star phase at all, and these black holes became the seeds of the earliest galaxies.

MARTIN URBAN
Silver Spring, Md.

Dark matter doesn't interact much, if at all, with normal matter and radiation. Would not black holes continue to gorge themselves on dark matter regardless of the intensity of the surrounding radiation field? Maybe the combination of black holes and dark matter has something to teach us about both.

PETER J. TURCHI
Santa Fe, N.M.

LEMONICK REPLIES: Several readers have pointed out that dark matter must have had some role in the formation of the first stars and galaxies. Indeed, it did. Because dark matter doesn't interact with electromagnetic radiation, it was free to begin collapsing under gravity even before matter and energy were decoupled from each other about 400,000 years after the big bang. When that happened, there were already “halos” of dark matter whose gravity sucked in the ordinary matter that ultimately formed into the first stars.

Because it can't cool by radiating energy, dark matter can't collapse the way ordinary matter can, so it is hard to imagine how it could form a black hole. It is also likely that the amount within reach of even a supermassive black hole would be relatively small. Not much to gorge on.

“The way Internet providers currently charge their customers is perverse and needs to change.”

FRANK WEIGERT *WILMINGTON, DEL.*

INTERNET ECONOMICS

In “The Great Net Debate” [TechnoFiles], David Pogue discusses net neutrality, the principle that Internet providers should not be able to charge varying amounts for different data or to discriminate against particular data by blocking them or slowing them down.

The way such providers currently charge their customers is perverse and needs to change. They charge a flat fee per month for unlimited high-speed Internet usage. The elderly widow who checks her e-mail twice a week pays the same as the twentysomething dude who downloads two Blu-ray movies every day.

Internet providers can adjust their fee schedule to make exactly the same amount of money as they do now. The only difference is that low-volume users will no longer be subsidizing high-volume ones.

FRANK WEIGERT
Wilmington, Del.

BULLET TIME RUNNING OUT

In “False Hope,” Michael E. Mann explains that the slight easing of the rate of global warming during the past decade was not a “pause,” because temperatures still rose, and even if it proves to be more persistent than expected, that would give us only until 2046, rather than 2036, before our current emissions cause enough warming to harm human civilization.

I think there is an easy way to explain that this recent slowdown isn't a pause and that it's still leading to disaster. Consider a bullet speeding toward your head. It slows down, but it's still heading toward you. You have a little more time to duck, but if you continue to stand there, you're dead. We have a little more time to reduce or eliminate use of fossil fuels. If we continue with what we're doing, we'll have a catastrophe.

TED GRINTHAL
Berkeley Heights, N.J.

MATH WARS

In “The Secret Spiritual History of Calculus,” Amir Alexander argues that Jesuit mathematicians did not accept 17th-century Italian mathematician Bonaventura Cavalieri's “method of indivisibles,” in which every plane is made of an infinite number of lines and every solid is made of an infinite number of planes.

But Flemish Jesuit mathematician Gregory of Saint-Vincent developed a method that was essentially the same as Cavalieri's indivisible calculus in the 1620s, before Cavalieri.

Gregory hoped to use his *ductus plani in planum* method of summing infinitely thin rectangles to find a volume to solve the problem of squaring the circle. But his superiors in Rome refused to grant him permission to publish his work on the grounds that the method lacked a solid logical basis.

AD MESKENS
Artesis Plantijn University College
Antwerp, Belgium

Alexander translates the Latin title of Italian mathematician Bonaventura Cavalieri's “In Guldinum”—his response to criticism from Swiss mathematician Paul Guldin—as “On Guldin.”

If Cavalieri had wished to say “On Guldin,” he would have written “In Guldino,” with the ablative case. The preposition “in,” with the accusative case, means

against a person, as in "Against Guldin," which was, plainly enough, the point of the response.

John Traill
Professor Emeritus, Department of Classics
University of Toronto

ALEXANDER REPLIES: In addition to Meskens's account of the suppression of Gregory of Saint Vincent's ductus *method in the 1620s, I would add the story of another Flemish mathematician, Jesuit André Tacquet, who showed an interest in indivisibles three decades later. Tacquet insisted that indivisibles were mere heuristic devices and denounced them for "destroying" geometry, but this did not mollify the Jesuit authorities. Superior-General Goswin Nickel ordered him to desist from original mathematical research, and he spent the rest of his days writing textbooks for Jesuit schools.*

"Against Guldin" is indeed the right translation and more appropriate to the context.

AVOIDING OVERPRESCRIPTION

In "Antibiotic Overkill" [Advances], Dina Fine Maron reports on a study finding that physicians who had signed a pledge to avoid unnecessarily prescribing antibiotics reduced such overprescription.

When I feel "cornered" into writing an "unnecessary" prescription, I write one but also explain why the antibiotic may not be necessary. And I give patients an option to wait for more specific signs of treatable infection and to call me if they choose to start treatment. I find that many prescriptions then go unfilled, with no harm.

I do not have numbers to show how effective this patient empowerment/education approach is, but I hope this letter, by itself, will reduce some overkill.

Janivara P. Umesh
Lakeland, Fla.

ERRATUM

"Journey to the Bottom of the Sea," by Mark Schrope, incorrectly referred to the epicenter of the 2011 Tohoku earthquake occurring below the seafloor. An epicenter is the surface directly above the place where an earthquake starts. The correct term is hypocenter.

SCIENTIFIC AMERICAN™
ESTABLISHED 1845

EDITOR IN CHIEF AND SENIOR VICE PRESIDENT **Mariette DiChristina**

EXECUTIVE EDITOR **Fred Guterl**
DESIGN DIRECTOR **Michael Mrak**
MANAGING EDITOR **Ricki L. Rusting**
MANAGING EDITOR, ONLINE **Philip M. Yam**
NEWS EDITOR **Robin Lloyd**

SENIOR EDITORS
Mark Fischetti ENERGY / ENVIRONMENT
Josh Fischmann BIOLOGY / CHEMISTRY / EARTH SCIENCES
Seth Fletcher TECHNOLOGY **Christine Gorman** BIOLOGY / MEDICINE
Michael Moyer SPACE / PHYSICS / SPECIAL PROJECTS
Gary Stix MIND / BRAIN **Kate Wong** EVOLUTION

ASSOCIATE EDITORS
David Biello ENERGY / ENVIRONMENT **Larry Greenemeier** TECHNOLOGY
Dina Fine Maron BIOLOGY / MEDICINE **Clara Moskowitz** SPACE / PHYSICS
Amber Williams ADVANCES

PODCAST EDITOR **Steve Mirsky**
BLOGS EDITOR **Curtis Brainard**

CONTRIBUTING EDITORS
Davide Castelvecchi, Katherine Harmon Courage, Anna Kuchment, Maryn McKenna, George Musser, Christie Nicholson, John Rennie, Sarah Simpson

CONTRIBUTING WRITER
Ferris Jabr

ART DIRECTOR **Jason Mischka**
ART DIRECTOR, INFORMATION GRAPHICS **Jen Christiansen**
ART DIRECTOR, ONLINE **Ryan Reid**
PHOTOGRAPHY EDITOR **Monica Bradley**
PHOTO RESEARCHER **Liz Tormes**
ASSOCIATE ART DIRECTOR, IPAD **Jason Arias**
ASSISTANT ART DIRECTOR, IPAD **Bernard Lee**
MANAGING PRODUCTION EDITOR **Richard Hunt**
SENIOR PRODUCTION EDITOR **Michelle Wright**
INFORMATION GRAPHICS CONSULTANT **Bryan Christie**
ART CONTRIBUTORS **Edward Bell, Lawrence R. Gendron, Nick Higgins**
COPY DIRECTOR **Maria-Christina Keller**
SENIOR COPY EDITORS **Michael Battaglia, Daniel C. Schlenoff**
COPY EDITOR **Aaron Shattuck**
SENIOR EDITORIAL PRODUCT MANAGER **Angela Cesaro**
PRODUCT MANAGER **Kerrissa Lynch**
WEB PRODUCTION ASSOCIATES **Nick Bisceglia, Nick Weilbacher**
EDITORIAL ADMINISTRATOR **Avonelle Wing**
SENIOR SECRETARY **Maya Harty**

SENIOR PRODUCTION MANAGER **Christina Hippeli**
ADVERTISING PRODUCTION MANAGER **Carl Cherebin**
PREPRESS AND QUALITY MANAGER **Silvia De Santis**
CUSTOM PUBLISHING MANAGER **Madelyn Keyes-Milch**
PRODUCTION COORDINATOR **Lisa Headley**

PRESIDENT
Steven Inchcoombe

EXECUTIVE VICE PRESIDENT **Michael Florek**
VICE PRESIDENT AND ASSOCIATE PUBLISHER, MARKETING AND BUSINESS DEVELOPMENT **Michael Voss**
DIRECTOR, INTEGRATED MEDIA SALES **Stan Schmidt**
ASSOCIATE VICE PRESIDENT, BUSINESS DEVELOPMENT **Diane McGarvey**
DIRECTOR, GLOBAL MEDIA SOLUTIONS **Jeremy A. Abbate**
VICE PRESIDENT, CONSUMER MARKETING **Christian Dorbandt**
DIRECTOR, E-COMMERCE **Scott Rademaker**
ASSOCIATE CONSUMER MARKETING DIRECTOR **Catherine Bussey**
E-COMMERCE MARKETING MANAGER **Evelyn Veras**
SENIOR MARKETING MANAGER / ACQUISITION **Patricia Elliott**
ONLINE MARKETING ASSOCIATE **Alexandra Egan**
MARKETING AND CUSTOMER SERVICE COORDINATOR **Christine Kaelin**
SALES DEVELOPMENT MANAGER **David Tirpack**
PROMOTION MANAGER **Diane Schube**
PROMOTION ART DIRECTOR **Maria Cruz-Lord**
MARKETING RESEARCH DIRECTOR **Rick Simone**
ONLINE MARKETING PRODUCT MANAGER **Zoya Lysak**
CORPORATE PR MANAGER **Rachel Scheer**
SENIOR INTEGRATED SALES MANAGER **Jay Berfas**
SALES REPRESENTATIVE **Chantel Arroyo**
INTEGRATED MEDIA SALES **Nate Murray**
SENIOR ADMINISTRATOR, EXECUTIVE SERVICES **May Jung**
CUSTOM PUBLISHING EDITOR **Lisa Pallatroni**
RIGHTS AND PERMISSIONS MANAGER **Karin M. Tucker**

LETTERS TO THE EDITOR

Scientific American
75 Varick Street, 9th Floor
New York, NY 10013-1917
or editors@sciam.com

Letters may be edited for length and clarity. We regret that we cannot answer each one. Post a comment on any article at ScientificAmerican.com/aug2014

HOW TO CONTACT US

Subscriptions
For new subscriptions, renewals, gifts, payments, and changes of address: U.S. and Canada, 800-333-1199; outside North America, 515-248-7684 or www.ScientificAmerican.com

Submissions
To submit article proposals, follow the guidelines at www.ScientificAmerican.com. Click on "Contact Us." We cannot return and are not responsible for materials delivered to our office.

Reprints
To order bulk reprints of articles (minimum of 1,000 copies): Reprint Department, Scientific American, 75 Varick Street, 9th Floor, New York, NY 10013-1917; 212-451-8877; reprints@SciAm.com. For single copies of back issues: 800-333-1199.

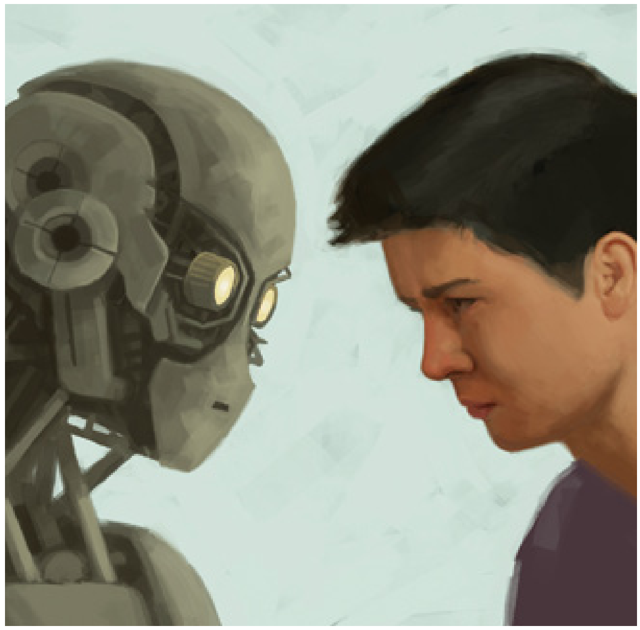
Permissions
For permission to copy or reuse material: Permissions Department, Scientific American, 75 Varick Street, 9th Floor, New York, NY 10013-1917; randp@SciAm.com; www.ScientificAmerican.com/permissions. Please allow three to six weeks for processing.

Advertising
www.ScientificAmerican.com has electronic contact information for sales representatives of Scientific American in all regions of the U.S. and in other countries.


A SMASH UP OF ART, SCIENCE AND ENGINEERING
Beakerhead
Let go.
SEPTEMBER 10 - 14, 2014
CALGARY, CANADA
BEAKERHEAD.ORG
Photo: Neil Zeller Photography
Canada
Alberta Government
SUNCOR
In partnership with Travel Alberta Canada
TALISMAN ENERGY
APEGA

Will Work for Machines

Are computers taking our jobs? It is surprisingly hard to say, largely because of a lack of good data



Last fall economist Carl Benedikt Frey and information engineer Michael A. Osborne, both at the University of Oxford, published a study estimating the probability that 702 occupations would soon be computerized out of existence. Their findings were startling. Advances in data mining, machine vision, artificial intelligence and other technologies could, they argued, put 47 percent of American jobs at high risk of being automated in the years ahead. Loan officers, tax preparers, cashiers, locomotive engineers, paralegals, roofers, taxi drivers and even animal breeders are all in danger of going the way of the switchboard operator.

Whether or not you buy Frey and Osborne's analysis, it is undeniable that something strange is happening in the U.S. labor market. Since the end of the Great Recession, job creation has not kept up with population growth. Corporate profits have doubled since 2000, yet median household income (adjusted for inflation) dropped from $55,986 to $51,017. At the same time, after-tax corporate profits as a share of gross domestic product increased from around 5 to 11 percent, while compensation of employees as a share of GDP dropped from around 47 to 43 percent. Somehow businesses are making more profit with fewer workers.

Erik Brynjolfsson and Andrew McAfee, both business researchers at the Massachusetts Institute of Technology, call this divergence the "great decoupling." In their view, presented in their recent book *The Second Machine Age,* it is a historic shift.

The conventional economic wisdom has long been that as long as productivity is increasing, all is well. Technological innovations foster higher productivity, which leads to higher incomes and greater well-being for all. And for most of the 20th century productivity and incomes did rise in parallel. But in recent decades the two began to diverge. Productivity kept increasing while incomes—which is to say, the welfare of individual workers—stagnated or dropped.

Brynjolfsson and McAfee argue that technological advances are destroying jobs, particularly low-skill jobs, faster than they are creating them. They cite research showing that so-called routine jobs (bank teller, machine operator, dressmaker) began to fade in the 1980s, when computers first made their presence known, but that the rate has accelerated: between 2001 and 2011, 11 percent of routine jobs disappeared.

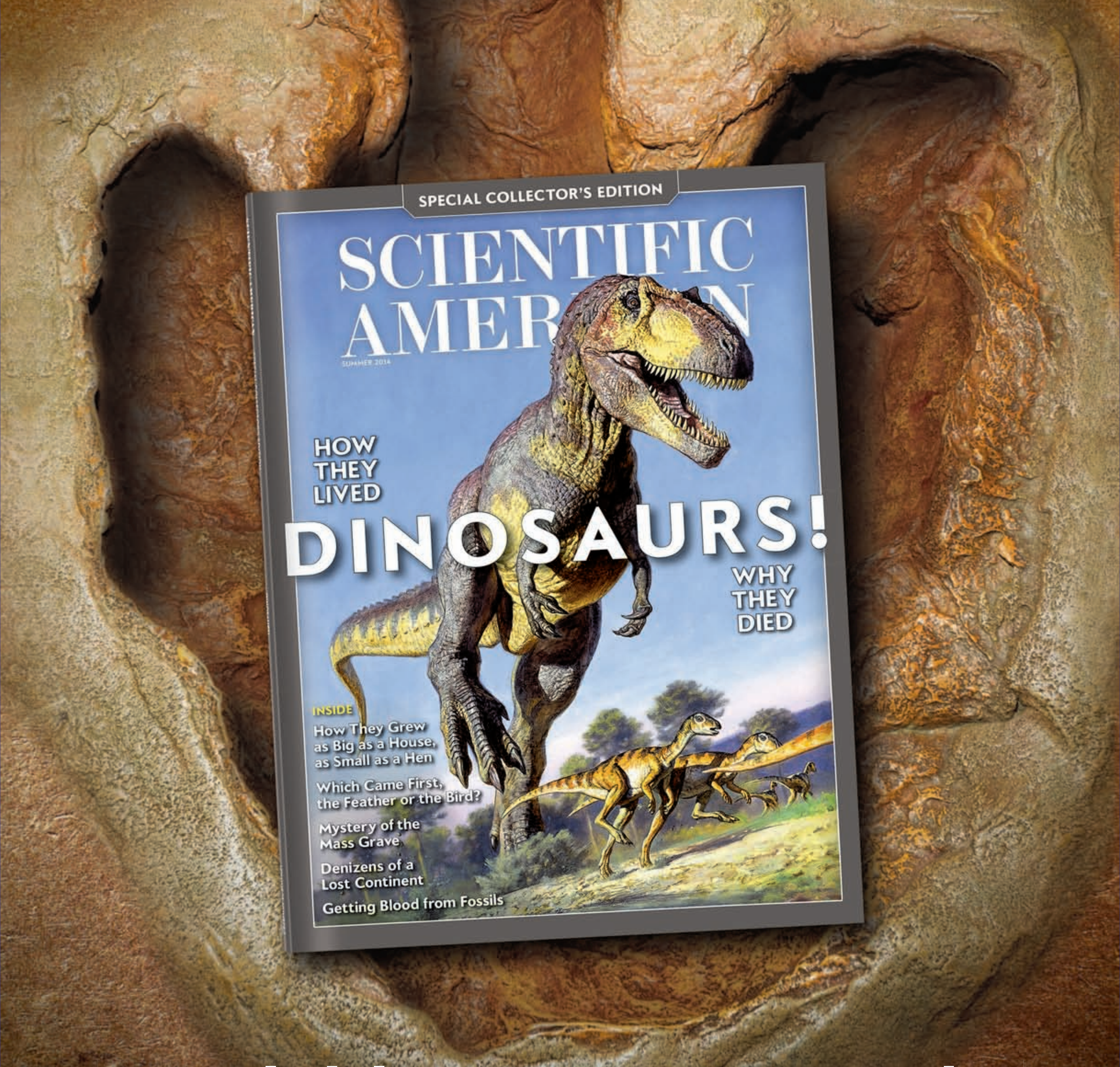
Plenty of economists disagree, but it is hard to referee this debate, in part because of a lack of data. Our understanding of the relation between technological advances and employment is limited by outdated metrics. At a roundtable discussion on technology and work convened this year by the European Union, the IRL School at Cornell University and the Conference Board (a business research association), a roomful of economists and financiers repeatedly emphasized how many basic economic variables are measured either poorly or not at all. Is productivity declining? Or are we simply measuring it wrong? Experts differ. What kinds of workers are being sidelined, and why? Could they get new jobs with the right retraining? Again, we do not know.

In 2013 Brynjolfsson told Scientific American that the first step in reckoning with the impact of automation on employment is to diagnose it correctly—"to understand why the economy is changing and why people aren't doing as well as they used to." If productivity is no longer a good proxy for a vigorous economy, then we need a new way to measure economic health. In a 2009 report economists Joseph Stiglitz of Columbia University, Amartya Sen of Harvard University and Jean-Paul Fitoussi of the Paris Institute of Political Studies made a similar case, writing that "the time is ripe for our measurement system to shift emphasis from measuring economic production to measuring people's well-being." An IRL School report last year called for statistical agencies to capture more and better data on job market churn—data that could help us learn which job losses stem from automation.

Without such data, we will never properly understand how technology is changing the nature of work in the 21st century—and what, if anything, should be done about it. As one participant in this year's roundtable put it, "Even if this is just another industrial revolution, people underestimate how wrenching that is. If it is, what are the changes to the rules of labor markets and businesses that should be made this time? We made a lot last time. What is the elimination of child labor this time? What is the eight-hour workday this time?" SA

SCIENTIFIC AMERICAN ONLINE
Comment on this article at ScientificAmerican.com/aug2014

Illustration by Bernard Lee


SPECIAL COLLECTOR'S EDITION
SCIENTIFIC AMERICAN
HOW THEY LIVED
DINOSAURS!
WHY THEY DIED
INSIDE
How They Grew as Big as a House, as Small as a Hen
Which Came First, the Feather or the Bird?
Mystery of the Mass Grave
Denizens of a Lost Continent
Getting Blood from Fossils

Rena F. Subotnik is director of the Center for Psychology in Schools and Education at the American Psychological Association.

Paula Olszewski-Kubilius is director of the Center for Talent Development at Northwestern University.

Frank C. Worrell is a professor of school psychology at the University of California, Berkeley.

The Talent Gap

The U.S. is neglecting its most promising science students

The U.S. education policy world—the entire country, for that matter—is on a quest to increase the ranks of future innovators in science and technology. Yet the programs that get funded in K–12 education do not support students who are already good at and in love with science. These students have potential for outstanding contributions, but without public investment they will not be prepared for the rigors of a scientific career. This is especially true for those without highly educated and resource-rich parents.

This lack of investment is not a matter of chance. It is the result of two related myths about who these students are and what they need from our education system. The first myth is that all talented students come from privileged backgrounds. A second is that students who are successful at a particular time in their school career can somehow thrive on their own, unassisted and unsupervised. We argue that all children deserve to be challenged cognitively, including the most able. Many students with low socioeconomic backgrounds never get the opportunity to develop their talents beyond the rudimentary school curriculum. Jonathan Plucker of the University of Connecticut has shown that high-achieving, low-income students fall further behind their higher-socioeconomic-status peers the closer they get to graduation. Moreover, international comparison studies show science scores improving for all students except those in the top 10 percent.

We know how to identify students who are talented in science and motivated to achieve. We find them thriving in enriched environments (think math and rocketry clubs) inside and outside of school. Standardized tests identify exceptional reasoning abilities in mathematics and spatial skills. Expressing and showing interest in science in elementary or middle school are good predictors of future pursuit of career interests in science, technology, engineering or mathematics.

We also know something about the services most likely to help talented kids sustain their curiosity in science, even through advanced courses. According to researchers at Vanderbilt University, middle school is the best time to start looking for students with exceptional mathematical ability and for offering mathematics and science at an advanced level—currently widely done through university talent-search programs at Northwestern, Johns Hopkins, Duke and the University of Iowa. At this age, talented students can be taught to write in the language and format employed in scientific journals. Clearly, these advanced skills and content will require teachers who themselves have the requisite knowledge and skill—particularly a strong grounding in mathematics.

Classwork, no matter how enlightening, cannot replicate the camaraderie or excitement (and sometimes frustration) of science in the workplace. Students can witness science in a university, hospital, corporation or museum laboratory through mentoring or apprenticeship relationships. Local, regional and national competitions such as science fairs and olympiads are also excellent opportunities for creative problem solving and for mastering advanced material. These venues provide students from various social and economic backgrounds opportunities to share their aptitudes and interests.

Competition can be exciting, but it can also drain self-confidence. Ask any musician or athlete how essential coaching is to get them past setbacks. Therefore, another feature of a comprehensive program for talent development would include psychological strength training tailored to the academic realm that enhances teenagers' ability to persist by learning how to "up their game" or switch tactics when the going gets rough.

If we really care about forging new generations of scientists and innovators, we should be finding scientifically talented young people and helping them reach their potential. Channeling even a small fraction of our nation's science education funding to students with demonstrated interests and achievements could have big payoffs. More fundamentally, it would challenge misguided assumptions about talent and elitism that have blinded policy makers and educators and prevented them from engaging with this population of students. SA

SCIENTIFIC AMERICAN ONLINE
Comment on this article at ScientificAmerican.com/aug2014

Illustration by Danny Schwartz

For people with a higher risk of stroke due to Atrial Fibrillation (AFib) not caused by a heart valve problem

ELIQUIS® (apixaban) is a prescription medicine used to reduce the risk of stroke and blood clots in people who have atrial fibrillation, a type of irregular heartbeat, not caused by a heart valve problem.

IMPORTANT SAFETY INFORMATION:

- **Do not stop taking ELIQUIS for atrial fibrillation without talking to the doctor who prescribed it for you. Stopping ELIQUIS increases your risk of having a stroke.** ELIQUIS may need to be stopped, prior to surgery or a medical or dental procedure. Your doctor will tell you when you should stop taking ELIQUIS and when you may start taking it again. If you have to stop taking ELIQUIS, your doctor may prescribe another medicine to help prevent a blood clot from forming.
- **ELIQUIS can cause bleeding, which can be serious,** and rarely may lead to death.
- **You may have a higher risk of bleeding if you take ELIQUIS and** take other medicines that increase your risk of bleeding, such as aspirin, NSAIDs, warfarin (COUMADIN®), heparin, SSRIs or SNRIs, and other blood thinners. **Tell your doctor about all medicines, vitamins and supplements you take.** While taking ELIQUIS, you may bruise more easily and it may take longer than usual for any bleeding to stop.
- Get medical help right away if you have any of these signs or symptoms of bleeding:
  - unexpected bleeding, or bleeding that lasts a long time, such as unusual bleeding from the gums; nosebleeds that happen often, or menstrual or vaginal bleeding that is heavier than normal
  - bleeding that is severe or you cannot control
  - red, pink, or brown urine; red or black stools (looks like tar)
  - coughing up or vomiting blood or vomit that looks like coffee grounds
  - unexpected pain, swelling, or joint pain; headaches, feeling dizzy or weak
- **ELIQUIS is not for patients with artificial heart valves.**
- **Spinal or epidural blood clots or bleeding (hematoma).** People who take ELIQUIS, and have medicine injected into their spinal and epidural area, or have a spinal puncture have a risk of forming a blood clot that can cause long-term or permanent loss of the ability to move (paralysis).

I focused on finding something better than warfarin.

NOW I TAKE ELIQUIS® (apixaban) FOR 3 GOOD REASONS:

1 ELIQUIS reduced the risk of stroke better than warfarin.

2 ELIQUIS had less major bleeding than warfarin.

3 Unlike warfarin, there's no routine blood testing.

ELIQUIS and other blood thinners increase the risk of bleeding which can be serious, and rarely may lead to death.

Ask your doctor if ELIQUIS is right for you.

This risk is higher if, an epidural catheter is placed in your back to give you certain medicine, you take NSAIDs or blood thinners, you have a history of difficult or repeated epidural or spinal punctures. Tell your doctor right away if you have tingling, numbness, or muscle weakness, especially in your legs and feet.

- **Before you take ELIQUIS,** tell your doctor if you have: kidney or liver problems, any other medical condition, or ever had bleeding problems. Tell your doctor if you are pregnant or breastfeeding, or plan to become pregnant or breastfeed.

- **Do not take ELIQUIS if you** currently have certain types of abnormal bleeding or have had a serious allergic reaction to ELIQUIS. A reaction to ELIQUIS can cause hives, rash, itching, and possibly trouble breathing. Get medical help right away if you have sudden chest pain or chest tightness, have sudden swelling of your face or tongue, have trouble breathing, wheezing, or feeling dizzy or faint.

You are encouraged to report negative side effects of prescription drugs to the FDA. Visit www.fda.gov/medwatch, or call 1-800-FDA-1088.

Please see additional Important Product Information on the adjacent page.

Individual results may vary.

Visit ELIQUIS.COM
or call 1-855-ELIQUIS

Eliquis®
(apixaban) tablets 5mg 2.5mg

IMPORTANT FACTS about ELIQUIS® (apixaban) tablets

℞ ONLY

The information below does not take the place of talking with your healthcare professional. Only your healthcare professional knows the specifics of your condition and how ELIQUIS may fit into your overall therapy. Talk to your healthcare professional if you have any questions about ELIQUIS (pronounced ELL eh kwiss).

What is the most important information I should know about ELIQUIS (apixaban)?

For people taking ELIQUIS for atrial fibrillation: Do not stop taking ELIQUIS without talking to the doctor who prescribed it for you. Stopping ELIQUIS increases your risk of having a stroke. ELIQUIS may need to be stopped, prior to surgery or a medical or dental procedure. Your doctor will tell you when you should stop taking ELIQUIS and when you may start taking it again. If you have to stop taking ELIQUIS, your doctor may prescribe another medicine to help prevent a blood clot from forming.

ELIQUIS can cause bleeding which can be serious, and rarely may lead to death. This is because ELIQUIS is a blood thinner medicine that reduces blood clotting.

You may have a higher risk of bleeding if you take ELIQUIS and take other medicines that increase your risk of bleeding, such as aspirin, nonsteroidal anti-inflammatory drugs (called NSAIDs), warfarin (COUMADIN®), heparin, selective serotonin reuptake inhibitors (SSRIs) or serotonin norepinephrine reuptake inhibitors (SNRIs), and other medicines to help prevent or treat blood clots.

Tell your doctor if you take any of these medicines. Ask your doctor or pharmacist if you are not sure if your medicine is one listed above.

While taking ELIQUIS:

- you may bruise more easily
- it may take longer than usual for any bleeding to stop

Call your doctor or get medical help right away if you have any of these signs or symptoms of bleeding when taking ELIQUIS:

- unexpected bleeding, or bleeding that lasts a long time, such as:
  - unusual bleeding from the gums
  - nosebleeds that happen often
  - menstrual bleeding or vaginal bleeding that is heavier than normal
- bleeding that is severe or you cannot control
- red, pink, or brown urine
- red or black stools (looks like tar)
- cough up blood or blood clots
- vomit blood or your vomit looks like coffee grounds
- unexpected pain, swelling, or joint pain
- headaches, feeling dizzy or weak

ELIQUIS (apixaban) is not for patients with artificial heart valves.

Spinal or epidural blood clots or bleeding (hematoma). People who take a blood thinner medicine (anticoagulant) like ELIQUIS, and have medicine injected into their spinal and epidural area, or have a spinal puncture have a risk of forming a blood clot that can cause long-term or permanent loss of the ability to move (paralysis). Your risk of developing a spinal or epidural blood clot is higher if:

- a thin tube called an epidural catheter is placed in your back to give you certain medicine
- you take NSAIDs or a medicine to prevent blood from clotting
- you have a history of difficult or repeated epidural or spinal punctures
- you have a history of problems with your spine or have had surgery on your spine

If you take ELIQUIS and receive spinal anesthesia or have a spinal puncture, your doctor should watch you closely for symptoms of spinal or epidural blood clots or bleeding. Tell your doctor right away if you have tingling, numbness, or muscle weakness, especially in your legs and feet.

What is ELIQUIS?

ELIQUIS is a prescription medicine used to:

- reduce the risk of stroke and blood clots in people who have atrial fibrillation.
- reduce the risk of forming a blood clot in the legs and lungs of people who have just had hip or knee replacement surgery.

It is not known if ELIQUIS is safe and effective in children.

Who should not take ELIQUIS (apixaban)?

Do not take ELIQUIS if you:

- currently have certain types of abnormal bleeding
- have had a serious allergic reaction to ELIQUIS. Ask your doctor if you are not sure

What should I tell my doctor before taking ELIQUIS?

Before you take ELIQUIS, tell your doctor if you:

- have kidney or liver problems
- have any other medical condition
- have ever had bleeding problems
- are pregnant or plan to become pregnant. It is not known if ELIQUIS will harm your unborn baby
- are breastfeeding or plan to breastfeed. It is not known if ELIQUIS passes into your breast milk. You and your doctor should decide if you will take ELIQUIS or breastfeed. You should not do both

Tell all of your doctors and dentists that you are taking ELIQUIS. They should talk to the doctor who prescribed ELIQUIS for you, before you have **any** surgery, medical or dental procedure. **Tell your doctor about all the medicines you take, including** prescription and over-the-counter medicines, vitamins, and herbal supplements. Some of your other medicines may affect the way ELIQUIS works. Certain medicines may increase your risk of bleeding or stroke when taken with ELIQUIS.

How should I take ELIQUIS?

Take ELIQUIS exactly as prescribed by your doctor. Take ELIQUIS twice every day with or without food, and do not change your dose or stop taking it unless your doctor tells you to. If you miss a dose of ELIQUIS, take it as soon as you remember, and do not take more than one dose at the same time. **Do not run out of ELIQUIS (apixaban). Refill your prescription before you run out.** When leaving the hospital following hip or knee replacement, be sure that you will have ELIQUIS available to avoid missing any doses. **If you are taking ELIQUIS for atrial fibrillation, stopping ELIQUIS may increase your risk of having a stroke.**

What are the possible side effects of ELIQUIS?

- See **"What is the most important information I should know about ELIQUIS?"**
- ELIQUIS can cause a skin rash or severe allergic reaction. Call your doctor or get medical help right away if you have any of the following symptoms:
  - chest pain or tightness
  - swelling of your face or tongue
  - trouble breathing or wheezing
  - feeling dizzy or faint

Tell your doctor if you have any side effect that bothers you or that does not go away.

These are not all of the possible side effects of ELIQUIS. For more information, ask your doctor or pharmacist.

Call your doctor for medical advice about side effects. You may report side effects to FDA at 1-800-FDA-1088.

This is a brief summary of the most important information about ELIQUIS. For more information, talk with your doctor or pharmacist, call 1-855-ELIQUIS (1-855-354-7847), or go to www.ELIQUIS.com.

Manufactured by:
Bristol-Myers Squibb Company
Princeton, New Jersey 08543 USA
Marketed by:
Bristol-Myers Squibb Company
Princeton, New Jersey 08543 USA
and
Pfizer Inc
New York, New York 10017 USA

Based on 1289808A0 / 1289807A0 / 1298500A0 / 1295958A0
March 2014
432US14BR00770-04-01

EARTH SCIENCE

Africa's Great Divide

Primordial gases confirm the cause of a continental rift

Olduvai Gorge in Great Rift Valley, Tanzania

EMORY KRISTOF *National Geographic*

Africa is splitting in two. The reason: a geologic rift runs along the eastern side of the continent that one day, many millions of years in the future, will be replaced with an ocean. Scientists have argued for decades about what is causing this separation of tectonic plates. Geophysicists thought it was a superplume, a giant section of the earth's mantle that carries heat from near the core up to the crust. As evidence, they pointed to two large plateaus (one in Ethiopia and one in Kenya) that they said were created when a superplume pushed up the mantle. Geochemists were not able to confirm that theory. Instead they thought there might be two small, unrelated plumes pushing up the plateaus individually. The theories did not align, says David Hilton, a geochemist at the Scripps Institution of Oceanography in La Jolla, Calif. "There was a mismatch between the chemistry and the physics."

So in 2006 and 2011 Hilton headed to East Africa to see whether he could lay the argument to rest. He and his team decided to use gases emanating from the rift to determine how it was created. Donning gas masks, they hiked to the tops of volcanoes in Tanzania and Ethiopia and climbed into *mazuku* (the Swahili word for "evil wind")—geothermal vents and depressions where deadly gases accumulate and often kill animals. At these locations, the team collected samples of rocks deposited during eruptions, including olivines, crystals that trap volcanic gases like a bottle.

Back home in California, Hilton crushed the rocks inside a vacuum to release their gases. He was looking for helium 3, an isotope of helium present when the planet was forming that was trapped in the earth's core. Hilton figured that if rocks around both the Ethiopian and Kenyan plateaus contained this primordial gas, that would at least confirm that underground mantle plumes created them. The readings showed that, indeed, both plateaus contained helium 3. But Hilton and his group still had to wonder: Was one superplume behind it all? Or were there a couple of lesser plumes?

To answer this question, they turned to another primordial gas trapped in the mantle: neon 22. They found that neon 22 existed in both plateaus and that the ratios of helium to neon in those locations matched, results published in April in *Geophysical Research Letters*. That meant that the plume underneath both plateaus was of the same material and of the same age. Hence, there was one common superplume. The geophysicists, it turns out, had been right all along.

"The 'naysayers' who claim that the rifting and plume activity are unconnected—and some who would even deny a mantle plume is present—no longer have a leg to stand on," says Pete Burnard, a geochemist at the French National Center for Scientific Research, who was not involved in the latest work.

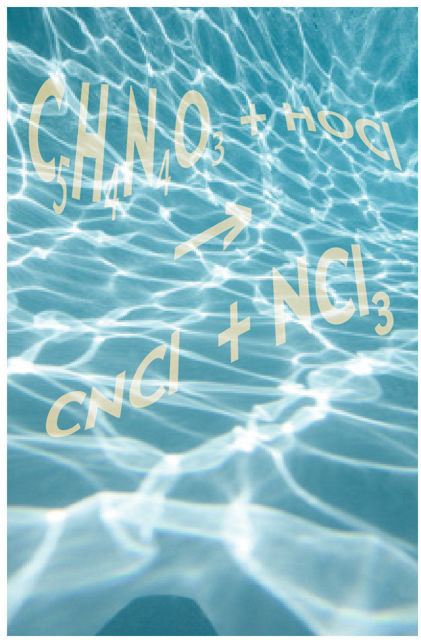
The African superplume will provide scientists with easier access to study the earth's inner workings (another lies underneath the Pacific Ocean). Hilton and his team are now measuring how much carbon the mantle in East Africa is releasing, how old it is and if it has been recycled from carbon originally captured on the surface billions of years ago. This information, Hilton says, will help geologists figure out how the earth's layers interact on a longer time scale, including the hundreds of millions of years it takes for continents to form—and split.

—Erin Biba

CHEMISTRY

Don't Put the "Pee" in Pool

It's dangerous. Really



RIC FRAZIER *Gallery Stock*

One in five of us will do the unthinkable this summer: take a leak in the pool.

The lazy act is more than gross, though. It results in toxic chemicals, albeit in very small amounts. "There's this perception that peeing in a pool is okay because there's chlorine, and that's just not true," says Ernest Blatchley, a chemical engineer at Purdue University. In a pool, chlorine's job is to kill bacteria. It does not take care of bodily functions. In fact, it readily reacts with uric acid, the nitrogen-containing chemical that gives urine its name. The resulting compounds are cyanogen chloride (CNCl) and trichloramine (NCl_3), which are potentially hazardous and present in every pool Blatchley has sampled for the past 10 years. His most recent study, published in the journal *Environmental Science & Technology,* shows that 93 percent of the uric acid used to make these compounds comes from human urine (sweat also contains uric acid).

And it does not take very much pee to drive levels of these chemicals above acceptable limits set by the U.S. Environmental Protection Agency: a previous study found that levels of trichloramine rose by a factor of four after swim meets. Other scientists have found frequent exposure to trichloramine and cyanogen chloride in pools—like swimmers and lifeguards experience—raises the likelihood of asthma and other respiratory problems, although these links require more study.

So if the ick factor isn't enough already, *please,* don't pee in the pool. *—Carrie Arnold*

COMMENT AT ScientificAmerican.com/aug2014

MOBILE TECHNOLOGY

A Network That Never Goes Down

Future cell phones will be able to make emergency calls at all times

When Hurricane Sandy battered the Eastern seaboard in 2012, it took down up to half of all cellular towers in the hardest-hit areas. The storm highlighted a flaw in our reliance on wireless phones as a primary means of communication. Qualcomm and other wireless companies have been working on a new cellular standard—a set of technical procedures that ensures devices can "talk" to one another—that will keep the lines open if the network fails. The Proximity Services, or so-called LTE Direct, standard will be approved by the end of the year.

In a typical cell phone call, the signal travels through a cellular tower. LTE Direct cuts out that middleman. In emergencies, phones that use it will be able to connect directly with one another over the same frequency as 4G LTE transmissions. Users will be able to call other users or first responders within about 500 meters. If the target is not nearby, the system can relay a message through multiple phones until it reaches its destination.

Qualcomm and others will need to update their antennas and processors to take advantage of LTE Direct, so it will be a year or more before phones have this functionality. But an approved standard means companies can get working. —*Corinne Iozzio*

Illustrations by Thomas Fuchs

Google's new autonomous car, announced in May.

AUTOMOTIVE

Street-Legal Robots

Self-driving vehicles get new laws in California

The law is finally catching up to driverless cars. As of September 16, the state of California—home of auto newcomer Google—will require test drivers to have a special license, like a trucker or school bus driver. They will need to be employees or contractors of the car manufacturer, complete safety training, and have clean road records. Carmakers themselves will have to apply for a testing permit annually, install manual controls and override systems in each car, submit incident reports and secure $5 million in insurance.

These new rules come into effect at a time when a handful of players, including Google and Nissan, are testing driverless technologies. Up until now, autonomous test vehicles have had a spotless record; Google's fleet of modified Lexus sedans, for instance, has driven more than 700,000 miles without an accident. The most pressing issue for the California Department of Motor Vehicles and manufacturers is ensuring the ongoing safety of these cars—prototypes, all—and the cars around them.

In essence, regulators are trying to keep pace with driverless technology, says Bryant Walker Smith, a fellow at the Center for Automotive Research at Stanford University. The upcoming California laws will make many of the safety checks already in place in driverless prototypes, including the presence of a human operator and a vehicle that is street legal, mandatory. (That means that Google engineers will need to add manual controls to the company's new self-driving car before it can go onto public roads.) The California DMV is not stipulating anything about the technologies themselves, which keeps companies free to test new systems.

Laws will continue to evolve as the technology becomes more advanced. By December the California DMV will release another set of regulations laying out the requirements for everyday drivers to pilot autonomous vehicles. A second set may also be necessary for cars that drive themselves absent any driver. But that does not mean we will be hailing robo taxis by this time next year. Nissan says it will not roll out a driverless car until 2020, and everyone else will also proceed with caution. "Every company wants to have the first self-driving car," Walker Smith says, "but no one wants to have the first self-driving car crash." —*Corinne Iozzio*

AP PHOTO

COMMENT AT ScientificAmerican.com/aug2014

KNOW THE
JARGON

Unnatural base pairs:

(n., pl.) Man-made carbon-based molecules that can substitute for or extend the natural set of molecules that make up DNA.

The genes that direct all life on earth employ just four base units: A is for adenine, which bonds with thymine (T). G is for guanine, which bonds with cytosine (C). Combinations of A, T, G and C appear in each and every living thing—and now scientists have added two new letters to the alphabet. These unnatural base pairs are a first for the burgeoning field of synthetic biology.

In 2008 a team of chemical biologists at the Scripps Research Institute in La Jolla, Calif., began experimenting with compounds that could serve as new bases for the genetic code, a dream of some scientists since the 1960s. They found that two in particular— d5SICS and dNaM—worked well with the enzymes that read or copy DNA in living organisms.

So the team inserted these unnatural base pairs into a plasmid, a short sequence of free-floating DNA that can persist inside a cell, and put that plasmid into the microbe *Escherichia coli.* The addition went well: the *E. coli* happily copied the unnatural base pairs and its internal DNA editors, which usually get rid of oddities, did not notice them, either. Despite the alien DNA inside, new daughter cells had no trouble growing. The team published the results in May in *Nature.* (*Scientific American* is part of Nature Publishing Group.)

Next, the researchers aim to get the unnatural base pairs into the actual genome of a microbe rather than an adjacent plasmid. If they can do that, they might be able to get the unnatural base pairs to code for genes that produce new compounds, such as amino acids that could be useful in medicine or other areas. Jargon to watch for in the future may include such terms as "unnatural amino acids." Regardless, the genetic alphabet has now gotten a bit longer, which means that, in principle, the book of life can be rewritten.

—David Biello

BY THE NUMBERS

In May, the study cited above was the most talked about science paper by news outlets and on social media combined.

85
News Outlets

29
Blogs

688
Tweets

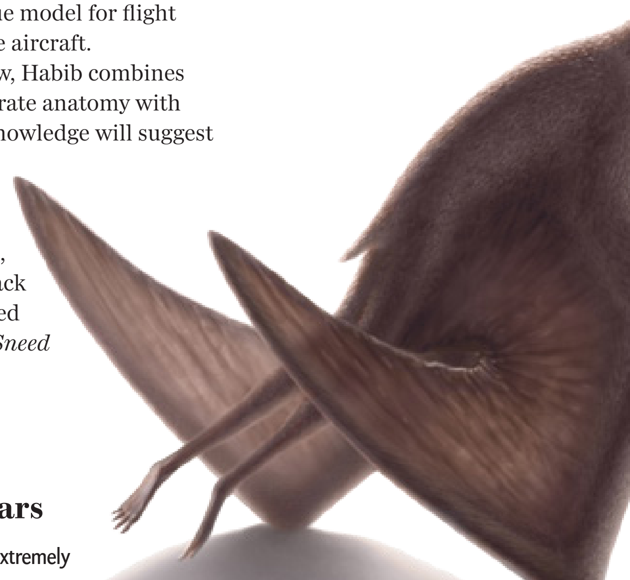
SOURCE: Altmetric
(part of Nature Publishing Group)

BIOMECHANICS

Pterosaur Tech

Why the U.S. Department of Defense has shown interest in pterosaurs, the winged reptiles that dominated the skies 228 million to 66 million years ago

Jeholopterus ninchengensis



Paleontologist Michael Habib studies the biomechanics of pterosaurs, the biggest of which—at 550 pounds and with a 34-foot wingspan—were the size of modern-day fighter jets. They were the largest flying animals ever to exist and sported anatomy different from any bird or bat. This makes them a unique model for flight mechanics, particularly for large aircraft.

To model how pterosaurs flew, Habib combines principles of physics and vertebrate anatomy with fossil data. He hopes that this knowledge will suggest new aircraft designs and other technology to places like NASA and the DOD—it already has in some cases. In an abstract sense, he has brought these animals back from the dead. Pterosaur-inspired applications follow. *—Annie Sneed*

Flying Robots over Mars

Traditional spacecraft would need to fly extremely fast to stay aloft in Mars's thin atmosphere, an impracticality if scientists want to survey Martian terrain in detail. One solution may be a robot that flies like a pterosaur—with swift beating wings and a relatively slow-moving body. Hummingbirds and bumblebees also fly this way, and NASA has created designs for robots based on the biomechanics of these "flapping fliers."

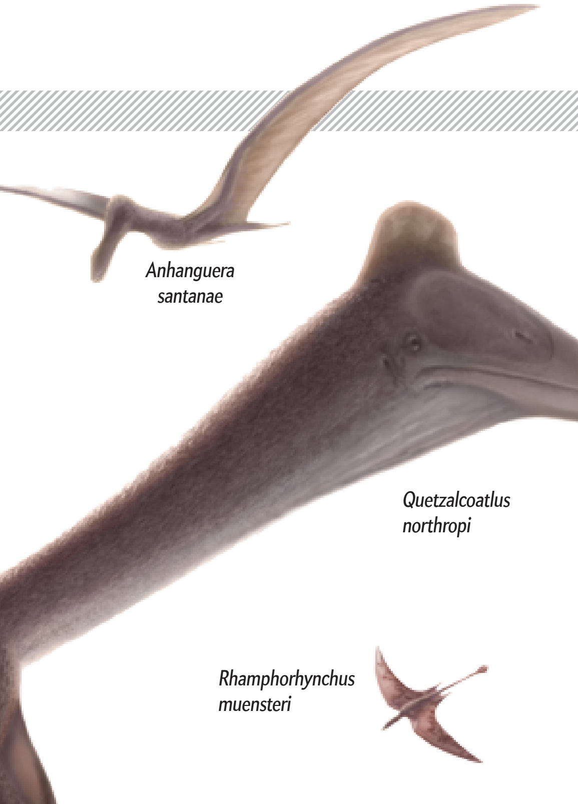
ENVIRONMENT

5 National Landmarks Threatened by Climate Change

Climate change, with its associated droughts, storms, food shortages and wildfires, puts humans at physical risk. Yet global warming also imperils what is less tangible but still valuable: our national identity. In May the Union of Concerned Scientists released a report detailing more than 30 iconic sites in the U.S. that are at risk of damage. Write the authors: "If future generations of Americans are to experience the joy and wonder that these extraordinary places engender, we must act now to protect them from the impacts of climate change." —Annie Sneed

Statue of Liberty, New York City
Hurricanes; storm surges; rising tides; flooding
Protection: *After Hurricane Sandy, the National Park Service began work on flood-proofing Liberty Island's climate-control systems and elevating its electrical systems.*

COMMENT AT ScientificAmerican.com/aug2014



Rapid-Launch Systems

Unlike planes today, giant pterosaurs did not need runways. They were experts at vertical takeoff, a feat that is impossible or incredibly inefficient for today's aircraft. Because the reptiles had stiff but lightweight, hollow bones, they could use all four limbs—both their feet and wings—to push powerfully against the ground. That action allowed them to generate more speed over a shorter distance as they leaped into flight. Habib is currently negotiating a Defense Advanced Research Projects Agency grant proposal with the DOD to design an aircraft system with analogous physical characteristics and a quadrupedal launch strategy that would allow pilots to perform a quick vertical launch or takeoff on low fuel.

Morphing Wings

In each wing, pterosaurs had a single tapered finger that grew up to 2.5 meters long in the largest species. When pterosaurs flew, those fingers bent with the force of the downward wing stroke and then reflexively snapped back into position on the upward stroke. The spontaneous return to equilibrium saved pterosaurs significant energy when flapping. Habib says roboticists in the U.S. Air Force are interested in morphing wings, which they could use in flight systems in aircraft or in parachutes—essentially highly convex wings.

Low-Flutter Tents

To fly, pterosaurs kept their wings uniformly taut. Those wings were membranous, with long, thick fibers crisscrossed by smaller fibers that controlled how much the wings fluttered. The fibers individually moved under high air pressure, but their varied dimensions meant they oscillated at opposing frequencies that ultimately canceled out, enabling pterosaurs to maintain a steady wing. Habib has approached manufacturers with a tent fabric design that exploits the same physical principle to reduce noisy flapping and improve stability in high wind conditions.

Faneuil Hall, Boston
Rising seas; coastal flooding
Protection: *The city is planning building renovations that may include flood-protection walls.*

Cape Hatteras Lighthouse, Buxton, N.C.
Shoreline erosion; sea-level rise
Protection: *In 1999 the National Park Service moved the lighthouse 2,900 feet back—a project that cost $11.8 million.*

NASA Johnson Space Center, Houston
Hurricanes
Protection: *The center installed new roofs designed to withstand 130-mph winds. Hurricane Ike repairs from 2008 cost roughly $80 million.*

Mesa Verde National Park Mesa Verde, Colo.
Wildfires; flooding
Protection: *The National Park Service performs prescribed burns. It is also adding silicone to cliff faces to reroute water and prevent erosion.*

Illustrations by Stephanie Abramowicz (pterosaurs) and Ariel Weiss (icons)

PLANT SCIENCE

Foliage Friendships

Microbial communities on a plant's roots, stems and leaves may improve crop growth

The Human Microbiome Project revealed tens of trillions of microbes residing in and on humans. Now scientists are taking a census of plant microbes—and not just the hundreds of billions found in soils. Distinct microbial communities live inside roots, on leaves and within flowers, and all in all have an estimated three to six orders of magnitude greater genetic diversity than their plant hosts. This second genome, much like the human microbiome, provides plants access to nutrients and helps to suppress disease. Scientists and farmers alike think it represents the next big thing in agriculture.

NIGEL CATTLIN *Getty Images*

We are only just beginning to understand the interactions between plants and microorganisms. For instance, Jeff Dangl, a plant immunologist at the University of North Carolina at Chapel Hill, and his colleagues recently found that soil bacteria help to determine the flowering time of a wild plant in the mustard family. The results were published in June in *Ecology Letters*. And back in 2012, the team was surprised to find an abundance of streptomycetes bacteria living in a plant. Streptomycetes are often used to make antibiotics and may protect plants against infection. What is more, Dangl and others think understanding these intimate relationships is critical for increasing agricultural productivity, especially given rising global demand for food.

Commercial companies think so, too. Within the past two years BASF, Bayer CropScience, Chr. Hansen, Novozymes, Monsanto and numerous start-ups have invested about $2 billion in research and development in the area. Most of them are working on so-called biologicals—living crop aids. For example, Tom Johnson, who recently sold his South Dakota–based company TJ Technologies to Novozymes, developed QuickRoots, a seed coating of bacteria and fungi that spurs root growth.

Microorganisms may also be used to get rid of disease faster than breeding and genetic modification as well as to reduce wasteful applications of fertilizers. Thomas Videbæck, an executive vice president at Novozymes, says the company expects advances in the use of microorganisms to supplement rather than replace traditional methods. "There's not a silver bullet in any one of these technologies," he says, "but we need to overcome the enormous hurdle of being able to produce twice as much food to feed nine billion people." Earlier this year Novozymes announced the construction of a facility in North Carolina's Research Triangle Park to develop microbial cocktails that function as pesticides and support plant growth. It and other companies are waiting to see just what the plant microbiome will yield.

—Peter Andrey Smith

BY THE NUMBERS

30,000

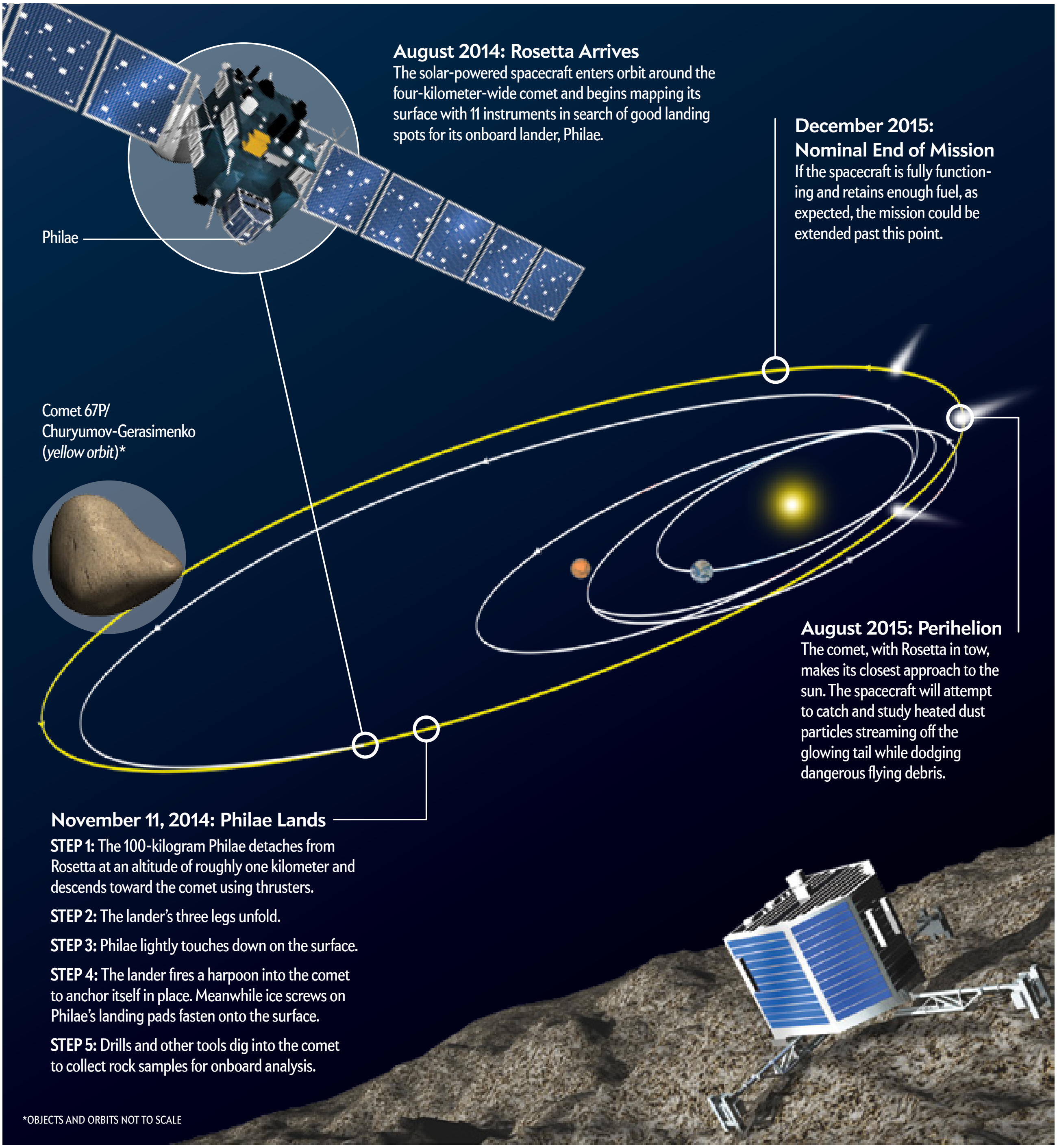
Estimated number **of microbial species in a plant's rhizosphere, the narrow zone of soil around its roots.**

SOURCE: "The Rhizosphere Microbiome and Plant Health," by Roeland L. Berendsen et al., in *Trends in Plant Science,* Vol. 17, No. 7; August 2012

SPACE

Rendezvous with a Comet

The European Space Agency's Rosetta spacecraft has been flying toward its target, Comet 67P/Churyumov-Gerasimenko, for 10 years. This month, at long last, it arrives. Astronomers think that comets were the building blocks of our solar system, and by studying one up close, they can better understand these planetary raw materials. Rosetta will also document how a comet's tail forms by watching its target shed dust and gas as it nears the sun. But that's only if its lander can do something never before attempted: land on a comet hurtling through space. *—Clara Moskowitz*



SOURCE: EUROPEAN SPACE AGENCY

Illustration by Don Foley

CONSERVATION

Top-down Control

Big animals keep smaller ones carrying disease in check

Biologists have long thought that when large mammals, such as elephants and gazelles, are driven to extinction, small critters will inherit the earth. As those critters (think rodents) multiply, so will the number of disease-carrying fleas. Scientists have now experimentally confirmed this scenario, which is troubling because it could lead to a rise in human infection by diseases that can be transferred between animals and people.

The research started 20 years ago, when biologists working at the Mpala Research Center in Kenya embarked on a large-scale experiment to understand the importance of diversity. They divided swaths of the center's land into 10-acre chunks and changed the types of wildlife living on each one. In some, they removed all large animals, such as giraffes and zebras, leaving behind only mammals smaller than 33 pounds. As the years went on, they kept a record of the species that inhabited each plot of the savanna.

Using those records, Hillary Young, an ecologist at the University of California, Santa Barbara, compared rodent abundance in tracts free of large mammals with similar areas open to all wildlife. She and her colleagues discovered that the landscapes rid of these large mammals contained twice as many rodents as the uncontrolled areas. The findings were published in May in the journal *Proceedings of the National Academy of Sciences USA*.

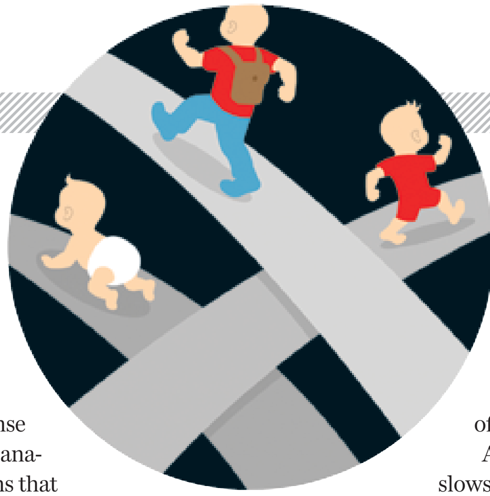
Out of the 11 mammal species present on the land devoid of megafauna, Mearns's pouched mice were most populous, accounting for 75 percent of the total count. As expected, the chances of finding a flea carrying the bacterium *Bartonella* also doubled. *Bartonella* infects mammals, including humans, and can cause major organ damage.

"Changes in wildlife communities can and do cause significant impacts on disease risk," says Young, who adds that the results should apply to all places, not just the African savanna. She hopes that if people understand that preserving wildlife also preserves their own health, perhaps they will be less likely to tolerate losses to biodiversity. —*Jason G. Goldman*

NEUROSCIENCE

Why Babies Forget

The fast growth of young brains may come at the expense of infant memories



It's easy to recall events of decades past—birthdays, high school graduations, visits to Grandma—yet who can remember being a baby? Researchers have tried for more than a century to identify the cause of "infantile amnesia." Sigmund Freud blamed it on repression of early sexual experiences, an idea that has been discredited. More recently, researchers have attributed it to a child's lack of self-perception, language or other mental equipment required to encode memories.

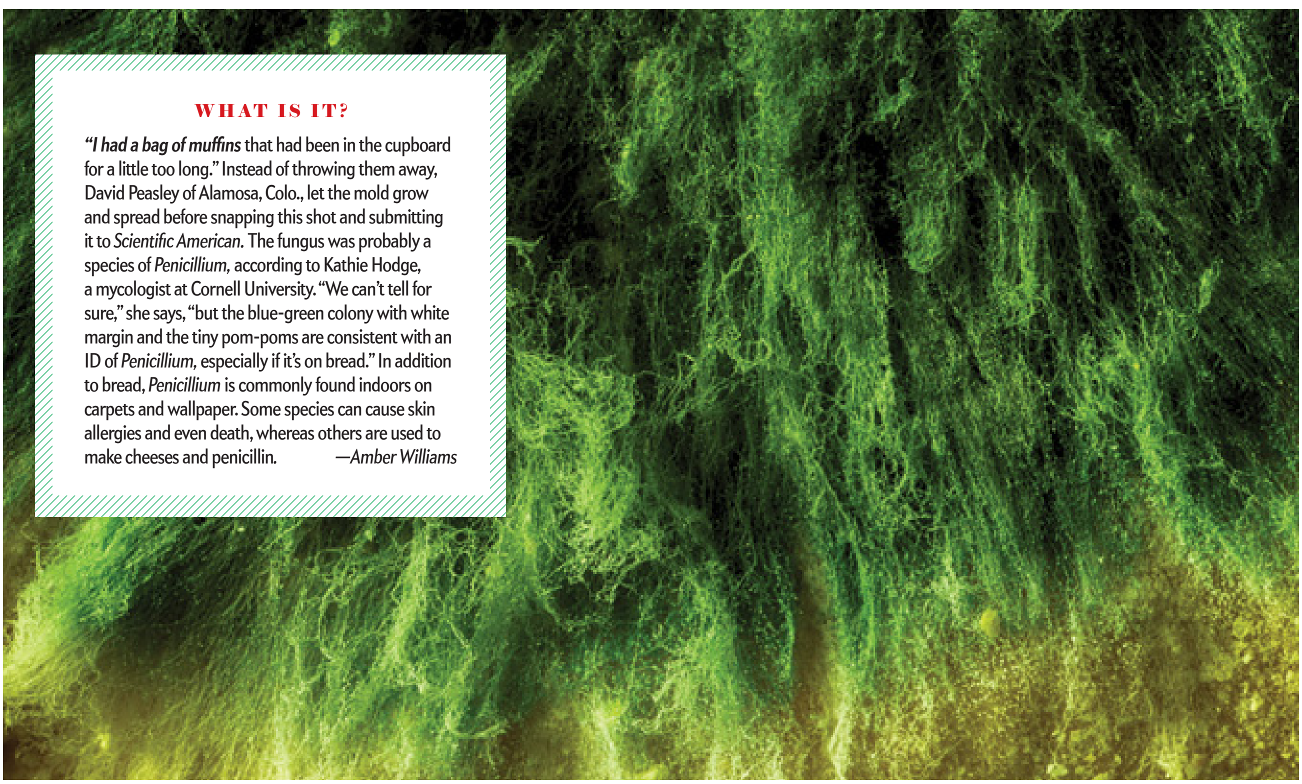
Neuroscientists Paul Frankland and Sheena Josselyn, both at the Hospital for Sick Children in Toronto, do not think linguistics or a sense of self offers a good explanation, either. It so happens that humans are not the only animals that experience infantile amnesia. Mice and monkeys also forget their early childhood. To account for the similarities, Frankland and Josselyn have another theory: the rapid birth of many new neurons in a young brain blocks access to old memories.

In a new experiment, the scientists manipulated the rate at which hippocampal neurons grew in young and adult mice. The hippocampus is the region in the brain that records autobiographical events. The young mice with slowed neuron growth had better long-term memory. Conversely, the older mice with increased rates of neuron formation had memory loss.

Based on these results, published in May in the journal *Science,* Frankland and Josselyn think that rapid neuron growth during early childhood disrupts the brain circuitry that stores old memories, making them inaccessible. Young children also have an underdeveloped prefrontal cortex, another region of the brain that encodes memories, so infantile amnesia may be a combination of these two factors.

As we age, neurogenesis slows, and the hippocampus achieves a balance of memory formation and retention. Of course, we still forget a lot, but that may be a good thing. "The sad truth in life is that most things we do are pretty mundane," Frankland says. "The idea is that for healthy adult memory function, you need not only to be able to remember things but also to clear out the inconsequential memories." Like all that sleeping, crying and crawling. Who needs to remember that?

—Annie Sneed



WHAT IS IT?

"I had a bag of muffins that had been in the cupboard for a little too long." Instead of throwing them away, David Peasley of Alamosa, Colo., let the mold grow and spread before snapping this shot and submitting it to *Scientific American.* The fungus was probably a species of *Penicillium,* according to Kathie Hodge, a mycologist at Cornell University. "We can't tell for sure," she says, "but the blue-green colony with white margin and the tiny pom-poms are consistent with an ID of *Penicillium,* especially if it's on bread." In addition to bread, *Penicillium* is commonly found indoors on carpets and wallpaper. Some species can cause skin allergies and even death, whereas others are used to make cheeses and penicillin. *—Amber Williams*

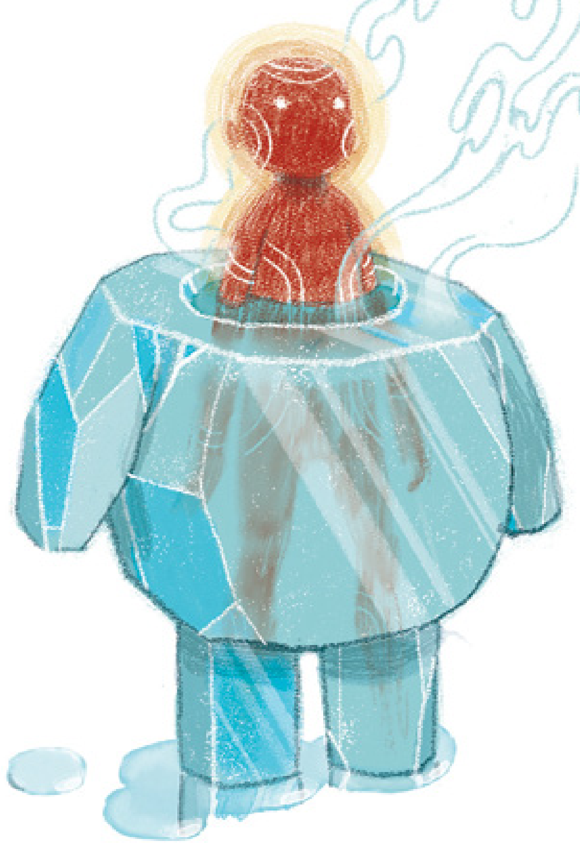
COURTESY OF DAVID PEASLEY

SUBMIT PHOTOS AT ScientificAmerican.com/what-is-it

Melinda Wenner Moyer is a science and health writer and an adjunct assistant professor at the City of New York Graduate School of Journalism. She writes a parenting advice column for Slate and contributes to *Nature, Newsweek* and *O, The Oprah Magazine.*

Can Brown Fat Defeat Obesity?

Why turning down the thermostat could help win the battle of the bulge



For most people, "fat," particularly the kind that bulges under the skin, is a four-letter word. It makes our thighs jiggle; it lingers despite our torturous attempts to eliminate it. Too much of it increases our risk for heart disease and type 2 diabetes (the most common form of the condition). For decades researchers have looked for ways to reduce our collective stores of fat because they seemed to do more harm than good.

But biology is rarely that simple. In the late 2000s several research groups independently discovered something that shattered the consensus about the absolute dangers of body fat. Scientists had long known that humans produce at least two types of fat tissue—white and brown. Each white fat cell stores energy in the form of a single large, oily droplet but is otherwise relatively inert. In contrast, brown fat cells contain many smaller droplets, as well as chestnut-colored molecular machines known as mitochondria. These organelles in turn burn up the droplets to generate heat. Babies, who have not yet developed the ability to shiver to maintain their body temperature, rely on thermogenic deposits of brown fat in the neck and around the shoulders to stay warm. Yet investigators assumed that all brown fat disappears during childhood. The new findings revealed otherwise. Adults have brown fat, too.

Suddenly, people started throwing around terms like holy grail to describe the promise of brown fat to combat obesity. The idea was appealingly simple: if researchers could figure out how to incite the body to produce extra brown fat or somehow rev up existing brown fat, a larger number of calories would be converted into heat, reducing deposits of white fat in the process.

Brown fat proved difficult to study, however, in part because it was so hard to find in adults. In addition, some experts doubted that enough brown fat could remain in the grown-up body to make much of a difference for the obese. Finally, the easiest way to get brown fat warmed up and going is to expose people to low temperatures, which somewhat diminishes brown fat's appeal as a weight-loss tool. The more researchers learned about brown fat, the more complications and questions arose.

Now, however, the understanding of brown fat is turning a corner. Scientists have learned new ways to pinpoint its location underneath the skin. The latest evidence suggests that it can indeed reduce excess stores of fat even in the obese. Researchers have also identified compounds that can activate brown fat without the need for unpleasantly chilling temperatures. As bizarre as it sounds, fat may become an important ally in the fight against obesity.

BIG FAT COMPLEXITIES

IN 2009 THREE DIFFERENT GROUPS independently published papers in the *New England Journal of Medicine* confirming their discovery of active brown fat cells in healthy adults. Investigators spent the next five years figuring out how to study brown fat more easily and in greater detail.

The most popular method of mapping where brown fat is located under the skin has been to scan the body using combined positron-emission tomography and computed tomography (PET-CT). This technique produces highly detailed images of the body's interior but requires a costly and invasive procedure, says Paul Lee, a research officer at the Garvan Institute of Medical Research in Sydney. To perform such scans, doctors first inject patients with solutions of radioactive but benign sugar molecules. Once the mitochondria inside brown fat cells start working, they consume the radioactive sugar, which emits gamma rays that the PET part of the scan can detect. The CT scan outlines the various different types of tissue, and the combination of the two technologies identifies brown fat cells that happen to be ac-

Illustration by Richie Pope

tive while overlooking all the dormant deposits.

Lee says several new methodologies are on the horizon that could make investigating brown fat in people easier and far more accurate. Scientists have, for example, devised ways of measuring brown fat with magnetic resonance imaging (MRI), a technology that uses giant magnets to harmlessly align water molecules in the body in such a way that detailed images of its different tissues are created and that is much less invasive than PET-CT scans because no injections are necessary. Another relatively inexpensive and noninvasive option is thermal imaging, which identifies hotspots of brown fat under the skin by monitoring the temperature of the overlying skin.

Even very modest increases in metabolism over a long period can lead to significant weight reduction.

As tools for studying brown fat have improved, experimenters have challenged previous pessimism about its ability to help people lose weight. In a 2012 study, six men remained inactive for three hours while wearing a cold suit that circulated water with a temperature of 64.4 degrees Fahrenheit over their skin—cold enough to lower their body temperature without causing too much shivering. That way the researchers could be sure that most of the extra calories burned during those three hours were expended by brown fat cells rather than quivering muscles.

The volunteers burned an extra 250 calories compared with what they would have used up during three hours of inactivity at more typical indoor temperatures. Although that may not sound like a lot, an extra 250 calories a day for two weeks would consume enough energy to allow a dieter to lose a pound of fat. "Even very modest increases in metabolism over a long period can lead to significant weight reduction," says Barbara Cannon, a physiologist at the Wenner-Gren Institute for Experimental Biology in Stockholm, who was not involved in the study.

Recent experiments have also revealed that brown fat's benefits go far beyond burning calories. A 2011 study using mice found that brown fat can fuel itself with triglycerides taken from the bloodstream—exactly the kind of fatty molecules known to increase the chances of developing metabolic syndrome, a cluster of conditions that raises the risk for heart disease, stroke and diabetes. Brown fat cells also draw sugar molecules from the blood, which could help lower the risk for type 2 diabetes; chronically high levels of blood glucose wreak havoc on the body's ability to manage those levels in the first place, which in turn sets the stage for diabetes.

BEIGE POWER

GIVEN THESE FINDINGS, an increasing number of scientists and biotech companies are trying to develop ways to multiply the number of brown fat cells in the body or somehow boost their activity. In addition, they are exploring the possibility of transforming white fat cells into tissue that behaves a lot like brown fat—what they call "beige" or "brite" (brown in white) fat.

Figuring out whether cool temperatures trigger the production of beige fat, in addition to revving up brown fat, seemed like a good starting point. Last year Japanese researchers asked 12 young men with lower than average amounts of active brown fat to sit in a 63 degree F room for two hours a day for six weeks. At first, the study participants burned an average of 108 extra calories in the cold compared with more normal indoor temperatures. After six weeks, however, their bodies were burning an extra 289 calories in the cold, and PET-CT scans indicated that their beige fat activity had indeed increased. A group of similarly aged and healthy men who were not repeatedly exposed to the cold showed no change in their metabolism. The researchers think that over the six weeks low temperatures increased the activity of a gene named *UCP1,* which seems to guide the conversion of white fat into beige fat.

Don't fancy low temperatures? Investigators have identified several molecules that may be able to stimulate such "browning" of white fat without the need for cold. Two 2012 studies showed that a hormone called irisin, which is released from muscle cells after exercise, coaxes white fat to behave like brown fat. In one of these studies, researchers injected mice with a gene that tripled the levels of the hormone in the blood of mice that were obese and had dangerously high amounts of sugar in their bloodstream. The mice lost weight and regained control of their glucose levels in just 10 days.

Exercise has also been shown to increase *UCP1* activity in brown fat, making it more active. Other naturally derived browning stimulators currently under investigation include brain-derived neurotrophic factor—a molecule that usually promotes growth of neurons—and SIRT1, a protein whose purpose remains mysterious but that may help the body manage stress.

Whereas converting existing white fat into beige fat is a promising approach, some researchers, including Cannon, think it may prove more helpful to increase amounts of brown fat itself. In 2013 she and her colleagues reported that brown fat can burn at least five times more stored energy than beige fat. Ideally, Cannon says, scientists will learn how to keep stores of brown fat as large and active throughout adulthood as they are in infancy: "The goal should be to maintain brown fat forever rather than having to re-create it."

Many researchers are confident that they will eventually hit on specific brown fat–based treatments, although most admit that such interventions most likely are 10 years away at least. In the meantime, though, self-motivated individuals can start applying some of the insights about brown fat to their own lives. "There is no doubt that an unhealthy diet and sedentary lifestyle are the two chief drivers of the obesity epidemic," Lee says, but "lack of exposure to temperature variation could be a subtle contributor."

In other words, central heating has its drawbacks, in part because it may dampen brown fat's activity. No one is quite ready to suggest turning down the thermostat in winter as a way of losing weight, however—although it undoubtedly saves money on your heating bill. Whether it might also help keep you trim and ward off chronic diseases remains to be seen. SA

SCIENTIFIC AMERICAN ONLINE
Comment on this article at ScientificAmerican.com/aug2014

David Pogue is the anchor columnist for Yahoo Tech and host of several *NOVA* miniseries on PBS.

The Two Tribes of Technology

Why it's nearly impossible to design new tech that will please everyone

At a recent party, a man was telling me about something that had happened at his nine-year-old's elementary school. Apparently the teacher was having trouble getting his laptop to work with a projector. In the end, a kid—a kid, mind you—stood up, walked to the front of the classroom and solved the problem.

"Can you believe it?" this guy concluded. "We've reached the point where the students know more than the teachers!"

I laughed politely, but I thought it was one of the dumbest anecdotes I had heard in years. The young knowing more about tech than their parents? Who hasn't heard that old trope a trillion times? This is surprising?

I forgot all about that exchange until I posted a how-to article recently, a step-by-step guide to PC hard-drive maintenance (defragmenting, cleaning, and so on). In the comments for the article, scorn and ridicule rained down. "I've only been doing that since Windows XP," said one commenter (that is, 2001). "What kind of moron needs an article to show him how?"

A lot of morons, it would seem; it was our most shared article of the week.

We recognize and name many of our demographic tribes: liberal and conservative, wealthy and poor, gay and straight. We classify ourselves that way, we watch out for oppression against one group or another, we pass laws to ensure equal treatment. But when will we recognize the existence of the two different types of technical consumers—the Knows and the Know-Nots?

Over and over again, I run into products that have been tacitly designed for either group. The creators have a mental picture of a product's audience and the users' technical experience. You can tell from terminology, the amount of detail in the instructions, the number of steps required to accomplish anything.

Unfortunately, there is no one type of tech consumer. Someone winds up unhappy. If the design and interface are too technical, novices feel incompetent, shut out and stupid; if the experience is too simple, tech geeks feel insulted and talked down to.

The first step in addressing these problems is acknowledging that there are two groups (okay, a wide spectrum) in the tech audience. The publishers of the *For Dummies* books have known about one end for years. They have not only marketed directly to the Know-Nots, but (equally important) they have also clearly labeled their products that way. The makers of the Jitterbug phone for older consumers—big buttons, large type, extra volume—don't pretend to be selling to everyone, either.

And on the advanced end of the spectrum—well, you don't see Oracle, SAP and Salesforce systems marketed to folks who only use simple applications.

Exactly. The real frustrations arise when products are marketed to everyone. Microsoft Word gives millions an inferiority complex, whereas others rebel at their lack of control over the program. Superusers are frustrated by the iPhone's lack of customizability, whereas first timers are overwhelmed by the options. Even cameras wind up alienating opposite groups.

Yes, it is hard to design a tech product that works equally well for everyone. Remember Office 2003? It featured menus that collapsed, hiding commands to present a simpler face. With another click, you could expand the menus to their full majesty.

It was a flop. It was impossible to learn the software because the menu commands were never in the same place twice.

Apple once designed a help system with animated Sharpies drawing red circles around things on the screen that you were supposed to click. Nobody used it. (Nobody knew it was there.)

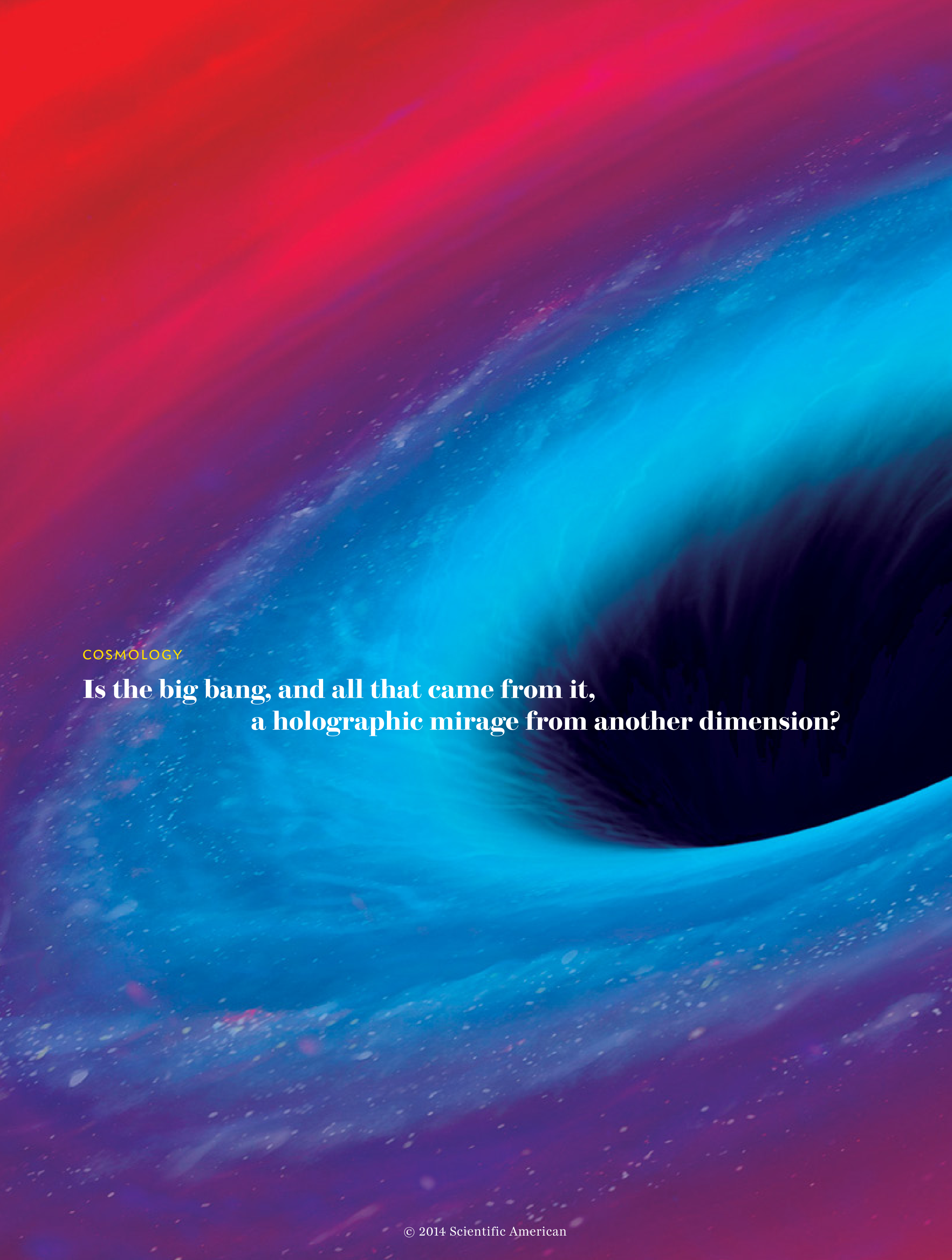
So, yes, it's a difficult art. But it can be done. When something powerful is designed elegantly, neither novices nor power users complain. The Nest thermostat. Fitness-tracking wristbands. Google searches.

The world will always need products that are clearly designed for people at the ends of the technical spectrum, and that's fine—as long as they are labeled that way (the products, not the people).

In the meantime, there's another step that we all can take to relieve some of the technical-level frustration: Quit judging. We were all Know-Nots once. SA

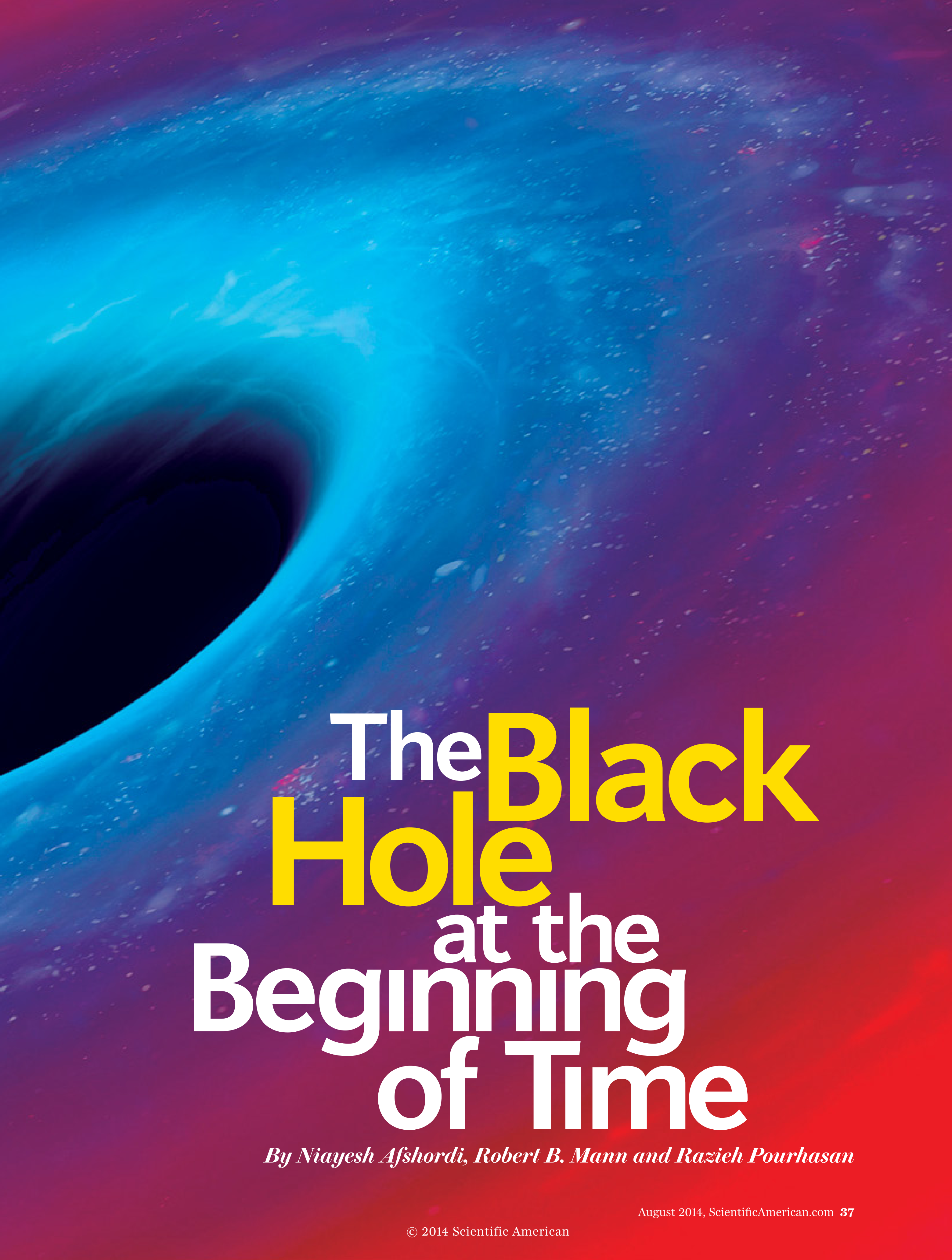
SCIENTIFIC AMERICAN ONLINE
Tech products for the Knows and the Know-Nots: ScientificAmerican.com/aug2014/pogue

Illustration by Thomas Fuchs



COSMOLOGY

Is the big bang, and all that came from it, a holographic mirage from another dimension?

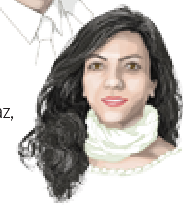


The Black Hole at the Beginning of Time

By Niayesh Afshordi, Robert B. Mann and Razieh Pourhasan


Niayesh Afshordi is an assistant professor of physics and astronomy at the University of Waterloo and an associate faculty member in cosmology and gravitation at the Perimeter Institute for Theoretical Physics. His research and teaching focus on astrophysics, cosmology and the physics of gravity.


Robert B. Mann is a professor and former chair of physics and astronomy at the University of Waterloo and an affiliate faculty member at the Perimeter Institute. A past president of the Canadian Association of Physicists and winner of two teaching awards, his interests include black holes and quantum information.


Razieh Pourhasan is a Ph.D. candidate at the Perimeter Institute and the University of Waterloo. She was born in Shiraz, Iran, and received her B.Sc. and M.Sc. in theoretical physics from Shiraz University in Iran.

IN HIS ALLEGORY OF THE CAVE, THE GREEK PHILOSOPHER PLATO DESCRIBED prisoners who have spent their entire lives chained to the wall of a dark cavern. Behind the prisoners lies a flame, and between the flame and prisoners parade objects that cast shadows onto a wall in the prisoners' field of view. These two-dimensional shadows are the only things that the prisoners have ever seen—their only reality. Their shackles have prevented them from perceiving the true world, a realm with one additional dimension to the world that they know, a dimension rich with complexity and—unbeknownst to the prisoners—capable of explaining all that they see.

Plato was on to something.

We may all be living in a giant cosmic cave, created in the very first moments of existence. In the standard telling, the universe came into being during a big bang that started from an infinitely dense point. But according to recent calculations that we have carried out, we may be able to track the start of the universe back to an era before the big bang—an era with an additional dimension of space. This protouniverse may have left visible traces that upcoming astronomical observations could uncover.

The universe appears to us to exist in three dimensions of space and one of time—a geometry that we will refer to as the "three-dimensional universe." In our scenario, this three-dimensional universe is merely the shadow of a world with *four* spatial dimensions. Specifically, our entire universe came into being during a stellar implosion in this suprauniverse, an implosion that created a three-dimensional shell around a four-dimensional black hole. Our universe is that shell.

Why would we postulate something that sounds, on the face of it, so absurd? We have two reasons. First, our ideas are not idle speculation—they are firmly grounded in the mathematics that describe space and time.

Over the past couple of decades physicists have developed a rich theory of holography, a set of mathematical tools that allows them to translate descriptions of events in one dimension to the physics of a different dimension. For example, researchers

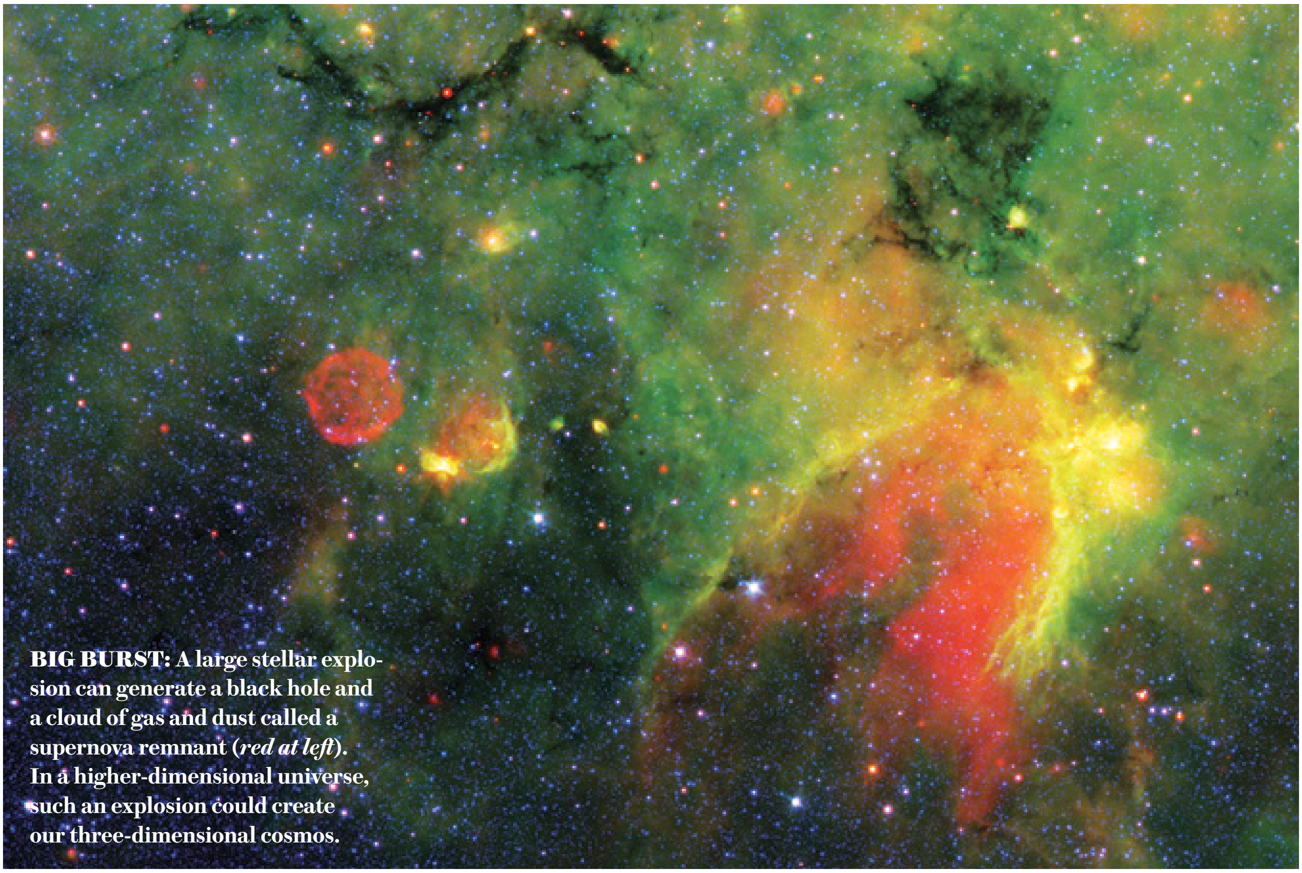
IN BRIEF

Cosmologists have detailed a remarkably accurate description of the history of the universe. But a few profound questions seem to defy all attempts at understanding.

One of these mysteries is the nature of the big bang itself—the sudden, violent origin of our universe from a point of infinite density.

The authors have developed ideas that would explain how the big bang came to be. They imagine that it emerged as a consequence of the formation of a black hole in a higher-dimensional universe. This theory provides answers to a number of difficult questions. It could also be tested.

PRECEDING PAGES: MARK GARLICK *Getty Images (artist's conception)*



BIG BURST: A large stellar explosion can generate a black hole and a cloud of gas and dust called a supernova remnant (*red at left*). In a higher-dimensional universe, such an explosion could create our three-dimensional cosmos.

COURTESY OF NASA/JPL-CALTECH

can solve relatively straightforward equations of fluid dynamics in two dimensions and use those solutions to understand what is going on in a much more complicated system—for example, the dynamics of a three-dimensional black hole. Mathematically, the two descriptions are interchangeable—the fluid serves as a perfect analogue for the extraordinary black hole.

The success of holography has convinced many scientists that more is at work here than a simple mathematical transformation. Perhaps the boundaries between dimensions are less stable than we thought. Perhaps the rules of the cosmos are written in another set of dimensions and translated into the three we perceive. Perhaps, like Plato's prisoners, our personal circumstances have tricked us into believing the world is three-dimensional when in fact a deeper understanding of what we perceive will come only when we look for explanations in the fourth dimension.

The second reason that our four-dimensional universe is worth thinking about is because a close study of this universe could help us understand deep questions about the origin and nature of the cosmos. Consider, for example, the big bang, the primordial flash that brought our universe into existence. Modern cosmology holds that the big bang was immediately followed by "inflation"—a period of rapid expansion of space in which the early universe increased its volume by a factor of 10^{78} (or more). Yet this expansion provides no insight into what caused the big bang. Our four-dimensional universe, in contrast, gives us an answer to the ultimate mystery: Where did the universe come from?

THE KNOWN AND UNKNOWN COSMOS

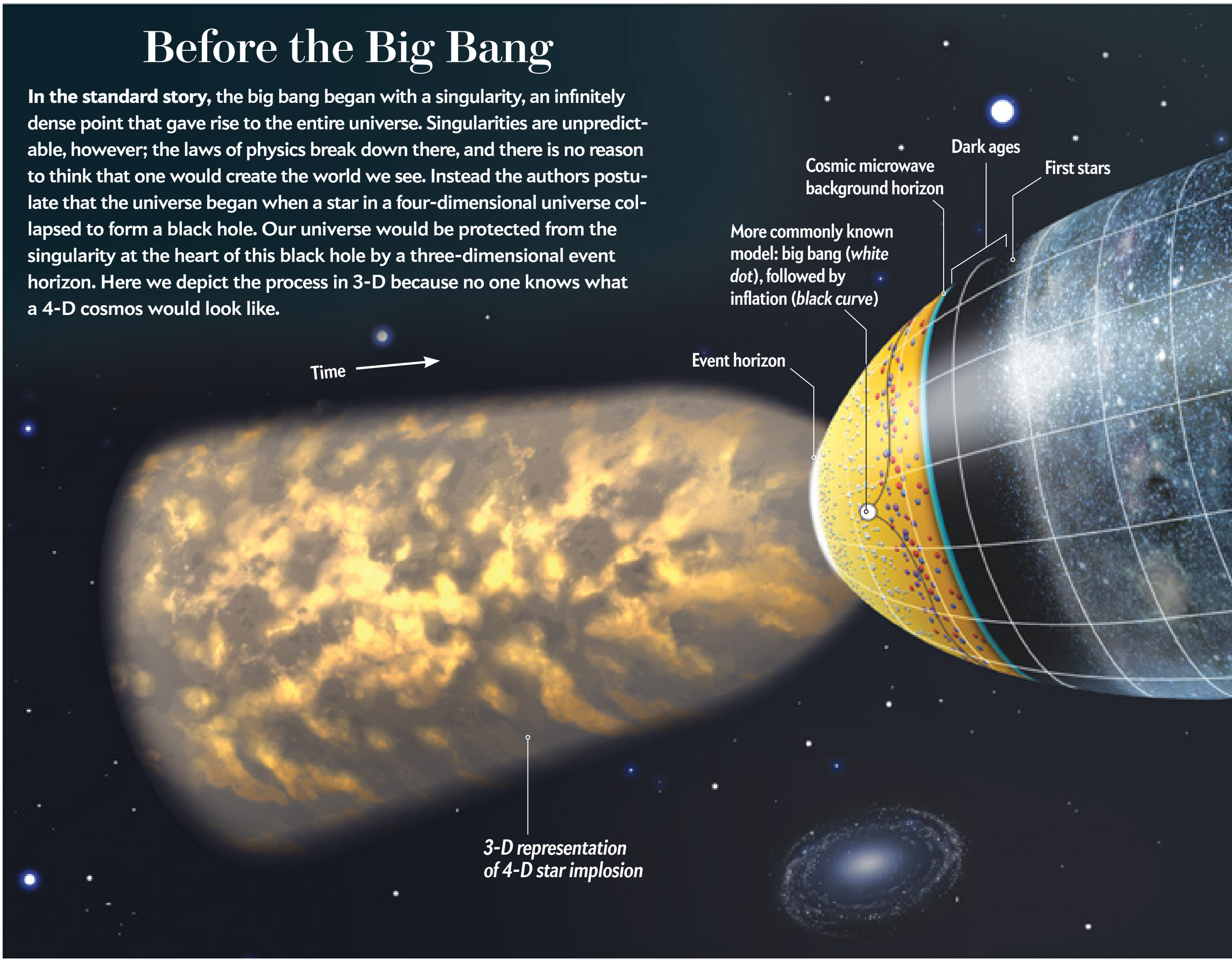
OUR INVESTIGATIONS into the four-dimensional universe came about because of the problems that we have had contemplating the three-dimensional one. Modern cosmology has been fantastically successful, but its successes belie deep and complex mysteries that may lend themselves to a holographic explanation.

Cosmologists can describe the history of the entire universe—from the present day all the way back to a fraction of a fraction of a second after the big bang—using only a few equations (chief among them the ones provided by Albert Einstein) and five independent numbers, or parameters. These parameters include the densities of ordinary matter, dark matter and dark energy (more on these in a moment), along with the amplitude and shape of quantum fluctuations in the early universe. This model—the Lambda Cold Dark Matter (Λ-CDM) cosmological paradigm—describes hundreds (if not thousands) of observational data points, covering scales from a million light-years to 10 billion light-years across, right up to the edge of our observable universe. But these observational successes do not mean our task is complete. The story of the universe is pocked with troublesome holes. We are confronted by fundamental questions about the nature of the cosmos—problems that we have not, as of yet, been able to answer.

***Problem 1:* We don't understand the five parameters.** Consider the density of matter and energy in the universe. Only a few decades ago astronomers believed that ordinary matter—the elements that make up the periodic table—would be the

Before the Big Bang

In the standard story, the big bang began with a singularity, an infinitely dense point that gave rise to the entire universe. Singularities are unpredictable, however; the laws of physics break down there, and there is no reason to think that one would create the world we see. Instead the authors postulate that the universe began when a star in a four-dimensional universe collapsed to form a black hole. Our universe would be protected from the singularity at the heart of this black hole by a three-dimensional event horizon. Here we depict the process in 3-D because no one knows what a 4-D cosmos would look like.



dominant form of mass-energy. Cosmological observations have radically revised this picture (and secured three Nobel Prizes along the way). We now know that the density of ordinary matter is only 5 percent of the universe's total energy density. Another 25 percent comes in the form of dark matter, an unknown form of matter whose existence is inferred from its gravitational attraction. And 70 percent of the universe is made of dark energy, the mysterious stuff that is causing the expansion rate of our universe to speed up (instead of slowing down, as originally expected from gravitational attraction). What are dark matter and dark energy, and why do they make up 25 and 70 percent of the universe, respectively? We do not know.

Perhaps answers would come if we better understood the big bang—the abrupt origin of space and time in a hot plasma of radiation and particles at a temperature above 10^{27} degrees. It is very difficult to imagine how a situation like the universe in the moments after the big bang could lead to what we observe today—a cosmos of nearly uniform temperature and with a flat large-scale spatial curvature (in which the angles of triangles sum up to 180 degrees).

Cosmic inflation might be the best idea we have for understanding the large-scale structure of the universe. Inflation would tend to "flatten" the universe, smoothing out any curved regions of spacetime, and bring it to a uniform temperature. Like a cosmic magnifier, inflation also amplifies tiny quantum fluctuations in energy density to cosmic size during this process. These fluctuations in turn become the seeds for the growth of structures such as galaxies, stars, planets and even living organisms such as ourselves.

Inflation is generally regarded as a very successful paradigm [*see box above*]. For decades cosmologists have been checking on inflation's predictions by observing the cosmic microwave background (CMB) radiation, a cosmic record of density fluctuations in the early universe. Recent observations by the European Space Agency's Planck satellite confirm that our universe is flat (or very nearly so) and that it is uniform to better than one part in 60,000—both key predictions of inflation. Furthermore, the observed amplitude and shape of primordial matter fluctuations are in broad agreement with how we would expect inflation to magnify the quantum vacuum.

 Illustration by George Retseck

satisfactory explanation for the origin of the five parameters of the Λ-CDM model, some of which must be very precisely chosen to agree with observations. And we lack a satisfactory description of the history of our cosmos before the inflationary era—those first trillionths of trillionths of trillionths of a second after the big bang.

Problem 3: *We don't understand how it all began.*

Cosmology's greatest challenge is understanding the big bang itself—the sudden, violent emergence of all space, time and matter from an infinitely dense point called a singularity. A singularity is an unimaginably bizarre thing, a point where space and time curve in on themselves, making it impossible to distinguish the future from the past. All the laws of physics break down. A singularity is a universe without order or rules. Out of a singularity could come anything that might logically exist. We have no reason to think that a singularity would generate a universe as ordered as the one we see.

We would expect the emergence of a universe from a singularity to be unthinkably chaotic, marked by huge temperature fluctuations from one point to the next. Furthermore, the magnifying power of inflation might be expected not to smooth everything out. In fact, if these fluctuations are too large, inflation may never get a chance to begin. The problems of a singularity cannot be solved by inflation alone.

Singularities are strange, but not unfamiliar. They also form at the centers of black holes, those collapsed remains of giant stars. All stars are nuclear furnaces that fuse lighter elements (primarily hydrogen) into heavier ones. This process of nuclear fusion powers a star for most of its life, but eventually the star exhausts all its nuclear fuel, and gravity takes over. A star at least 10 times more massive than our sun will collapse on itself before exploding as a supernova. If the star is even larger—15 to 20 solar masses or more—the supernova will leave behind a dense core that goes into a runaway collapse, contracting into a point of zero size—a black hole.

Black holes can be thought of as regions of space from which not even light can escape. Because the speed of light is the maximum speed attainable by any form of matter, the boundary of a black hole—a two-dimensional surface called the event horizon—is a point of no return: once stellar matter (or anything else) falls within this boundary, it is cut off from the rest of the universe and inexorably pulled toward the singularity at the center.

As with the big bang, the laws of physics break down at this singularity as well. *Unlike* the big bang, however, a black hole is surrounded by an event horizon. This surface acts like armored wrapping paper—it prevents any information about the singularity

Problem 2: *We don't really understand inflation.*

We might ask what drove this inflation, which took a lot of energy. We imagine that, shortly after the big bang, the universe was filled with energy that takes the form of a hypothetical particle called the inflaton (pronounced "IN-flah-tahn"). The Higgs particle, recently discovered by the Large Hadron Collider at CERN near Geneva, shares many similar properties with, and is a possible candidate for, the proposed inflaton. The inflaton would be responsible for both early accelerated expansion and for structure in our universe because the only significant density differences in the early universe are caused by the tiny quantum fluctuations in the inflaton field's energy.

Yet the inflaton does not solve our problems; it just pushes them back a step. We do not know the inflaton's properties, or where it came from, or how to find it. We are not sure whether it really exists.

In addition, physicists do not understand how to naturally end inflation—the so-called graceful exit problem. If some kind of energy field drives an exponentially expanding universe, what would make that field suddenly turn off? We also do not have a

Whispers from Creation

The recent discovery of gravitational waves emerging from the big bang may point a way forward

DARK POLE: Telescopes at the South Pole search for clues about the universe's first moments.

COURTESY OF STEFFEN RICHTER *Harvard University*

Apart from the terrible weather hanging around from an unusually cold winter, the second week of March started like any other week. But then rumors started floating around in the cosmology community about an imminent announcement out of the Harvard-Smithsonian Center for Astrophysics. The rumors spread to Facebook, Twitter and the blogosphere by the weekend. Details began to emerge. This was not any ordinary announcement but rather the kind that, if correct, would happen once per lifetime. It was something that most of us dreamed we could see only in a few decades if we were lucky, if at all.

On Monday, March 17, 2014, BICEP-Keck collaboration, which operates an array of microwave telescopes located at the geographical South Pole, announced the discovery of patterns in the polarization of the cosmic microwave background that could have been generated in the early universe. If this interpretation of the observations is correct, it could confirm a 30-year-old prediction of the cosmic inflation theory: that the simplest models of inflation can generate an observable level of gravitational waves, comparable to density or temperature fluctuations in the early universe. It would also be our first direct evidence for the quantum nature of gravity, the most outstanding puzzle in theoretical physics over the past century.

Yet in science, as in life, things are rarely as simple as they first appear. For example, the simple inflationary models that predict observable levels of gravitational waves also suggest that hints of these waves should have been seen in the temperature fluctuations observed by the European Space Agency's Planck satellite. But they were not! Furthermore, microwave emission from dust in our galaxy tends to be polarized, which could confuse BICEP-Keck observations, at least to some extent.

What does all this mean for our holographic theory of the big bang? When it comes to the observations of the early universe, we are limited to a handful of (now seemingly contradictory) probes. The Planck team is expected to release additional data in October, and other teams will also weigh in soon. Reconstructing the first moments of the universe is difficult business. Only with time—and perhaps some luck—will we know how it all began.

—N.A., R.B.M. and R.P.

from leaking out. The event horizon of the black hole shields outside observers from the singularity's catastrophically unpredictable effects (a situation referred to as cosmic censorship).

Cloaked by an event horizon, the singularity is rendered impotent. Its disturbing effects cannot escape, making it possible for the laws of physics to describe and predict all that we observe. Seen from a distance, a black hole is a very simple, smooth and uniform structure, described only by its mass and angular momentum (and electric charge if it has any). Physicists quip that "a black hole has no hair"—no distinguishing features beyond the basics of mass, angular momentum and electric charge.

In contrast, the big bang singularity (as commonly understood) is not cloaked. It has no event horizon. We would like to have a way to shield ourselves from the big bang's singularity

SCIENTIFIC AMERICAN ONLINE For a video about what happened at the beginning of everything, visit ScientificAmerican.com/aug2014/big-bang and its catastrophic unpredictability, perhaps with something akin to an event horizon.

We have proposed just such a scenario—one that turns the big bang into a cosmic mirage. Our picture would cloak the singularity at the big bang just as an event horizon cloaks the singularity at the heart of a black hole. It would protect us from the singularity's mercurial and nefarious effects.

EXTRADIMENSIONAL COLLAPSE

SUCH A CLOAK would differ from an ordinary event horizon in one critical way. Because we perceive that our universe has three spatial dimensions, the event horizon that cloaks the singularity at the heart of the big bang must also have three spatial dimensions—not just two. If we imagine that this event horizon also came about as a result of a cosmic collapse—just as a black hole's two-dimensional event horizon is formed by the collapse of a three-dimensional star—then the collapse would have to take place in a universe with four spatial dimensions.

This kind of extradimensional scenario, in which the number of dimensions of space exceeds the obvious three, is an idea almost as old as general relativity itself. It was originally proposed by Theodor Kaluza in 1919 and expanded by Oskar Klein in the 1920s. Their idea was largely forgotten for more than half a century before being picked up by physicists studying string theory in the 1980s. More recently, scientists have used it to build a cosmology of so-called brane worlds.

The basic idea of a brane world is that our three-dimensional universe is a subuniverse embedded in a larger space of four or more spatial dimensions. The three-dimensional universe is called a brane, and the larger universe is called the bulk. All known forms of matter and energy are stuck to our three-dimensional brane like a movie projected on a screen (or the shadow reality for Plato's prisoners in the cave). The exception is gravity, which permeates all of the higher-dimensional bulk.

Let's think about the bulk suprauniverse of four spatial dimensions that may have existed before the big bang. We can imagine that this bulk universe was filled with objects such as four-dimensional stars and four-dimensional galaxies. These higher-dimensional stars might run out of fuel, just as our three-dimensional stars do, and collapse into black holes.

What would a four-dimensional black hole look like? It would also have an event horizon, a surface of no return from which no light could escape. But instead of a two-dimensional surface, as we have in ordinary black holes, a four-dimensional black hole would generate an event horizon with three spatial dimensions.

Indeed, by modeling the collapsing death of a four-dimensional star, we find, under a variety of circumstances, that the material ejected from the stellar collapse can form a slowly expanding three-brane surrounding this three-dimensional event horizon. Our universe is this three-brane—a hologram of sorts for a four-dimensional star collapsing into a black hole. The cosmic big bang singularity becomes hidden to us—locked forever behind a three-dimensional event horizon.

IS THIS REAL?

OUR MODEL has a number of things going for it, starting with the fact that it eliminates the naked singularity that gave rise to the universe. But what of the other long-standing cosmological problems, such as the near flatness and high uniformity of the cosmos? Because the four-dimensional bulk universe could have existed for an infinitely long time in the past, any hot and cold spots in the bulk would have had plenty of time to come to equilibrium. The bulk universe would be smooth, and our three-brane universe would inherit this smoothness. In addition, because the four-dimensional black hole would also appear to be nearly featureless (or without "hair"), our emergent three-brane universe would likewise be smooth. The larger the mass of the four-dimensional star, the flatter the three-brane, and so the flatness of our universe is a consequence of it being residual detritus from the collapse of a heavy star.

In this way, our model of a holographic big bang resolves not only the main puzzles of uniformity and near flatness of standard cosmology without resorting to inflation but also nullifies the damaging effects of the initial singularity.

The idea may sound crazy, but there are several ways one might be able to test it. One way is by studying the cosmic microwave background radiation. Outside of our three-brane, we would expect there to be some extra four-dimensional bulk matter—something pulled close by the gravitational pull of the black hole. We can show that thermal fluctuations in this extra matter will create fluctuations on the three-brane that in turn distort the CMB by small but potentially measurable amounts. Our calculations differ from the latest data from the European Space Agency's Planck space observatory by about 4 percent. But this discrepancy may be the result of secondary effects that we have not yet properly modeled.

In addition, if the four-dimensional black hole is spinning (it is very common for black holes to spin), then our three-brane may not look the same in all directions. The large-scale structure of our universe would appear slightly different in different directions. Astronomers may also be able to find this directionality by studying subtle variations in the CMB sky.

Of course, even as the holographic big bang resolves one giant question—the origin of our universe—it simultaneously raises a new set of mysteries. Foremost among them: Where did our universe's *parent* universe come from?

For an answer to this puzzle, we might again turn to Plato. When Plato's prisoners emerged from the cave, the light of the sun burned their eyes. It took them time to adjust to the brightness. At first, the prisoners were only able to make out shadows and reflections. Soon they could see the moon and the stars. Finally, they correctly concluded that the sun was "the author of all that we see"—day, night, season and shadow. Plato's prisoners didn't understand the powers behind the sun, just as we don't understand the four-dimensional bulk universe. But at least they knew where to look for answers. SA

MORE TO EXPLORE

Out of the White Hole: A Holographic Origin for the Big Bang. Razieh Pourhasan, Niayesh Afshordi and Robert B. Mann in *Journal of Cosmology and Astroparticle Physics,* Vol. 2014, Article No. JCAP04(2014)005; April 2014.

FROM OUR ARCHIVES

Out of the Darkness. Georgi Dvali; February 2004.
The Illusion of Gravity. Juan Maldacena; November 2005.
Origin of the Universe. Michael S. Turner; September 2009.

scientificamerican.com/magazine/sa

A New Kind of Inheritance

Harmful chemicals, stress and other influences can permanently alter which genes are turned on without changing any of the genes' code. Now, it appears, some of these "epigenetic" changes are passed down to—and may cause disease in—future generations

By Michael K. Skinner

Michael K. Skinner is a professor of biology at Washington State University. He has published more than 250 peer-reviewed articles, including dozens of studies on epigenetic transgenerational inheritance. His Web site is at http://skinner.wsu.edu

WHEN MY KIDS WERE BORN, ABOUT 30 YEARS AGO, I KNEW THEY HAD INHERITED ABOUT half their DNA from me. At the time, the transfer of DNA from sperm or egg to an embryo was thought to be the only way that heritable information could flow from parents to children, at least in humans and other mammals.

Of course, I understood that DNA is not destiny. Yes, many characteristics of a child may be written into his or her DNA and specifically into protein-coding genes—the sequences of DNA code that dictate the shapes and functions of proteins, the workhorses of the cell. But nurture matters, too. Many of the contingencies of life—what we eat, what pollutants are in our environment, how often we are stressed—affect how the genes operate. Social and environmental influences are often invoked, for instance, to explain why identical twins can end up with different diseases despite having highly similar complements of genes.

But we did not know back then that our biological bequest to our children includes more than just our DNA sequences—that, indeed, not just our kids but our grandchildren and great-grandchildren might inherit what is known as epigenetic information. Like DNA, epigenetic information resides in our chromosomes (which house our genes) and regulates cellular functions. But it is distinct from the DNA sequence and responds to the environment. It can take various forms, including small molecules that attach chemically to the DNA and to proteins in chromosomes.

Research at my laboratory and others, mainly on rats and mice, has found that certain pollutants—including agricultural chemicals, jet fuel and even some common plastics—can induce epigenetic modifications that cause disease and reproductive problems, all without changing the sequence of the animals' DNA. More startlingly, when such epimutations occur in the cells that give rise to eggs and sperm, they can apparently become fixed in place and then transmitted—along with any resulting health risks—to later generations.

The science in this area is evolving rapidly, and long-term studies in people now hint that epimutations may pass from generation to generation in humans as well. Given the many aspects of biology that we share with other mammals, it seems reasonable to expect that such epigenetic transgenerational inheritance does occur in people. If so, the implications for public health could be profound. Some part of the increases in obesity, diabetes and other fast-rising diseases among baby boomers and more recent generations might have originated with their parents' and grandparents' exposure to pollutants such as DDT and dioxin.

THE DARK MATTER OF THE GENOME

EPIGENETIC EFFECTS ON CELLS have been recognized for some time, but the extent of their involvement has become clear only recently. Decades ago biologists noticed that lots of places in mammalian DNA have a methyl (CH_3) radical attached to them [*see box on pages 48 and 49*]. In humans, this epigenetic mark often occurs where a cytosine (C) code letter precedes a guanine (G) in the DNA sequence, which happens at about 28 million spots along the chromosomes. Scientists first thought that the main function of DNA methylation was to shut down transposons—dangerous stretches of DNA that can move themselves from their original positions on the chromosomes to other parts of the genome, sometimes in ways that cause disease. We now know that methylation also helps regulate the activity of normal genes and that it goes awry in many cancers and other disorders.

In the 1990s researchers began to work out the operation of more kinds of epigenetic marks. They found that methyl, acetyl and several other chemical modifications can tag beadlike structures composed of a group of proteins called histones. The DNA in chromosomes wraps around each histone bead. By controlling how tightly the DNA loops around the histone groups and whether adjacent beads spread apart or bunch up, the histone marks can effectively turn entire sets of genes on and off. Genes in tightly wound areas, for instance, get hidden from proteins that switch on gene activity.

Other epigenetic actors have since emerged, including the ever shifting, three-dimensional structure of the DNA and chromosomes and a number of RNA varieties known as noncoding RNAs. Some of these RNAs interact with the epigenetic marks that sit on DNA and the histones. (They are called noncoding to distinguish

IN BRIEF

The actions of genes can be regulated by "epigenetic" factors, such as chemicals that attach to DNA and proteins in chromosomes and that encode information independently from the DNA sequence. Most epigenetic marks reset shortly after conception.

Pollutants, stress, diet and other environmental factors can cause persistent changes in the mix of epigenetic marks in chromosomes and, in that way, can alter how cells and tissue behave. Surprisingly, some acquired changes can be passed on to descendants.

Conceivably, the health of both you and your children may be affected by what your great-grandmother was exposed to during pregnancy. Epigenetic inheritance might play a role in health problems such as obesity and diabetes, as well as in the evolution of species.

PRECEDING PAGES: CHRIS FRAZER SMITH *Gallery Stock*

them from the RNA strands that get copied from DNA to serve as templates for making the proteins encoded by genes.)

Together these epigenetic actors influence gene activity in complex ways that are independent of the DNA sequence. The interplay between the genes and the epigenome is dynamic and still rather mysterious. We do know, however, that each time a cell replicates, the epigenetic marks in its chromosomes get copied into the chromosomes of the daughter cells. Epigenetic events early in life can thus alter how cells behave later on.

We also know that whereas cells work hard to protect the sequence of DNA in the chromosomes from any alterations, they revise the patterns of epigenetic marks during an organism's development and aging. These changes help to determine how cells specialize to become, for example, a skin cell or a brain cell; subtle shifts in epigenetic information modify which genes are active in each part of the body. Harmful chemicals, nutrient deficiencies and other stresses can also cause epigenetic marks to be added or removed in ways that affect gene activity.

Today no one doubts that epigenetic effects play a crucial role in development, aging and even cancer. But biologists debate whether epimutations—abnormal epigenetic changes—can be passed down through many generations in mammals. Evidence from a rapidly growing number of experiments, by my group and many others, has convinced me that they can.

As the great-great-grandpups matured, the males suffered problems similar to those of their distant ancestors. All from a fleeting dose of widely used agricultural chemicals.

ACCIDENTAL INHERITANCE

MY FIRST GLIMPSE of multigenerational epimutations was a product of serendipity. About 13 years ago Andrea Cupp and I, with a few of our colleagues at Washington State University, were using rats to study the reproductive effects of two chemicals widely applied in farming—the pesticide methoxychlor and the fungicide vinclozolin. Like many agricultural chemicals, they are endocrine disruptors: they interfere with the hormonal signals that help to direct the formation and operation of the reproductive system. We had injected the chemicals into pregnant rats during the second week of gestation—when the embryo's gonads develop—and saw that nearly all male offspring grew up to have abnormal testes that make weak sperm and too few of them.

We were not thinking about epigenetics at the time, and it never occurred to us that these defects might be heritable, so we had no plan to breed the rats that had been exposed to methoxychlor or vinclozolin while in the womb. But one day Cupp came into my office to apologize: by mistake, she had mated unrelated male and female pups from that experiment.

I told her to check the grandchildren of the exposed dams for defects, although I did not expect she would find any. To our amazement, more than 90 percent of the males in these litters showed the same testicular abnormalities as their fathers, even though their parents were just pinhead-sized fetuses when they and their grandmothers were briefly exposed.

This result was surprising because many toxicology studies had looked for evidence that environmental chemicals such as vinclozolin cause DNA mutations but had found none. We confirmed ourselves that the frequency of genetic mutations was not elevated in the rats exposed to the agents. Moreover, classical genetics could not explain a new trait that appears with 90 percent frequency in different families.

I knew, however, that the minuscule fetus contains primordial germ cells, which are the progenitor cells that give rise to sperm or eggs. Most likely, I thought, the chemical had directly influenced these progenitor cells, and this effect simply persisted as the cells divided into sperm or eggs—and eventually into grandchildren. If this were the case, then the brief chemical exposure caused the grandpups' testicular problems directly, and future generations should be perfectly normal.

There was one sure test to find out whether direct influence was to blame. We bred a fourth generation and then a fifth, each time mating unrelated descendants of the original exposed rats to avoid diluting the trait. As the great-grandchildren—and later the great-great-grandchildren—matured, the males of each generation suffered problems similar to those of their ancestors. All these changes stemmed from a fleeting (but unnaturally high) dose of agricultural chemicals that for decades were sprayed on fruits, vegetables, vineyards and golf courses.

I was shocked by these results. Over several years we repeated the experiments multiple times to confirm them and collect additional evidence. The most plausible explanation, we concluded, was that the exposure causes an epimutation that interferes with gonad development in male embryos—and this epimutation passes from sperm to the cells of a developing embryo, including to primordial germ cells, and so on for generations. In 2005 we published these results in *Science,* along with our epimutation hypothesis and tantalizing but preliminary supportive evidence that exposure to the fungicide had altered methylation at several important spots in the DNA of the descendants' sperm.

TROUBLING IMPLICATIONS

A TEMPEST OF DEBATE ensued. One reason was that researchers at companies that sell vinclozolin, as well as a nonindustry study, reported difficulty reproducing some of our results—probably because they used different experimental methods, such as giving the chemical orally, using inbred strains of rats, or breeding the affected males with those from an unexposed control lineage, a practice that depresses the trait substantially in subsequent generations.

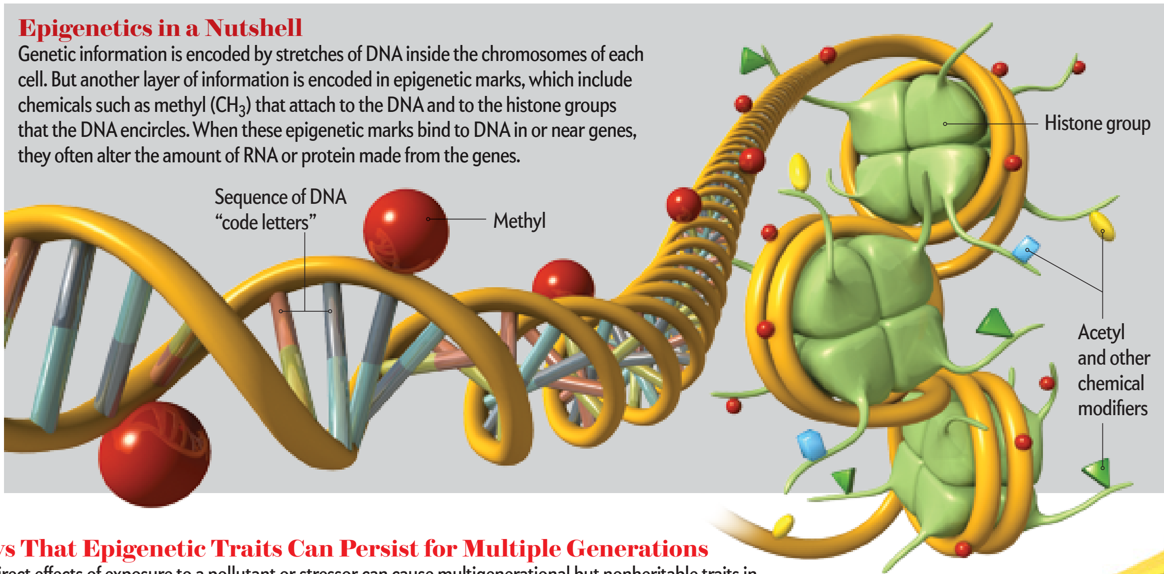
In recent years, however, evidence has accumulated that epi-

Inheritance outside the Genes

Biologists have discovered that the life experiences of animals and plants—such as exposure to certain pollutants or stressful events—can affect the health of their descendants without mutating their DNA. Such exposures can have multigenerational effects on children and grandchildren through their direct actions on sperm, eggs and other reproductive cells. But transgenerational epigenetic inheritance, via heritable alterations to chemicals attached to the DNA inside these cells, can affect even more distant descendants.

Epigenetics in a Nutshell

Genetic information is encoded by stretches of DNA inside the chromosomes of each cell. But another layer of information is encoded in epigenetic marks, which include chemicals such as methyl (CH_3) that attach to the DNA and to the histone groups that the DNA encircles. When these epigenetic marks bind to DNA in or near genes, they often alter the amount of RNA or protein made from the genes.



Ways That Epigenetic Traits Can Persist for Multiple Generations

The direct effects of exposure to a pollutant or stressor can cause multigenerational but nonheritable traits in two generations if the exposure occurs to a male and his sperm or in up to three generations if it occurs to a female at a particular stage of pregnancy (*blue highlighting on opposite page*). For an epigenetic trait to be inherited by subsequent generations (*red*), altered marking must survive two distinct waves of reprogramming (*below*) after conception. Both waves remove most epigenetic tags from the chromosomes and later rewrite them afresh. Rodent studies indicate that such persistence is possible.

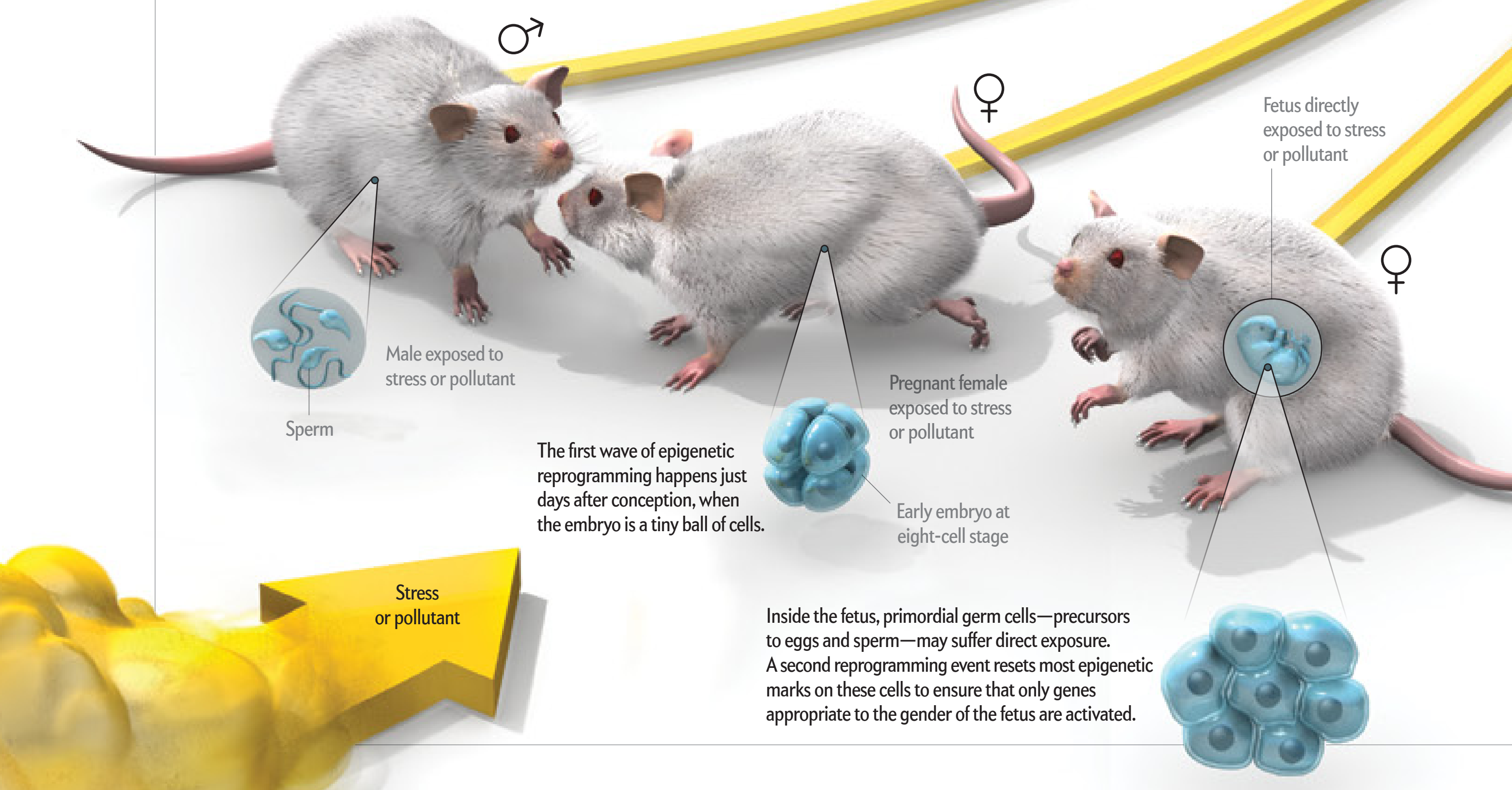
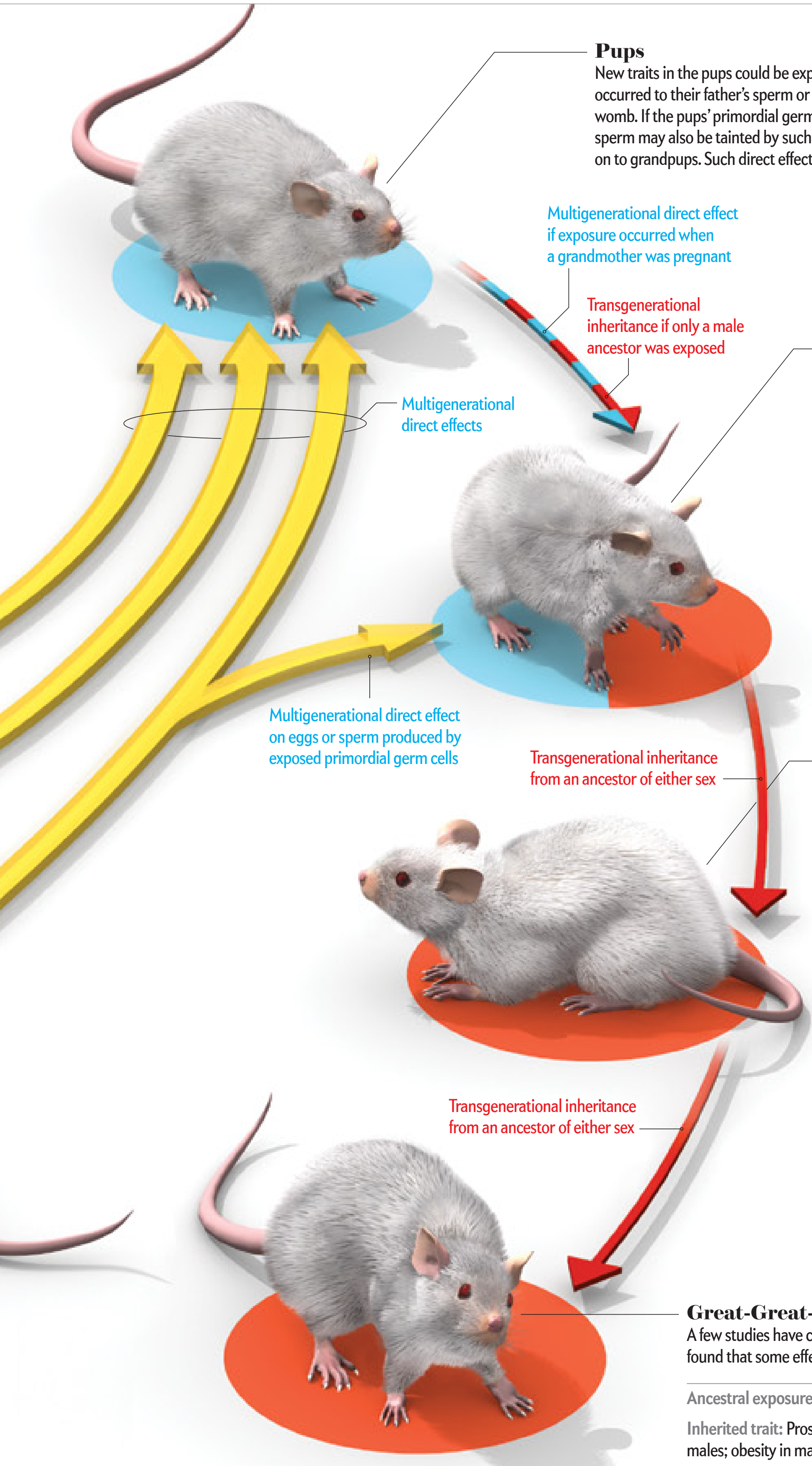


Illustration by Emily Cooper



Pups

New traits in the pups could be explained by the direct exposure that occurred to their father's sperm or to their mother while they were in the womb. If the pups' primordial germ cells were exposed, then their eggs or sperm may also be tainted by such direct effects and could be passed on to grandpups. Such direct effects are not, strictly speaking, inherited.

Grandpups

True transgenerational inheritance can appear in the third generation if the exposure occurred to a male grandparent. Studies to date have observed this phenomenon for several kinds of exposures.

Ancestral exposure: Fear conditioning to an unfamiliar odor

Inherited trait: Heightened startle response when the odor is present

Ancestral exposure: High-fat diet and a drug that causes prediabetes

Inherited trait: Glucose intolerance and insulin resistance

Great-Grandpups

In most studies of this phenomenon, researchers expose pregnant females to a toxic compound or stressful condition. They must then breed at least fourth-generation offspring to prove that new traits are truly heritable.

Ancestral exposure: Methoxychlor; vinclozolin

Inherited trait: Reduced sperm count and motility; heightened anxiety in females

Ancestral exposure: Dioxin

Inherited trait: Low testosterone in males; infertility or premature delivery in females

Ancestral exposure: Bisphenol A (BPA)

Inherited trait: Low testosterone in males; abnormal ovaries or early puberty in females

Ancestral exposure: Jet fuel; DDT

Inherited trait: High rates of obesity; polycystic ovarian disease

Great-Great-Grandpups

A few studies have continued on to a fifth generation and found that some effects persisted.

Ancestral exposure: Vinclozolin; DDT

Inherited trait: Prostate, kidney and testicular disease in males; obesity in males; ovarian disease in females

FOGGING WITH DDT, **a common mosquito-control practice in the 1940s and 1950s, might have caused epimutations that persist even in some babies born today.**

CORBIS

mutations can persist for several generations. Follow-up studies at my lab have shown that the great-grandchildren of fungicide-treated rats have consistently altered patterns of methylation in their sperm, testes and ovaries, as well as abnormal gene activity in their primordial germ cells. We also found that fourth-generation offspring are prone to weight gain and anxiety; they even select mates differently. Meanwhile we and other scientists have added more pollutants and stressors to the list of factors that induce the effect, and transgenerational inheritance of acquired characteristics has been observed in a wide range of species, including plants, flies, worms, fish, rodents and pigs.

My team reported in 2012 that exposure of pregnant rats to either the pollutant dioxin, jet fuel, insect repellent, or a combination of bisphenol A (BPA) and phthalates—chemical components of plastics in food containers and tooth fillings—induce a variety of heritable disorders in fourth-generation descendants, such as pubertal abnormalities, obesity, and diseases of the ovaries, kidneys and prostate. We have observed hundreds of exposure-specific changes in DNA methylation patterns in sperm. The effects do not follow the inheritance patterns of classical genetics, so we believe that epimutations, not mutations to the DNA sequence, are causing these disorders.

Kaylon Bruner-Tran and Kevin Osteen of the Vanderbilt University School of Medicine also studied dioxin's effects on mice and found that about half of the daughters of exposed dams were infertile; among those that could get pregnant, many had premature deliveries. These problems conceiving and gestating persisted for at least two more generations.

The chemical doses in these studies are much larger than one would typically receive from a contaminated environment, but research by Jennifer Wolstenholme and others at the University of Virginia School of Medicine reported transgenerational effects from doses that are more comparable to human experience. They found that when mice were given enough BPA in their food to produce blood levels similar to those measured in pregnant American women, their descendants out to the fifth generation spent less time exploring their cages and more time interacting with other mice. The researchers suspect that the personality shift was caused by altered activity of the genes for oxytocin and vasopressin, both of which are known to affect social behavior. Although it seems likely that, as in our study on BPA, the effects coincide with altered DNA methylation patterns, the evidence for this association is still indirect. Other kinds of epigenetic changes could also be involved.

Studies are now under way that may be able to determine whether epimutations affect multiple generations of people as they do rodents. One such investigation is following up on an unfortunate natural experiment. In 1976 an explosion at a chemical plant in Seveso, Italy, exposed nearby residents to the highest concentrations of dioxin ever recorded in a public release of this chemical. Scientists measured the amount of dioxin circulating in the blood of nearly 1,000 affected women and have followed them to observe their health.

In 2010 the researchers reported that for each 10-fold increase in a woman's exposure to dioxin during the accident, the average time needed to get pregnant rose by 25 percent, and the risk of infertility doubled. The team also observed in 2013 that women who were younger than 13 years at the time of the accident had, as adults, double the normal risk of developing metabolic syndrome—a collection of conditions, such as elevated blood pressure and blood glucose, that together predispose people to diabetes and heart disease. They found that many granddaughters of exposed women have abnormal results on thyroid tests.

Given that reproductive and metabolic disorders seem to be the most common kinds of ailments transmitted via the epigenome in lab animals, these findings hint that dioxins may promote epimutations in humans. The suspicion will be strengthened if, in years to come, the children and grandchildren of the exposed women show higher rates of infertility, obesity and related conditions—and show abnormal methylation patterns.

Capitalizing on another natural experiment, Marcus Pembrey of University College London, Lars Olov Bygren of the Karolinska Institute in Stockholm and their colleagues have done an intriguing series of studies using data from about 300 people born in 1890, 1905 and 1920 in Överkalix, Sweden, as well as their parents and grandparents. The researchers compared death records for the study subjects against reconstructed estimates of food supply in the town, which went through several two-year periods during the 19th century when good harvests were followed by crop failures. It appears that women whose paternal grandmothers experienced one of these feast-famine swings as young children had markedly higher rates of fatal cardiovascular disease.

Curiously, the increased risk was not seen for men, nor for women whose maternal grandmother or grandfathers endured

SCIENTIFIC AMERICAN ONLINE Watch a video of Skinner talking about epigenetic inheritance at ScientificAmerican.com/aug2014/epigenetics a rapid dive into food scarcity. For various reasons, such an odd inheritance pattern strongly suggests that epigenetics are at work and, in particular, a phenomenon known as imprinting. Similar observations have been made in descendants of a Dutch population that experienced famine during World War II.

THE EPIGENETIC IMPRINT OF PARENTHOOD

DESPITE THE MOUNTING evidence, many biologists still recoil from the idea that environmentally induced epimutations can settle into the germ line. The hypothesis seems to contradict a long-established belief that nearly all epigenetic marks are erased from the DNA and then rewritten during the reproductive process—not just once but twice. These processes, the reasoning goes, should wipe clean any acquired epimutations before they can cause trouble in the next generation. This same logic is another reason that our 2005 findings met with such a firestorm. The erasures do occur, but just how thoroughly is an open question.

The first wave of removal happens within days after conception. Methyl marks are stripped from the chromosomes—a process that confers on the embryonic stem cells the ability to give rise to every kind of cell. The tags are then added back while the fetus starts to develop. As the cells divide and specialize, distinctive patterns of DNA methylation appear in each cell type and help to tailor the cells to fit their particular functions.

Something shields a few special genes from this first wave of epigenetic erasure, however. Biologists refer to these genes as maternally or paternally "imprinted" because the epigenetic marks are preserved and guarantee that only the mother's copy or the father's copy of the gene gets used for making a protein. For example, in my children the gene *IGF2,* which encodes a hormone important for fetal growth, is active only on the chromosome they inherited from me. The copy of the gene from their mother is shut down by the combined action of DNA methylation and a form of noncoding RNA.

The second wave of epigenetic erasure and reprogramming begins later, when a rat fetus is the size of a pinhead and a human fetus is the size of a pea. This is when primordial germ cells start to appear inside the embryo's newly formed gonads—and when we administer vinclozolin or other pollutants to lab animals in our experiments on epigenetic inheritance. In rats, this period lasts about a week; in humans, it stretches from the sixth to the 18th week of pregnancy.

This second wave is thought to be essentially complete—methyl marks are stripped off even the imprinted genes in the precursor cells to eggs and sperm. Later, however, marks are added again to establish the sex-appropriate pattern: in females, the chromosomes that will end up in eggs get a maternal methylation pattern, whereas in males, the chromosomes that will end up in sperm get a paternal pattern. The process avoids any offspring receiving two inactivated or two activated copies of imprinted genes when what it needs is one active and one inactive copy.

The same mechanism that reestablishes tags on imprinted genes might be influenced by environmental insults to fix new epimutations into the germ line. If an exposure—whether to a pollutant, a hormonal imbalance brought on by stress, or a nutritional deficiency that affects methylation—hits the embryo when that second sweep is about to begin, it might alter which epigenetic tags are brushed away forever and which are spared the broom or reset at the end of the reprogramming phase.

Most epimutations probably have little consequence or get corrected in the next generation, but every rule has an exception. If an epimutation in a germ-line cell becomes protected from the reprogramming of the epigenome, in much the same way that an imprinted gene is, it may hang on to affect the next generation—and perhaps many generations down the line.

If this idea is correct, epigenetic inheritance could have important consequences for medicine. Some scientists are investigating whether "obesogens"—environmental chemicals that upset human metabolism in ways that induce weight gain—might increase the risk of obesity in heritable ways. Bruce Blumberg and his colleagues at the University of California, Irvine, showed last year that pregnant mice that drank water laced with tributyltin, widely used to keep barnacles off ship hulls, bore pups prone to developing extra fat cells and fatty livers. The changes persisted for two more generations, an effect that is most easily explained by an epimutation. Thus, although shifts in lifestyle and food availability no doubt account for much of the increase in obesity, diabetes and other "rich-country" diseases over the past 50 years, it is conceivable that ancestral exposures have increased our susceptibility to such diseases.

In countries like the U.S. where children in the 1940s and 1950s were exposed to DDT, for example, it might be significant that when we injected animals with DDT, we found that more than half of the fourth-generation great-grandpups developed obesity—even though the second-generation offspring were normal in size—and that epigenetics seemed to be at fault. In three generations since the 1950s, the obesity rate among American adults has risen dramatically and now exceeds 35 percent.

If the environment can sometimes directly produce long-term, transgenerational changes in gene activity without first altering the DNA coding sequence, then the classical view of evolution—as a slow product of random mutations that get "selected" because of the reproductive or survival advantage they offer—will have to be expanded. It is even conceivable that epigenetic inheritance could explain why new species emerge more often than one would expect, given the rarity of advantageous genetic mutations. Epigenetic changes appear to occur 1,000 times more frequently. The most important effect of epigenetic marks—maybe their reason for existing—might be to wildly expand the number of variant individuals in a population. Natural selection would then pick the best adapted among them to thrive and carry on—genome, epigenome, and all. SA

MORE TO EXPLORE

Epigenetic Transgenerational Actions of Environmental Factors in Disease Etiology. Michael K. Skinner, Mohan Manikkam and Carlos Guerrero-Bosagna in *Trends in Endocrinology and Metabolism,* Vol. 21, No. 4, pages 214–222; April 2010.

Understanding Transgenerational Epigenetic Inheritance via the Gametes in Mammals. Lucia Daxinger and Emma Whitelaw in *Nature Reviews Genetics,* Vol. 13, No. 3, pages 153–162; March 2012.

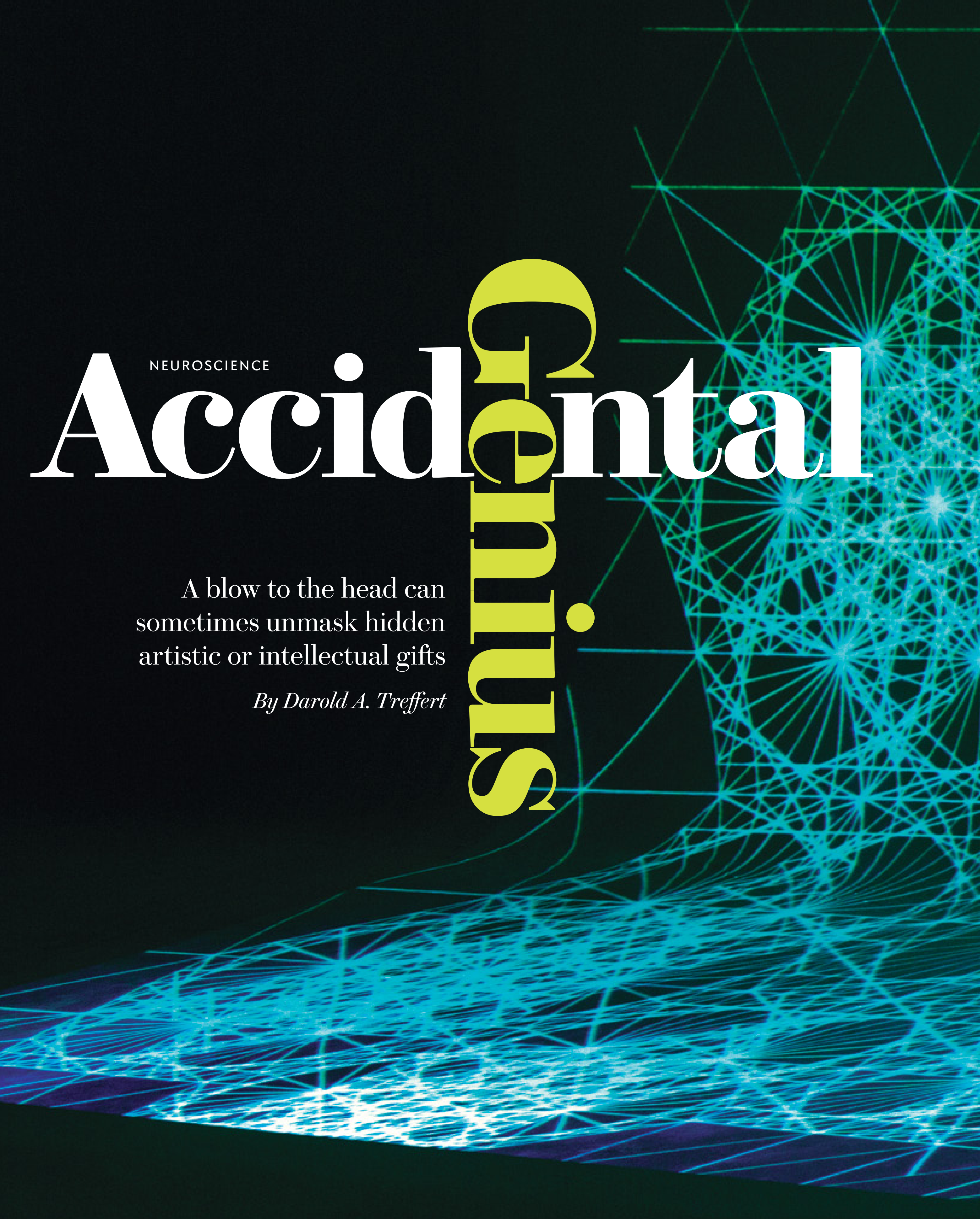
Genomic Imprinting in Mammals. Denise P. Barlow and Marisa S. Bartolomei in *Cold Spring Harbor Perspectives in Biology,* Vol. 6, No. 2, Article No. a018382; February 1, 2014.

FROM OUR ARCHIVES

The Unseen Genome: Beyond DNA. W. Wayt Gibbs; December 2003.

Hidden Switches in the Mind. Eric J. Nestler; December 2011.

scientificamerican.com/magazine/sa



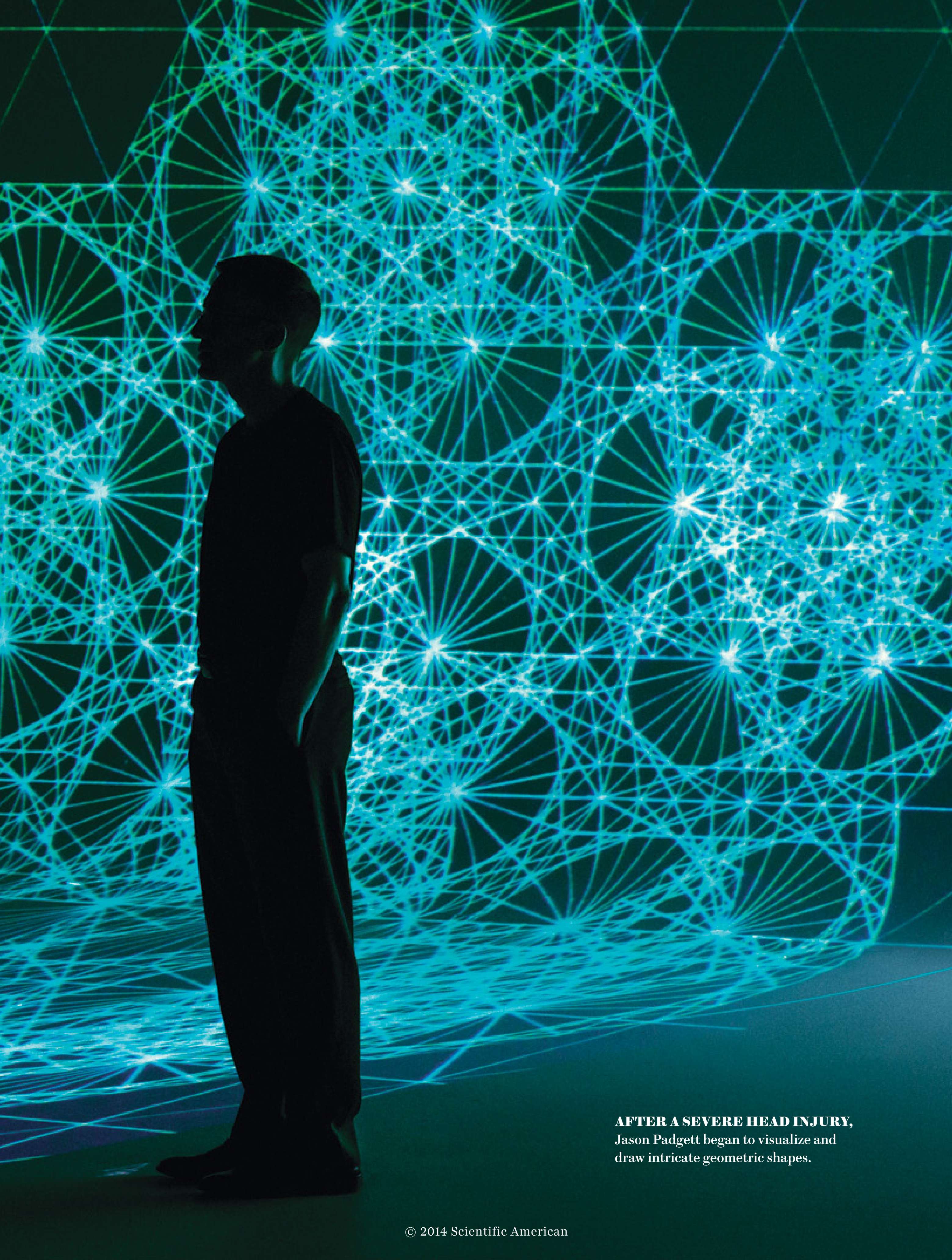
NEUROSCIENCE

Accidental Genius

A blow to the head can sometimes unmask hidden artistic or intellectual gifts

By Darold A. Treffert

Photographs by Michael Clinard



AFTER A SEVERE HEAD INJURY, Jason Padgett began to visualize and draw intricate geometric shapes.

Darold A. Treffert, a Wisconsin psychiatrist, met his first savant in 1962 and has done research on the syndrome ever since. He served as a consultant for the making of the movie *Rain Man* and maintains a Web page at www.savantsyndrome.com, hosted by the Wisconsin Medical Society.

A 10-year-old boy, Orlando Serrell, knocked unconscious one day by a baseball, discovered afterward that he could bring to mind the exact day of the week for any date after the accident and could remember the weather for each day since the trauma as well. He could also recall the most minute daily events.

Jason Padgett, the victim of a brutal mugging in 2002 that left him with a severe concussion, soon afterward began to see what he describes simply as "images." He began to sketch them out on paper. When he showed his work to others, he learned that the repeating, self-similar patterns were fractals.

These two people have a remarkable condition known as acquired savant syndrome. In the more familiar savantism—made famous by the 1988 movie *Rain Man*—people are endowed from early in life with extraordinary but narrowly defined musical, artistic, mathematical, memory and mechanical skills that stand in contrast to their marked impairments in language, social interactions and other mental faculties overall. In *Rain Man,* for instance, actor Dustin Hoffman's character, Raymond Babbitt, had stunning mathematical, calendar-calculating and other skills and a massive memory but also showed severe cognitive and behavioral limitations from his underlying autism.

In acquired savant syndrome, in contrast, near-genius levels of artistic or intellectual skills show up after dementia, a severe blow to the head or another insult to the brain. Discovery of this unusual phenomenon raises the possibility that dormant potential in some artistic or intellectual realm—an "inner savant"—resides in each of us. If so, perhaps a way can be found to tap these buried abilities in the absence of disease or injury.

YOUR INNER SCULPTOR

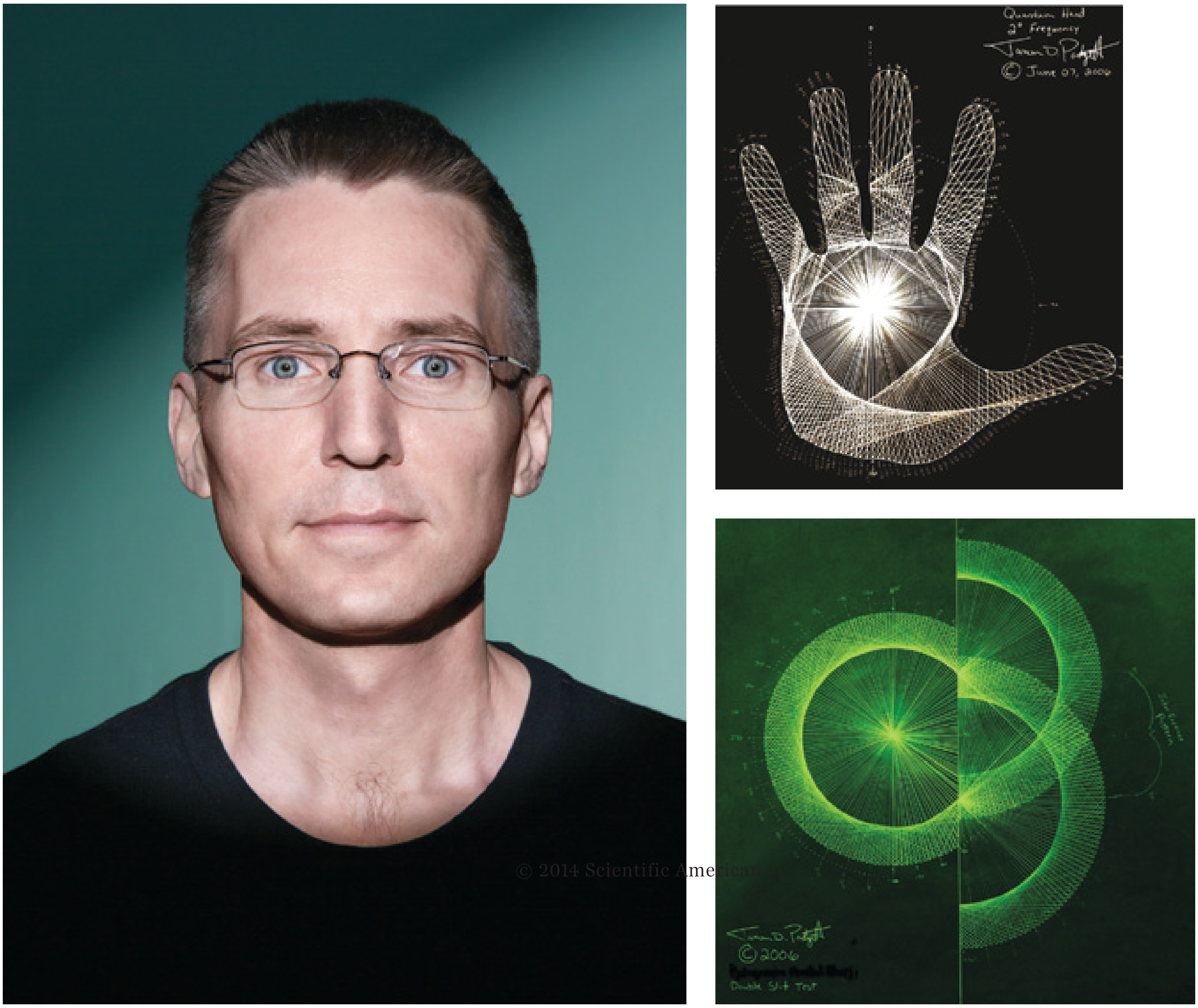
I HAVE STUDIED SAVANT SYNDROME for much of my career. Until the mid-1980s, I assumed it was present from birth—in other words, savant syndrome was a congenital condition. But then I attended the premier exhibition of exceptional sculptures made by Alonzo Clemons. As an infant, Clemons seemed to learn quickly.

IN BRIEF

Rain Man, the movie starring Dustin Hoffman, brought to popular attention the existence of savant syndrome—in which people with autism display exceptional intellectual or artistic gifts from birth.

Acquired savantism is an alternative form of the condition in which a person develops the ability to paint, play music or do mental calculations after experiencing some form of brain injury.

An inner savant may exist in most people if the proper brain circuits are activated or switched off through electrical stimulation technologies or even through focused practice of a particular skill.



GEOMETER: Padgett began to produce drawings like the ones at the right when a mugging that caused a concussion unlocked math, physics and artistic capabilities that the college dropout never knew he had.

COURTESY OF JASON PADGETT (*artwork*)

At about age three, however, a fall resulted in a brain injury, slowing his cognitive development precipitously and leaving him with a serious intellectual disability, including limited vocabulary and speech. But afterward, he developed a spectacular skill for sculpting using whatever materials were handy—even shortening from the kitchen. With his new talent came a growing fascination with animals. For example, he could look at a photograph of a horse in a magazine and then sculpt a three-dimensional replica in less than half an hour, each muscle and tendon reproduced in exacting detail.

Clemons sparked my interest in acquired savant syndrome, and I looked for reports of it in the medical literature but found only a few instances. In 1923 psychologist Blanche M. Minogue described the appearance of extraordinary musical abilities in a three-year-old following a bout of meningitis. In 1980 T. L. Brink, another psychologist, reported on a nine-year-old boy in whom superior mechanical skills appeared after a bullet wound to his left brain. In his case, he was able to dismantle, reassemble and modify multigear bicycles and invented a punching bag that could simulate the bobbing and weaving of a live opponent.

These sparse reports in the years before 1980 reflected the condition's rarity: a concussion or stroke does not usually enhance cognitive or creative capacity. I then decided to collect descriptions of such cases. By 2010 I had assembled a worldwide registry of 319 known savants, of whom only 32 had the acquired form.

Among the reports entered in my registry was work done by neurologist Bruce Miller, now at the University of California, San Francisco, and his colleagues. In 1996 Miller began compiling the first of 12 cases of people who had a disorder known as frontotemporal dementia (FTD). These elderly patients demonstrated musical or artistic skills for the first time, sometimes at prodigious levels, after their diagnosis. Frontotemporal dementia differs from Alzheimer's dementia in that the degenerative process affects only the frontal lobes and not wider areas of the brain.

FTD often targets the left anterior temporal area of the brain and the orbitofrontal cortex. Both regions normally inhibit activity in the visual system at the back of the brain, which is involved in processing incoming signals from the eyes. The disease seems to foster a newfound artistic sensibility by turning off inhibitory signals from the front of the brain. The releasing of the brakes allows the brain to process sight and sound in new ways. It unleashes artistic or other creative sensibilities even though damage to the frontal lobes may lead to the inappropriate behaviors that characterize the disorder. "FTD is an unexpected window into the artistic process," Miller says.

Further work implies that accidental genius results from diminished activity in some brain areas that is combined with a counterbalancing intensification in others. More specifically, it involves a set of events I call the three R's that occur after the brain is damaged—most often after the left hemisphere is stricken, similar to what happened with Miller's FTD cases. The process begins with "recruitment," a rise in electrical activity in still intact cortical tissue, often in the right hemisphere. Then the brain circuitry undergoes "rewiring" to establish newly formed connections between regions that were not previously linked. Next comes "release" of dormant capacity as a result of increased access to the newly connected brain areas.

An experiment done by Richard Chi and Allan Snyder, both then at the Center for the Mind at the University of Sydney, has used a relatively new technology to provide some evidence that these brain changes account for the acquired savant skills. Using transcranial direct-current stimulation (tDCS), these researchers induced savantlike abilities in human volunteers. The technique generates a polarized electric current to diminish activity in a part of the left hemisphere involved with sensory input, memory, language and other brain processes while increasing activity in the right hemisphere (the right anterior temporal lobe).

The investigators then asked study participants to solve the challenging "nine-dot" puzzle either with or without tDCS—a task that requires the creativity to search for a solution in an unconventional way. Participants had to connect three rows of three dots using four straight lines without lifting a pen or retracing lines. None of them could solve it before stimulation, and when 29 subjects were exposed to "sham" stimulation—electrodes emplaced without any current to test for placebo effects—they were still at a loss. With the current switched on, however, some 40 percent—14 of 33 participants—worked their way through the puzzle successfully.

How can a person suddenly perform so much better at the flip of a switch? Because these instant savants—and congenital and acquired savants as well—"know things" innately they were never taught. Clemons, the sculptor, had no formal training in art but knew instinctively how to produce an ar-

CASE HISTORIES

The Ultimate Eureka Moments

Acquired savantism has given people the ability to pursue poetry, music and instantaneous mental calculations. A few cases from a registry of savants follow.

The late Tommy McHugh was a 51-year-old builder in Liverpool, England, without any particular interest in poetry or painting. After suffering in 2001 a hemorrhage in the lining of the skull that damaged the frontal area of his brain, he suddenly began to fill notebooks with poems and to spend much of his time painting and sculpting. Physicians attributed this new talent to "relative disinhibition," which frees up the ability to evoke unusual word juxtapositions or imagery. McHugh has had exhibits in the U.K., and his story has been chronicled in a number of television documentaries.

Orlando Serrell, mentioned earlier, who began doing calendar calculations as a boy after being knocked out by a baseball, can determine the day of the week for any day since the injury occurred. He also recalls the weather every day since his injury. Now at 44, the Virginia man is still able to calendar-calculate, but his memory skills have advanced so that he can remember the minutest details of each day's activities—a condition known as hyperthymestic memory. Brain scans at Columbia University Medical Center have confirmed that Serrell engages in unconscious calculating—and his skill is not based on memorizing the calendar.

Derek Amato was a 40-year-old corporate trainer in Colorado with no special interest or skill in music. In 2006 he dove into the shallow end of a swimming pool, sustaining a severe concussion and losing some hearing in one ear. Following his hospital discharge, he was inexplicably drawn to the piano, which he had never touched before. He began to see black-and-white spots that he was able to transpose from his head into notes on the piano. He now makes his living composing, performing and recording.

Tony Cicoria, an orthopedic surgeon from New York, was talking on the telephone in 1994 when he was struck by lightning. Presumed to be in cardiac arrest, he was resuscitated by a nurse who was waiting to use the phone. For a week or two he had some mild memory problems. Those eventually subsided, and he resumed his orthopedic surgery practice full-time with no residual effects from the lightning strike. But one thing had changed. He developed a consuming obsession with classical music. Before the incident, he thought of himself as mainly a "rocker." But his newfound obsession morphed into a desire to play classical music as well. Shortly after his injury, he heard music in a dream. The tune stuck with him, resonating in his head whether he was awake or asleep. Finally, he decided to transcribe the earworm into a 26-page concert piano piece called Fantasia: The Lightning Sonata, op. 1.

Jason Padgett, who developed a passion for math, physics and drawing geometric shapes after he sustained a concussion following an assault, still runs three futon stores in Washington State. He now calls the injury, mentioned earlier, a "rare gift." Before the mugging, Padgett described himself as being among the "math-averse." Now the former college dropout takes higher-level math courses to fully understand the geometric figures that are his obsession, and he has written a popular book about his experiences. *—D.A.T.*

mature, the frame for the sculpture, to enable his pieces to show horses in motion.

One plausible explanation for the hidden talents that emerge in savant syndrome—whether early in life or induced by injury—is that these reservoirs of skill and knowledge must be inherited in some way. We do not start life with a blank slate that subsequently gets inscribed through education and other life experiences. The brain may come loaded with a set of innate predispositions for processing what it sees or for understanding the "rules" of music, art or mathematics. Savants can tap into that inherited knowledge far better than the average person can.

THE GENIUS SWITCH

KNOWING THAT THESE TALENTS can emerge even later in life raises the question of whether everyone has the capacity to become a savant—and whether it might be possible to do so without facing the travails of brain injury or dementia.

Another way to unleash buried brilliance would be to apply tDCS—or a related technology called repetitive transcranial magnetic stimulation—also a form of "thinking cap" that would toggle brain regions on and off to potentially augment a person's creative capacity. A technological solution may not be an absolute prerequisite, however. Meditation or simple adherence to assiduous practice of an artistic skill may suffice to allow us to switch on the more creative right side of the brain and thus explore undiscovered artistic capabilities.

As investigators understand the brain better, they may find other ways of determining what happens when brain circuits are turned up or down. Diffusion tensor imaging (DTI) and diffusion tensor tracking (DTT), which pinpoint connections among neurons ("fiber tracking"), are better suited than earlier methods for revealing the intricacies of the wiring inside a person's head, enabling researchers to correlate brain activity to the sudden appearance of skills. These more precise technologies can provide three-dimensional images of the fibers that tie together brain cells.

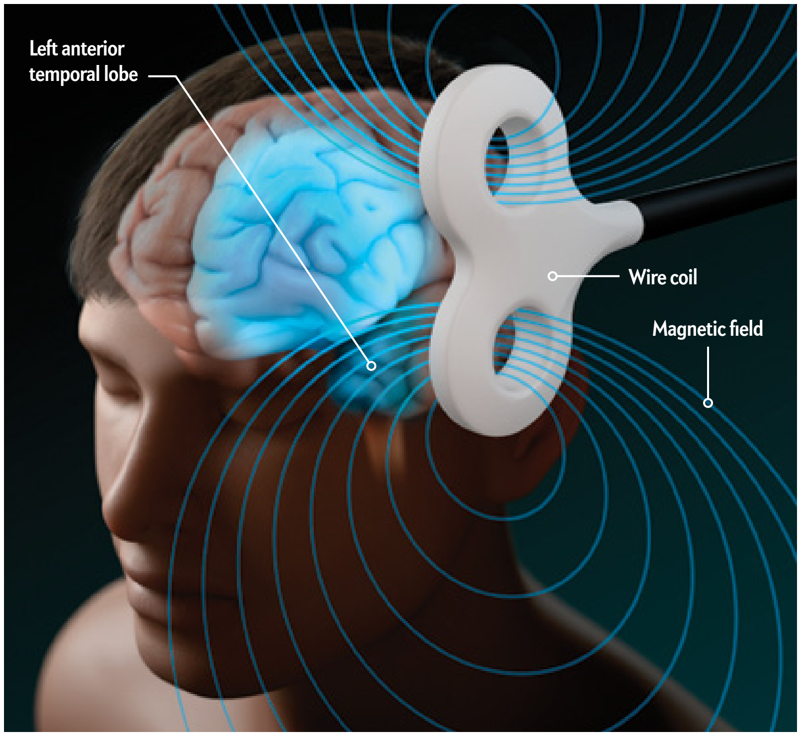
One challenge to uncovering the neurobiology underlying savantism has been the difficulty of observing brains as they carry out creative tasks that require movement. Not only is it hard to sculpt or play a piano inside an MRI machine, but any movement compromises image acuity. A newer technique—near-infrared spectroscopy (NIRS)—would sidestep such problems by replacing bulky machines with a comfortable skullcap that measures the amount of oxygen in blood flowing through the brain's blood vessels and relays the information to image-processing software. Even more promising is a recently developed helmet that uses another imaging method—positron-emission tomography (PET)—for monitoring when a person is sitting, standing or even exercising.

Such studies are worth pursuing. Acquired savantism provides strong evidence that a deep well of brain potential resides within us all. The challenge now is to find the best ways to tap into our inner savant—that little bit of Rain Man—while keeping the rest of our mental faculties intact. ■

NEURAL ENHANCEMENT

Instant Savant

A technology called repetitive transcranial magnetic stimulation can temporarily unleash savantlike abilities and offers a way to investigate how those abilities arise. When a coil placed over the left temple delivers a pulsed magnetic field through the skull, the field apparently turns off brain circuits in the left temporal area that process words and other information. Right-brain circuits dedicated to spatial tasks take on a more expansive role in mental processing. In some cases, subjects exposed to the magnetic fields were better able to guess the quantity of a large collection of objects.



MORE TO EXPLORE

Savant-Like Skills Exposed in Normal People by Suppressing the Left Fronto-Temporal Lobe. Allan W. Snyder et al. in *Journal of Integrated Neuroscience,* Vol. 2, No. 2, pages 149–158; December 2003.

Islands of Genius: The Bountiful Mind of the Autistic, Acquired, and Sudden Savant. Darold A. Treffert. Jessica Kingsley Publishers, 2010.

Struck by Genius: How a Brain Injury Made Me a Mathematical Marvel. Jason Padgett and Maureen Seaberg. Houghton Mifflin Harcourt, 2014.

FROM OUR ARCHIVES

Islands of Genius. Darold A. Treffert and Gregory L. Wallace; June 2002.

scientificamerican.com/magazine/sa

Illustration by AXS Biomedical Animation Studio

HEALTH

SICKN
IN THE ARCTIC

As the far north heats up, its inhabitants—from musk oxen to residents of growing cities—are getting ill

By Christopher Solomon

E S S

MUSK OXEN, huddled together to face a snowstorm, are powerless against a lungworm parasite that is threatening their ranks.

Christopher Solomon writes often about the environment and the outdoors for the *New York Times* and *Outside* magazine, among other publications.

THE SEA OTTERS SPLASHING OFF ALASKA'S ALEUTIAN ISLANDS SHOULD HAVE THRIVED IN THEIR HOME FAR FROM CIVILIZATION.

Instead the furry little creatures were in trouble. Their population throughout the Aleutians and southwestern Alaska had crashed by 70 percent in less than 10 years.

Trying to decipher the decline, Tracey Goldstein of the University of California, Davis, and her fellow researchers went looking for disease. What they found chilled them: evidence of a distemper virus usually found in seals. The virus had already killed more than 50,000 seals along Europe's shores over two decades. It had also been linked to seal deaths on the eastern coasts of Canada and the U.S. Yet seal distemper virus had never been found in the North Pacific. How did it get there?

The sleuthing soon pointed to Arctic ice—or the lack of it. The year of the last big seal distemper epidemic in northern Europe—2002—was also a time of extremely little summer sea ice in the Arctic. Goldstein theorized that a melting Arctic opened the fabled Northwest Passage to disease transmission, allowing an infected Atlantic marine mammal such as a ringed seal, or its feces, to mingle somewhere with marine animals from the North Pacific, spreading the virus to sea otters there. The fragment of virus found in the Aleutian otters was identical to that in Europe's 2002 outbreak.

The theory has some skeptics, but if it is correct, marine mammals in the Arctic and Pacific oceans, particularly harbor seals, may be threatened by the virus's spread, according to Goldstein, who directs the university's Marine Ecosystem Health Diagnostic and Surveillance Laboratory. What is more, other species are now encountering one another or their effluents in the Northwest Passage, possibly leading to new exchanges of disease. In the summer of 2010, for instance, bowhead whales from the Atlantic and the Pacific, which had been tagged and tracked by satellite, met there, a union that probably had not happened since the start of the Holocene epoch 12,000 years ago.

As climate change heats the world's highest latitudes faster than almost anywhere else, animals on land, as well as in the sea, are getting sick. Temperatures across Alaska increased by 1.9 degrees Celsius on average over the past 50 years, compared with 0.7 degree C worldwide. Alaskan winters are heating up even more quickly than summers, rising an average of 2.6 degrees C. That warming can create more hospitable conditions for pathogens and parasites and encourage northward migration of many animals and pests, such as ticks, that often carry disease. New life is also crawling and swimming toward a warmer north, carrying microbes to populations that have not seen them before.

The migration could spell trouble for humans, too. In a shrinking world where old barriers are sometimes literally melting away, animal diseases can spread to humans more readily. Indeed, more than 60 percent of the new infectious diseases emerging in humans worldwide since 1940 have been transmitted from animals to people—including those caused by Ebola virus and severe acute respiratory syndrome (SARS) virus. Simply put, says Michael Grigg, chief of molecular parasitology at the National Institute of Allergy and Infectious Diseases, "if the animals are sick, we can get sick."

A shift in disease could also alter animal populations and therefore threaten ecosystems and food supplies for indigenous peoples. It is not quite clear if the rising number of diseases being observed is simply the result of scientists looking more widely, and no one is ready to claim that Arctic life will collapse because of

IN BRIEF

Rising Arctic temperatures are helping pathogens spread and thrive where they had not been before.

Parasites in the far north are sickening musk oxen, ticks are transmitting viruses to people, and Atlantic seals may have transmitted a lethal virus to Pacific seals as vanishing sea ice allows their worlds to mix.

Changing climate could help some species, but researchers fear it will hurt more of them, raising the need for nations to find ways to improve biosecurity.

PRECEDING PAGES: NORBERT ROSING *National Geographic (musk oxen)*; COURTESY OF PRATAP KAFLE *University of Calgary (lungworm)*

Pathogens Move Northward

Researchers are finding surprising ailments in surprising places across the far north. Ticks and other parasites that carry pathogens from temperate zones are hitching a ride on animals that are migrating north with advancing forests. Mosquitoes are transmitting diseases at higher latitudes. Seals from the Atlantic and Pacific oceans are swapping illnesses. A few of the many discoveries appear here.

Sweden
Mosquitoes have spread the tularemia bacterium to people across the country.

Arkhangelsk Oblast, Russia
Tick-borne encephalitis cases in humans rose 50-fold from the decade 1980–1989 to the decade 2000–2009.

Aleutian Islands, Alaska
A distemper virus that infects seals in the North Atlantic Ocean now attacks sea otters in the North Pacific.

Saint Lawrence Island, Bering Sea
Avian cholera 200 kilometers off the Alaskan mainland has killed hundreds of northern fulmars, murres and crested auklets—seabirds that had not been afflicted before.

Sahtu, Northwest Territories
Ticks, never observed here before, have been discovered on moose hides.

Victoria Island, Arctic Archipelago
Lungworm has spread several hundred kilometers northward across the musk oxen population.

Hay Island, Nova Scotia
Ringed seals have passed a parasite to gray seals that killed 400 pups in 2012.

contagion. But changing dynamics, says Claire Heffernan, a specialist in global health at the University of Oxford, makes the Arctic "the Pandora's box of infectious disease and climate change."

PARASITES MATURE FAST

ONE WAY THAT A WARMING CLIMATE is promoting disease in the northern reaches of the planet is by helping parasites mature. A startling example is *Umingmakstrongylus pallikuukensis,* a lungworm that lives inside musk oxen, those shaggy, smelly Ice Age relics in Canada's upper Northwest Territories. The lungworm has evolved a fascinating relationship with its hosts: Female worms, which can be up to 65 centimeters (25.6 inches) long, lay eggs in large cysts in the lungs of musk oxen. After the eggs hatch, a musk ox coughs up the larvae, swallows them, then passes them out through its feces. The larvae are picked up by the feet of Arctic slugs and snails, eventually passing back into the ox when the bovine eats the gastropods.

The Arctic's modest summer temperatures always kept the lungworms in check. It rarely got warm enough for the larvae to grow to their final, infective stage in the slugs and snails, so they had to overwinter in their immature state and continue development the next summer.

But a "tipping point" has been reached, says Susan Kutz, associate professor of ecosystem public health at the University of Calgary. The warmth is lasting longer, allowing the parasite to mature in one summer instead of two. "They're far more likely to get taken up by a musk ox and complete the life cycle" in that time frame, Kutz says, and thus have more opportunities to thrive and spread.

Invigorated, the lungworm is on the march. In 2008 Kutz and others found that its range had expanded north several hundred kilometers, to Victoria Island in Canada's western Arctic Archipelago, home to as much as 30 percent of the global population of musk oxen. Today it is in all the oxen that live

Map by XNR Productions

in places on the island where the parasite has established itself.

The parasite's incursion is part of a double whammy. In a perfect world, *U. pallikuukensis* would not cause the animals much grief. The oxen "might have a smoker's cough or something," Kutz says. But toastier summers are also affecting the animals. "Remember," she says, "for a musk ox, warm weather is bad weather." If a musk ox is stressed by heat and its lungs are compromised because they are full of cysts, the animal can weaken, lose vital energy and become predisposed to various infections. "That can affect whether you live or die," Kutz says.

Sure enough, the population is declining dramatically. Indigenous peoples are worried, too, because they rely on a healthy population of the animals for food and natural materials.

WINTER TICKS, which burrow into moose to survive harsh temperatures, are being found much farther north, weakening the animals there.

TICKS AND MOSQUITOES SPREAD

WARMER TEMPERATURES are also allowing plant and animal species to migrate northward, bringing their infections with them. In Russia, for example, forests are advancing into tundra areas at about a kilometer a year. The field mouse, brown hare, hedgehog, wild boar, moose and a dozen new species of bird now occupy the growing northern taiga.

Ticks are among the invaders moving up with their hosts. In North America the winter tick survives the frigid months by attaching in autumn to animals such as moose and using the hosts' body warmth to endure. In 2013 researcher Cyntia Kayo Kashivakura found ticks on five of 30 moose hides in the Sahtu, an aboriginal region high up in Canada's Northwest Territories, the first time the bugs have been seen there.

Ticks and other threats are not just an animal problem in the Arctic. Roughly four million people now inhabit the far north, and they are at risk as well. About 10 percent of them live in smaller villages, but many other residents live in expanding cities as large as 300,000 (Murmansk, Russia). Energy exploration and tourism continue to bring newcomers. Sweden is one place already feeling the effects. The country saw a record number of tick-borne encephalitis (brain swelling) cases in 2011 and again in 2012. A warming climate and longer growing season have allowed roe deer, the main host for female ticks there, to expand their ranges northward. Lab data also suggest that the virus they carry may multiply to high concentrations in a tick's salivary glands during warm weather, so the virus is primed to infect when the tick attaches to a host.

Mosquitoes are expanding across Sweden, too. The insect is distributing *Francisella tularensis,* an infectious bacterium that is the primary agent of tularemia, which can cause severe fever, inflammation and death. The bacterium can be so lethal that during the cold war of the 1950s the U.S. and the U.S.S.R. weaponized it. The version now in Sweden causes about a week of flulike symptoms. Researchers have not pinpointed the mechanism allowing the mosquitoes and tularemia to thrive, but higher late-summer temperatures seem to be key, says researcher Anders Sjöstedt of Umeå University in Sweden. The threat is only going to get worse. According to models built by Sjöstedt and others, by this century's end the time period during which outbreaks will occur will lengthen by three and a half weeks to more than six and a half weeks in high-risk counties.

Humans are also in peril from other quarters. A warmer climate can alter the habitats of local animals in ways that can foster disease transmission to people. In the winter of 2006–2007 northern Sweden experienced a sudden explosion of nearly 500 cases of a hantavirus infection, transmitted to humans when they inhale feces or urine of infected rodents. The hantavirus causes nephropathia epidemica, a sometimes lethal viral hemorrhagic fever. Up to 30 percent of the sick were hospitalized; at least three people died.

Pathologists eventually figured out the odd but likely reason: Record-breaking warmth that winter caused rain and ice to fall instead of snow. The hantavirus is endemic in bank voles, a rodent that relies on snow cover during winter to hide from predators and cold. When the ground in northern Sweden had no snow cover for 25 of 31 days, voles probably sought refuge in barns and homes, thereby transmitting the infection to humans. Warmer, wetter winters are Sweden's future.

ONE SEAL KILLS ANOTHER

IT IS NOT ONLY MIGRATIONS on land that are worrisome. Fish and marine mammals are moving en masse toward the poles, seek-

DON JOHNSTON *Corbis (moose);* COURTESY OF RON MOEN *University of Minnesota Duluth (ticks)*

SCIENTIFIC AMERICAN ONLINE More on how pests survive in the Arctic can be found at ScientificAmerican.com/aug2014/solomon

ing cooler waters as midlatitude oceans warm. Researchers are finding more and more seaborne pathogens farther and farther north. For example, stocks of cod—one of the world's most important fisheries—continue to push up into the Arctic and now occur at record levels in the Barents Sea, northeast of Norway. The fish carry hitchhiker viruses. Predators follow, bringing more of the same.

Sometimes the reverse happens: a pathogen established in the north finds fertile ground in the new inhabitants. Gray seals, for example, are following fish stocks that are heading that way, in pursuit of a meal. In February 2012, 400 gray seal pups died on Hay Island off the coast of Nova Scotia, about a sixth of all pups typically born there each year. The killer, scientists think, was a parasite that is similar to *Sarcocystis canis,* a single-celled organism related to the one that causes malaria. The *S. canis*–like parasite is not always lethal, but in some populations it causes massive disease and death.

Researchers tested nearly a dozen species of Arctic marine mammals and found a likely culprit: the ringed seal. The seal spends most of its life on sea ice and is common in the Canadian Arctic. Soon-to-be-published research suggests that ringed seals either carry the parasite and pass it on, unchanged, or serve as its "definitive host"—one in which the parasite undergoes sexual reproduction and is passed through feces into the environment as an infective egg, or oocyst. Those oocysts can then enter and infect other animals such as gray seals, causing active disease, according to Katie Haman, a veterinarian and doctoral candidate at the University of British Columbia. For the first time, ringed seals are mingling with gray seals, says Grigg, who is Haman's adviser. Fishers in Newfoundland confirm the mixing. Researchers next hope to find ringed seal scat with those oocysts in it, which would confirm that the animals are the definitive host of the parasite.

Ominously, in every Arctic marine mammal that Grigg's team has examined, the group has found species of microbial pathogens not seen before. The Arctic is like an unread book, one that we ignore at our peril, according to Grigg.

BIOSECURITY NEEDED

FOR EONS THE ARCTIC's frigid temperatures, its snow and ice and lack of crowds, essentially kept a cap on infection. Native wildlife has grown accustomed to a place that is relatively free of disease and diversity. Some scientists even say that birds evolved to pursue taxing migrations north every year so they can focus their springtime energy on breeding instead of fighting off parasites and predators.

Now a chaotic reshuffling of factors affecting disease is under way, which scientists drily call "ecosystem reorganization." Species are mingling in strange and previously unobserved ways, such as polar bears seen fighting and mating with grizzlies in Kaktovik, Alaska. An unprecedented 20,000 walruses hauled themselves onto a beach off the coast of Alaska in 2011, when their usual summer home—ice floes in the Chukchi Sea—simply vanished. Out-of-towners, plus crowds, plus stress, all add up to a greater possibility of illness spreading, researchers say.

The sickening Arctic is the product of a broader trend—an entire world saddled with more disease under climate change. Viruses, fungi and parasites are invading not only the north but also tropical ecosystems such as coral reefs and rain forests. Tropical pathogens, in turn, are advancing into temperate zones; dengue fever is cropping up in Florida and Texas.

To be fair, the Arctic is not being crippled by contagion. Outbreaks to date have been relatively restrained. Some wildlife may even benefit from warmer times. Black brant geese that favor salt-marsh areas are starting to find more of that habitat on Alaska's North Slope as permafrost thaws and coastland subsides. It is possible, too, that some afflictions might decrease. Rabies persists in Alaska only in areas where Arctic foxes are present; as red foxes proliferate and displace Arctic foxes, rabies cases could ease, suggests Karsten Hueffer, associate professor of microbiology at the University of Alaska Fairbanks.

Still, researchers seem to find surprising illnesses in northern wildlife almost monthly: polar bears with alopecia (hair loss); seabirds with avian cholera. Whether these instances are multiplying or are just being discovered as more investigators look northward is still a bit hard to say. What is badly needed, researchers agree, is more baseline information about the state of disease. That goal is challenging. The Arctic is vast and remote, it is expensive to get around and it can be dangerous to study. Yet researchers say that in their gut, based on years of experience, they think a widespread problem is emerging.

More study would also help countries agree on solutions to spreading diseases as they are revealed. "What we're doing now is negotiating over resources up there," Oxford's Heffernan says of nations planting their flags on the seabed and scrambling for oil. "What we really should be doing is negotiating about biosecurity." Agreements need to be made about how to lower exposure to disease threats and prevent the inadvertent introduction of new pathogens to both human and wildlife populations at risk, she says. Nations need to forge collaborative actions "now."

The Arctic "has been cut off from the rest of the world for a large number of years," adds Grigg, the parasitologist. "It's got its own dynamic, so the pathogens that are in the hosts, and the hosts, have come to some balance." But when pathogens are liberated by a new environment, he says, big changes can sweep through populations.

Sometimes those changes drive a new balance fairly quickly, without too much distress, Grigg continues, citing the modest consequences of West Nile virus in the U.S., which raised major fear when it was first discovered. But then Grigg mentions rats and bubonic plague, and the devastation wrought by smallpox when it was introduced to the native populations of the New World. "Sometimes," he says, change "is catastrophic." SA

MORE TO EXPLORE

Phocine Distemper Virus in Northern Sea Otters in the Pacific Ocean, Alaska, USA. Tracey Goldstein et al. in *Emerging Infectious Diseases,* Vol. 15, No. 6, pages 925–927; June 2009. www.cdc.gov/eid

Invasion, Establishment and Range Expansion of Two Parasitic Nematodes in the Canadian Arctic. Susan J. Kutz et al. in *Global Change Biology,* Vol. 19, No. 11, pages 3254–3262; November 1, 2013.

Local Environmental Observer Network for northern communities: www.anthc.org/chs/ces/climate/leo

FROM OUR ARCHIVES

Arctic Plants Feel the Heat. Matthew Sturm; May 2010.

How Kitty Is Killing the Dolphins. Christopher Solomon; April 2013.

scientificamerican.com/magazine/sa

CYBERSECURITY

Saving Big Data from Itself

A three-step plan for using data right in an age of government overreach

By Alex "Sandy" Pentland

For the first few decades of its existence, the National Security Agency was a quiet department with one primary job: keeping an eye on the Soviet Union. Its enemy was well defined and monolithic. Its principal tools were phone taps, spy planes and hidden microphones.

After the attacks of September 11, all of that changed. The NSA's chief enemy became a diffuse network of individual terrorists. Anyone in the world could be a legitimate target for spying. The nature of spying itself changed as new digital communication channels proliferated. The exponential growth of Internet-connected mobile devices was just beginning. The NSA's old tools apparently no longer seemed sufficient.

In response, the agency adopted a new strategy: collect everything. As former NSA director Keith Alexander once put it, when you are looking for a needle in a haystack, you need the whole haystack. The NSA began collecting bulk phone call records from virtually every person in the U.S.; soon it was gathering data on bulk Internet traffic from virtually everyone outside of the U.S. Before long, the NSA was collecting an amount of data every two hours equivalent to the U.S. Census.

The natural place for the NSA to store this immense new haystack was the same place it had always stored intelligence assets: in the agency's own secure facilities. Yet such concentration of data had consequences. The private, personal information of nearly all people worldwide was suddenly a keystroke away from any NSA analyst who cared to look. Data hoarding also made the NSA more vulnerable than ever to leaks. Out-

IN BRIEF

Data about human behavior have always been essential for both government and industry to function. But how do we enable institutions to collect and analyze data without abusing that information?

We can start by embracing some basic principles. The NSA and other government organizations should leave big data resources spread across functionally separate databases overseen by separate organizations. Everyone who holds or shares personal data, including citizens, must safeguard transmission and storage through encryption.

In the digital era, we must also realize that existing policy and tradition will not suffice. Constant, transparent experimentation with big data procedures is the only way to find out what works.

Illustration by Bill Mayer

raged by the scope of the NSA's secret data-collection activities, then NSA contractor Edward Snowden managed to download thousands of secret files from a server in Hawaii, hop on a flight to Hong Kong and hand the documents over to the press.

Data about human behavior, such as census information, have always been essential for both government and industry to function. But a secretive agency collecting data on entire populations, storing those data in clandestine server farms and operating on them with little or no oversight is qualitatively different from anything that has come before. No surprise, then, that Snowden's disclosures ignited such a furious public debate.

So far much of the commentary on the NSA's data-collection activities has focused on the moral and political dimensions. Less attention has been paid to the structural and technical aspects of the NSA debacle. Not only are government policies for collecting and using big data inadequate, but the process of making and evaluating those policies also needs to move faster. Government practices must adapt as quickly as the technology evolves. There is no simple answer, but a few basic principles will get us on track.

Alex "Sandy" Pentland directs the M.I.T. Human Dynamics Laboratory and co-leads the World Economic Forum's big data and personal data initiatives. His latest book, *Social Physics,* was published in January by Penguin Press.

STEP

1

SCATTER THE HAYSTACK

ALEXANDER WAS WRONG about searching for needles in haystacks. You do not need the entire stack—only the ability to examine any part of it. Not only is it unnecessary to store huge amounts of data in one place, it is dangerous both for the spies and for the spied on. For governments, it makes devastating leaks that much more likely. For individuals, it creates the potential for unprecedented violations of privacy.

The Snowden disclosures made clear that in government hands, information has become far too concentrated. The NSA and other government organizations should leave big data resources in place, overseen by the organization that created the database, with different encryption schemes. Different kinds of data should be stored separately: financial data in one physical database, health records in another, and so on. Information about individuals should be stored and overseen separately from other sorts of information. The NSA or any other entity that has good, legal reason to do so will still be able to examine any part of this far-flung haystack. It simply will not hold the entire stack in a single server farm.

The easiest way to accomplish this disaggregation is to stop the hoarding. Let the telecoms and Internet companies retain their records. There need be no rush to destroy the NSA's current data stores, because both the content of those records and the software associated with them will quickly become ancient history.

It might be hard to imagine the NSA giving up its data-collection activities—and realistically, it will not happen without legislation or an executive order—but doing so would be in the agency's own interest. The NSA seems to know this, too. Speaking at the Aspen Security Forum in Colorado last summer, Ashton B. Carter, then deputy secretary of defense, diagnosed the source of the NSA's troubles. The "failure [of the Snowden leaks] originated from two practices that we need to reverse.... There was an enormous amount of information concentrated in one place. That's a mistake." And second, "you had an individual who was given very substantial authority to access that information and move that information. That ought not to be the case, either." Distributed, encrypted databases running on different computer systems would not only make a Snowden-style leak more difficult but would also protect against cyberattacks from the outside. Any single exploit would likely result in access to only a limited part of the entire database. Even authoritarian governments should have an interest in distributing data: concentrated data could make it easier for insiders to stage a coup.

How does distributing data help protect individual privacy? The answer is that it makes it possible to track patterns of communication between databases and human operators. Each category of data-analysis operation, whether it is searching for a particular item or computing some statistic, has its own characteristic pattern of communication—its own signature web of links and transmissions among databases. These signatures, metadata about metadata, can be used to keep an eye on the overall patterns of otherwise private communications.

Consider an analogy: When patterns of communication among different departments in a company are visible (as with physical mail), then the patterns of normal operations are visible to employees even though the content of the operations (the content of the pieces of mail) remains hidden. If, say, the person responsible for maintaining employee health records sees that an unusual number of these private records are suddenly being accessed by the financial records office, he or she can ask why. In the same way, structuring big data operations so that they generate metadata about metadata makes oversight possible. Telecommunications companies can track what is happening to them. Independent civic entities, as well as the press, could use such data to serve as an NSA watchdog. With metadata about metadata, we can do to the NSA what the NSA does to everyone else.

SCIENTIFIC AMERICAN ONLINE For more on big data and security, go to ScientificAmerican.com/aug2014/big-data

STEP

2

HARDEN OUR TRANSMISSION LINES

ELIMINATING the NSA's massive data stores is only one step toward guaranteeing privacy in a data-rich world. Safeguarding the transmission and storage of our information through encryption is perhaps just as important. Without such safeguards, data can be siphoned off without anyone knowing. This form of protection is particularly urgent in a world with increasing levels of cybercrime and threats of cyberwar.

Everyone who uses personal data, be they a government, a private entity or an individual, should follow a few basic security rules. External data sharing should take place only between data systems that have similar security standards. Every data operation should require a reliable chain of identity credentials so we can know where the data come from and where they go. All entities should be subject to metadata monitoring and investigative auditing, similar to how credit cards are monitored for fraud today.

A good model is what is called a trust network. Trust networks combine a computer network that keeps track of user permissions for each piece of data within a legal framework that specifies what can and cannot be done with the data—and what happens if there is a violation of the permissions. By maintaining a tamper-proof history of provenance and permissions, trust networks can be automatically audited to ensure that data-usage agreements are being honored.

Long-standing versions of trust networks have proved to be both secure and robust. The best known is the Society for Worldwide Interbank Financial Telecommunication (SWIFT) network, which some 10,000 banks and other organizations use to transfer money. SWIFT's most distinguishing feature is that it has never been hacked (as far as we know). When asked why he robbed banks, mastermind Willie Sutton allegedly said, "Because that's where the money is." Today SWIFT is where the money is. Trillions of dollars move through the network every day. Because of its built-in metadata monitoring, automated auditing systems and joint liability, this trust network has not only kept the robbers away, it has also made sure the money reliably goes where it is supposed to go.

With metadata about metadata, we can do to the NSA what the NSA does to everyone else.

Trust networks used to be complex and expensive to run, but the decreasing cost of computing power has brought them within the reach of smaller organizations and even individuals. My research group at the Massachusetts Institute of Technology, in partnership with the Institute for Data Driven Design, has helped build openPDS (open Personal Data Store), a consumer version of this type of system. The idea behind the software, which we are now testing with a variety of industry and government partners, is to democratize SWIFT-level data security so that businesses, local governments and individuals can safely share sensitive data—including health and financial records. Several state governments in the U.S. are beginning to evaluate this architecture for both internal and external data-analysis services. As the use of trust networks becomes more widespread, it will become safer for individuals and organizations to transmit data among themselves, making it that much easier to implement secure, distributed data-storage architectures that protect both individuals and organizations from the misuse of big data.

STEP

3

NEVER STOP EXPERIMENTING

THE FINAL and perhaps most important step is for us to admit that we do not have all the answers, and, indeed, there are no final answers. All we know for sure is that as technology changes, so must our regulatory structures. This digital era is something entirely new; we cannot only rely on existing policy or tradition. Instead we must constantly try new ideas in the real world to see what works and what does not.

Pressure from other countries, citizens and tech companies has already caused the White House to propose some limits on NSA surveillance. Tech companies are suing for the right to release information about requests from the NSA—metadata about metadata—in an effort to restore trust. And in May the House of Representatives passed the USA Freedom Act; though considered weak by many privacy advocates, the bill would begin to restrict bulk data collection and introduce some transparency into the process. (At press time, it is pending for the Senate.)

Those are all steps in the right direction. Yet any changes we make right now will only be a short-term fix for a long-term problem. Technology is continually evolving, and the rate of innovation in government processes must catch up. Ultimately, the most important change that we could make is to continuously experiment and to conduct small-scale tests and project deployments to figure out what works, keep what does and throw out what does not. SA

MORE TO EXPLORE

Personal Data: The Emergence of a New Asset Class. World Economic Forum, January 2011. www.weforum.org/reports/personal-data-emergence-new-asset-class

Social Physics: How Good Ideas Spread—The Lessons from a New Science. Alex Pentland. Penguin Press, 2014.

FROM OUR ARCHIVES

The Data-Driven Society. Alex "Sandy" Pentland; October 2013.

scientificamerican.com/magazine/sa

Researchers are using tools borrowed from medicine and economics to figure out what works best in the classroom. But the results aren't making it into schools

EDUCATION

The Science of Learning

By Barbara Kantrowitz

ANNA FISHER WAS LEADING AN UNDERGRADUATE SEMINAR on the subject of attention and distractibility in young children when she noticed that the walls of her classroom were bare. That got her thinking about kindergarten classrooms, which are typically decorated with cheerful posters, multicolored maps, charts and artwork. What effect, she wondered, does all that visual stimulation have on children, who are far more susceptible to distraction than her students at Carnegie Mellon University? Do the decorations affect youngsters' ability to learn?

IN BRIEF

Researchers are conducting hundreds of experiments in an effort to bring more rigorous science to U.S. schools.

The movement started with former president George W. Bush's No Child Left Behind Act and has continued under President Barack Obama.

Using emerging technology and new methods of data analysis, researchers are undertaking studies that would have been impossible even 10 years ago.

The new research is challenging widely held beliefs, such as that teachers should be judged primarily on the basis of their academic credentials, that classroom size is paramount, and that students need detailed instructions to learn.

Photograph by Fredrik Broden

To find out, Fisher's graduate student Karrie Godwin designed an experiment involving kindergartners at Carnegie Mellon's Children's School, a campus laboratory school. Two groups of 12 kindergartners sat in a room that was alternately decorated with Godwin's purchases or stripped bare and listened to three stories about science in each setting. Researchers videotaped the students and later noted how much each child was paying attention. At the end of the reading, the children were asked questions about what they had heard. Those in the bare classroom were more likely to pay attention and scored higher on comprehension tests.

Hundreds of experiments like Fisher's are part of an effort to bring more rigorous science to U.S. classrooms. The movement started with former president George W. Bush's No Child Left Behind Act and has continued under President Barack Obama. In 2002 the Department of Education established the Institute of Education Sciences (IES) to encourage researchers to pursue what was described as "scientifically valid research," especially randomized controlled trials, which advocates of IES considered the gold standard. The government also created the What Works Clearinghouse to provide a database of results for classroom educators on everything from reviews of particular curricula to evidence-based teaching techniques.

Now researchers are using emerging technology and new methods of data analysis to create experiments that would have been impossible to carry out even 10 years ago. Video cameras track eye movements to see where students are directing their attention; skin sensors report whether students are engaged or bored. Economists have figured out how to crunch data to mimic randomized trials—which are often difficult and expensive to implement in schools.

Much of the new research goes beyond the simple metric of standardized tests to study learning in progress. "I am interested in measuring what really matters," said Paulo Blikstein, an assistant professor at the Stanford Graduate School of Education. "We have been developing new technologies and new data-collection methods to capture the process." How well students complete a task is just part of the experiment; researchers also record students' eye gaze, galvanic skin response and exchanges with fellow students, among other things. Blikstein calls this approach "multimodal learning analytics."

The new methodology is already challenging widely held beliefs by finding that teachers cannot be judged solely on the basis of their academic credentials, that classroom size is not always paramount and that students may actually be more engaged if they struggle to complete a classroom assignment. Although these studies have not come up with the "silver bullet" to cure all that ails American schools, the findings are beginning to fill in some blanks in that hugely complex puzzle called education.

Barbara Kantrowitz is a senior editor at the Hechinger Report, a nonprofit news organization focused on education journalism. She teaches at Columbia Journalism School and was an editor and writer at *Newsweek* for more than 20 years, covering education, health and social issues.

LOOKING FOR PATTERNS

PROVOCATIVE QUESTIONS are yielding some of the most surprising results. In a series of experiments with middle school and high school students, Blikstein is trying to understand the best ways to teach math and science by going beyond relatively primitive tools like multiple-choice tests to assess students' knowledge. "A lot of what happens in engineering and science is the failure," he says. "You try something, it doesn't work, then you reevaluate your ideas; you go back and try it again with a new set of ideas." That is

Stop Lecturing Me

At the college level, the evidence is clear: science students learn less when they are expected to listen passively

By Carl Wieman

University science professors preach a gospel of seeking truth through data and careful experimentation, yet when they walk into a classroom, they use methods that are outmoded and ineffective. The overwhelming fraction of undergraduate science courses are taught by a professor lecturing to students, even in the face of many hundreds of studies showing that alternative teaching methods demonstrate much greater student learning and lower failure rates.

These different methods go by a number of names, including active learning. Their common feature is that, rather than listening passively, students spend class time engaged in answering questions, solving problems, discussing solutions with their peers and reasoning about the material they are studying, all while getting regular feedback from their teacher. As reported in a 2012 study by the National Academy of Sciences and in a detailed review published online in May in the *Proceedings of the National Academy of Sciences USA,* this approach improves learning across the science and engineering disciplines and in both introductory and advanced courses [*see graph on opposite page*].

There are many different ways to implement active learning. In smaller classes, students often work in groups to complete a series of steps that make up a larger problem. In classes of 100 to 300 students, instructors often use "clickers," devices that allow students to transmit answers to a teacher instantly by pushing a button from their seat. This allows a teacher to see immediately what fraction of the students comprehend the material. The best questions are challenging and involve understanding and using basic concepts rather than simple memorization. When most of the class gets a question wrong, the teacher has students discuss it with their neighbors and re-vote. Meanwhile the teacher listens in on those conversations and provides targeted help to the students. With any of these methods, the teacher still spends a considerable amount of time talking, but the listeners are students who have been prepared to learn. They understand why the material is worthwhile and how it can be used to solve problems. The material is now in a

PAGE 68: STYLING BY JULIE WHITMIRE

context that makes sense rather than being given as a set of meaningless facts and procedures that they can only memorize without understanding.

The educational research for K–12 classes offers a less clear picture in favor of active learning. That is because the research in K–12 is more difficult, with far more things that are outside the researchers' control. Perhaps the most important variable is the uneven and often low level of subject mastery by teachers. Because active learning requires practice and feedback on thinking like an expert (a scientist), it demands considerably greater subject expertise by the teacher. At the college level, teacher subject knowledge is not a problem, the student population is far more homogeneous, and there are far fewer issues that may affect learning. Unfortunately, the low level of subject mastery by K–12 science teachers will remain until college science teaching improves to the point that all students, including future K–12 teachers, graduate with a solid understanding of science and a better model for good science teaching and learning.

With so much scientific evidence behind active learning, the obvious question is, Why are these methods so seldom used in colleges and universities? Part of it is just habit; lectures began at universities because they did not have books, and so information had to be dictated and copied. Teaching methods have not yet adapted to the invention of the printing press. A second reason is a fundamentally flawed understanding of learning. Most people, including university faculty and administrators, believe learning happens by a person simply listening to a teacher. That is true if one is learning something very simple, like "Eat the red fruit, not the green one," but complex learning, including scientific thinking, requires the extended practice and interaction described earlier to literally rewire the brain to take on new capabilities. The most important reason higher education does not change methodologies, however, is that there is no incentive. Faculty and universities are recognized and rewarded only for how successful they are at pursuing the $40 billion a year of federal research money. There is zero incentive to use effective research-based teaching methods rather than pedagogical superstition and habit, and in fact, very few, if any, universities in the U.S. track what teaching methods are being used in their classrooms. As long as this holds true, prospective students have no way to compare the quality of education they will receive at different institutions, and so no institution needs to improve.

Carl Wieman, *who earned the Nobel Prize in Physics in 2001, holds a joint appointment at Stanford University's department of physics and its Graduate School of Education.*

one of the processes he hopes to capture with these new tools: "We bring kids to the lab, and we run studies where we tell them to build some kind of engineering or science project." The researchers put sensors in the lab and sometimes on the kids themselves. Then they collect the data and analyze them to look for patterns. "There are lot of counterintuitive things in how people learn," Blikstein notes. "We like to reveal that an intuition we have is sometimes wrong."

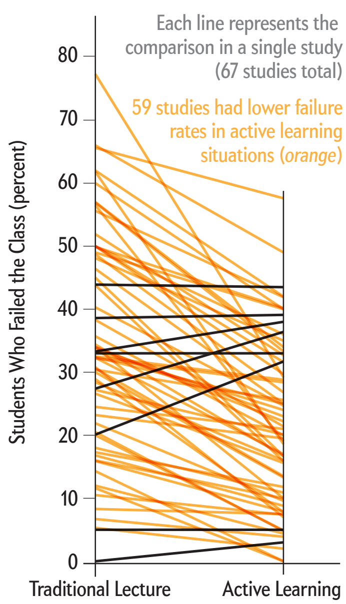
"Discovery" learning, in which students discover facts for themselves rather than receiving them directly from an instructor, has been in vogue lately; Blikstein and his colleagues at FabLab@School, a network of educational workshops Blikstein created in 2009, are trying to get at the heart of how much or how little instruction students really need. Parents may not like to see their kids frustrated in school, but Blikstein says that "there are levels of frustration and failure that are very productive, are very good ways to learn." In one set of studies, he and his colleagues tried to find out whether students learned more about a science topic if they first saw either a lecture or did an exploratory activity. Seeing the lecture first is called "tell and practice," he says. "First you're told, then you practice." Students were divided into two groups: one started with the lecture, and the other started with the exploratory activity. The researchers repeated the experiment in several studies and found fairly consistent results: students who practiced first performed 25 percent better than students who listened to a lecture first. "The idea here is that if you have a lecture first and you haven't explored the problem by yourself a little bit, you don't even know what questions the lecturing is answering," Blikstein says.

The new tools and methods of data analysis are making education research more efficient and precise. Jordan Matsudaira, a management and policy professor at Cornell University, has helped resurrect an old research tool and has employed it to look at the usefulness of summer school and the effect of funding from Title I, a federal program targeted at schools with a certain percentage of low-income students. The method, known as regression-discontinuity analysis, compares two groups of students on either side of a particular threshold. For example, in the study on summer school, Matsudaira compared students whose test scores were just above the level that made them eligible for summer school with those who were just below it to see if the extra schooling improved students' test scores. The design is used to mimic randomized controlled trials.

His conclusion: summer school could be a more cost-effective way of raising test scores than reducing class size.

In the Title I study, Matsudaira compared schools that fell just above the limit required to get the federal funds with those just below it. He found that the money did not make much of a

REVIEW published online in May in the journal *Proceedings of the National Academy of Sciences USA* found that science students enrolled in traditional lecture classes were more likely to fail than those enrolled in classes that used active learning techniques. Active learning includes group problem-solving tasks and regular feedback from the instructor.



SOURCE: "ACTIVE LEARNING INCREASES STUDENT PERFORMANCE IN SCIENCE, ENGINEERING, AND MATHEMATICS," BY SCOTT FREEMAN ET AL., IN *PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES USA*, VOL. 111, NO. 23; JUNE 10, 2014 difference in the academic achievement of the students most likely to be affected. But it also illustrated some of the limits of the research design. It is possible that schools with a much higher percentage of poor students might derive a greater benefit from the extra money. It is also possible that schools so close to the threshold would use the money for one-time expenditures rather than long-term investments because they cannot be certain that their population would remain the same and that they would continue to be eligible for the federal aid in the future.

Other researchers are mining data to track the progress of many students over time. Ryan Baker, an associate professor at Teachers College, Columbia University, and president of the International Educational Data Mining Society, recalls that when he was working on his Ph.D. in the early 2000s, he got up every morning at 6 A.M. to drive out to a school where he would spend the entire day standing on his feet taking notes on a clipboard. Fast-forward a decade, and Baker's work routine looks very different. He and his colleagues recently completed a seven-year longitudinal study, funded by the National Science Foundation, looking at log files of how thousands of middle school students used a Web-based math-tutoring program called ASSISTments. The researchers then tracked whether the students went to college and, if they did, how selective the college was and what they majored in to see whether they could make connections between students' use of the software and their later academic achievements.

"Big data allows us to look over long periods, and it allows us to look in very fine detail," Baker says. He and his colleagues were particularly interested in seeing what happened to students who were "gaming" the system—trying to get through a particular set of problems without following all the steps. "Whether you are intentionally misusing the educational software to get through that learning is a better predictor of whether you'll go to college than how much you show up to class," he says. It turns out that gaming the easier problems was not as harmful as gaming the harder problems. Students who gamed the easier problems could have simply been bored, whereas students who gamed the harder problems might not have understood the material. Baker thinks this kind of information could ultimately help teachers and guidance counselors figure out not only which students are at risk of academic problems but also why they are at risk and what can be done to help them.

BUILDING AN EVIDENCE BASE

THE NEW STUDIES are helping to build an evidence base that has long been missing in education. Grover Whitehurst, founding director of IES, recalls that when he started in 2002, just after No Child Left Behind took effect, the superintendent of a predominantly minority district asked him to suggest a math curriculum that had been proved effective for his students. "I said, 'There isn't any,'" Whitehurst says. "He couldn't believe that he was being required by law to base everything he did on scientifically based research, and there was none." That superintendent was far from alone, points out Whitehurst, who is now director of the Brown Center on Education Policy and a senior fellow at the Brookings Institution. "There was very little research that actually spoke to the needs of policy makers and educators. It was mostly research written by academics and schools of education to be read by academics and schools of education. That was about as far as it went."

Many researchers would disagree with that harsh assessment. Yet the criticism pushed the community to examine and explain its methods and mission. In the early years of IES, Whitehurst and others frequently compared education science with drug studies, indicating that people who study schools should test curricula or learning practices the way a pharmaceutical researcher might test a new drug. Strategies and curricula that passed that test would go into the What Works Clearinghouse.

Making educators part of the research process could get results into the classroom. Teachers often feel that the expertise they have gained is ignored and that they instead get a new curriculum every few years without much explanation.

John Easton, current director of IES and a former educational researcher at the University of Chicago, believes the clearinghouse is particularly useful as a way for the government to vet products that school districts might feel pressured to buy. "I think it's a really valuable source, a trusted source where you can go and find out if there is any evidence that this commercial product works," he says. The clearinghouse now houses more than 500 reports that summarize current findings on such topics as math instruction for young children, elementary school writing and helping students with the college application process. It has also reviewed hundreds of thousands of reports to aid in distinguishing the best-quality research from weaker work, including studies on such subjects as the effectiveness of charter schools and merit pay for teachers, which have informed the ongoing debate about these issues.

One of the most important contributions of the government's emphasis on rigorous science, Whitehurst says, has been a dramatic change in the definition of a high-quality teacher. In the past, quality was defined by credentials such as a specific degree or certification. Now, he asserts, "it's about effectiveness in the classroom, measured by observations and measured by the ability of a teacher to increase test scores." Whereas there is still a significant controversy over how to assess an individual teacher's effectiveness, Whitehurst believes that change in approach was driven by the research community, especially economists "who came to this topic because all of sudden there were resources—data resources and research support resources."

Many researchers have complained that the IES's emphasis on randomized controlled trials has disregarded other potentially useful methodologies. Case studies of school districts, for example, could describe learning practices in action the way business schools use case studies of companies. "The current picture is real-

SCIENTIFIC AMERICAN ONLINE Read more about Paulo Blikstein's FabLab@School at ScientificAmerican.com/aug2014/fab-lab

ly an ecosystem of methodologies, which makes sense because education is a complex phenomenon if ever there was one—complex in the scientific sense," says Anthony Kelly, a professor of education psychology at George Mason University. Easton says he still believes randomized controlled trials are an important part of that process but not necessarily as "the culminating event." He thinks trials might also be useful early in the process of developing an educational intervention to see whether something is working and worth more investigation.

FROM LAB TO CLASSROOM

GETTING THIS NEW SCIENCE into schools remains a challenge. "The thing with education research, as with many other fields, is that these are typically long trajectories of work," says Joan Ferrini-Mundy, assistant director of the Directorate for Education and Human Resources at the NSF. "It is very unlikely that any single study in any short period will have an impact." There is also a long-standing barrier between the lab and the classroom. In the past, many researchers felt it was not their job to find real-world applications for their work. And educators for the most part believed that the expertise they gained in the classroom generally trumped anything the researchers could tell them.

The What Works Clearinghouse was supposed to help bridge that gap, but in 2010 the General Accountability Office found that only 42 percent of school districts it surveyed had heard of it. The GAO survey also found that only about 34 percent of districts had accessed the clearinghouse Web site at least once and that even fewer used it frequently. In an updated report in December 2013, the GAO said dissemination remained problematic. The need is more urgent now, with the implementation of the Common Core state standards. Publishers are aggressively pushing curricula that claim to be aligned with the new standards, but district purchasing officers cannot just go to the clearinghouse and search for tested Common Core curricula. Instead they have to search for studies on the particular curricula they are considering—and not all of them are in the database.

Easton and others have acknowledged the need for a better pipeline to schools. As part of the solution, the clearinghouse has published 18 "practice guides" that lay out what is known about subjects such as teaching students who are learning English or teaching math to young children. Each is compiled by a panel that brings together researchers, teachers and school administrators. The practice guides may also direct future research, says psychology professor Sharon Carver, a member of the early math panel and director of Carnegie Mellon's Children's School. She urges her graduate students to read the guides that relate to their field and look for areas that need more exploration.

Each research question is an attempt to fit in another piece of a very large puzzle. "I don't think you can look at education from the point of view of whether it works or doesn't work, as if it's a lightbulb," says Joseph Merlino, president of the 21st Century Partnership for STEM Education, a nonprofit in suburban Philadelphia. "I don't think human knowledge is like that.... In a mechanical age, we are used to thinking of things mechanically. Does it work? Can you fix it? I don't think you can fix education any more than you can fix your tomato plant. You cultivate it. You nurture it."

Merlino's organization administered a five-year, IES-funded randomized controlled study of the effectiveness of applying four principles of cognitive science to middle school science instruction. A total of 180 schools in Pennsylvania and Arizona were randomly assigned modified or unmodified curricula. One part of the study was based on cognitive science research about how people learn from diagrams. Merlino says the researchers learned that some of the things that graphic artists might put into a diagram to make it jazzy—such as lots of colors—actually distract from learning. The researchers also found that students need instruction in reading diagrams. That is the kind of result that could be integrated into the design of a new textbook. Teachers could also take time to explain the meaning of different symbols in a diagram, such as arrows or cutaways.

Making educators an important part of the research process could also get results into the classroom. Teachers often feel that the expertise they have gained from their experience is ignored and that they instead get a new, supposedly evidence-based curriculum every few years without much explanation of why the new one is so much better than the old. And in the past, researchers have not generally felt that it was their role to explain their work to teachers. That is changing, says Nora Newcombe, a professor of psychology at Temple University and principal investigator of the Spatial Intelligence and Learning Center. "I think people are really waking up to the idea that if you take federal tax dollars, you are supposed to be sharing your knowledge."

The exchange of knowledge can go both ways. In the Pennsylvania and Arizona science curriculum study, teachers were involved in the initial design of the experiments. "They were more like master teachers," Newcombe says. "They taught, and they gave us feedback," she adds. Because the study took place in actual schools rather than a lab, the researchers trained the classroom teachers as the work proceeded.

Other researchers point to the model of Finland, where educational theories, research methodologies and practice are all important parts of teacher education, according to Pasi Sahlberg, who in 2011 wrote *Finnish Lessons,* an account of how the country rebuilt its education system and rose to the top of international math and literacy rankings. In some ways, the comparison to American schools is unfair because Finland is a more homogeneous country. But Newcombe thinks that U.S. teacher training should include the most recent developments in cognitive science. In many teacher education programs, students "are taught a psychology that is not just 10 but more like 40 years out-of-date," she says. That basic grounding could help teachers assess the importance of new research and find ways to incorporate it into their classrooms. "You can't really write a script for everything that happens in the classroom," Newcombe says. "If you have some principles in your mind for what you do in those on-the-fly moments, you can do a better job." SA

MORE TO EXPLORE

Visual Environment, Attention Allocation, and Learning in Young Children: When Too Much of a Good Thing May Be Bad. Anna V. Fisher et al. in *Psychological Science.* Published online May 21, 2014.

Active Learning Increases Student Performance in Science, Engineering and Mathematics. Scott Freeman et al. in *Proceedings of the National Academy of Sciences USA,* Vol. 111, No. 23, pages 8410–8415; June 10, 2014.

FROM OUR ARCHIVES

Learning in the Digital Age. Special Report on Education; August 2013.

scientificamerican.com/magazine/sa

To know whether life exists beyond Earth, we must come to terms with our own significance in the universe. Are we uniquely special or merely mediocre?

By Caleb Scharf

ASTRONOMY

COSMIC (IN)SIGNIFICANCE

WE ALL RESIDE ON A SMALL PLANET ORBITING A SINGLE, MIDDLE-AGED STAR that is one of some 200 billion stars in the great swirl of matter that makes up the Milky Way galaxy. Our galaxy is but one of an estimated several hundred billion such structures in the observable universe—a volume that now stretches in all directions from us for more than 270,000,000,000,000,000,000,000 (2.7×10^{23}) miles.

Adapted from The Copernicus Complex: Our Cosmic Significance in a Universe of Planets and Probabilities, *by Caleb Scharf, by arrangement with Scientific American/Farrar, Straus and Giroux, LLC (US) and Penguin Press (UK). Copyright © 2014 by Caleb Scharf.*

By any paltry human standard, this is an awful lot of stuff and an awfully large amount of room. Our species has sprung into existence within the barest instant of this universe's enormously long span of history, and it looks like there will be an even longer future that may or may not contain us. The quest to try to find our place, to discover our relevance, can seem like a monumental joke. We must be appallingly silly to imagine we can find any importance for ourselves at all.

Yet we are trying to do just that, despite our apparent mediocrity, which became evident when Renaissance scholar Nicolaus Copernicus decentralized Earth from the solar system around 500 years ago. His idea has been one of the greatest scientific guides for the past few hundred years and a critical signpost on our journey to discern the underlying structure of the cosmos and the nature of reality.

Illustration by Tim Bower

Caleb Scharf is director of the multidisciplinary Astrobiology Center at Columbia University and author of *Gravity's Engines: How Bubble-Blowing Black Holes Rule Galaxies, Stars, and Life in the Cosmos* (Scientific American/Farrar, Straus and Giroux, 2012).

In our efforts to assess our significance, we face a conundrum: Some discoveries and theories suggest life could easily be ordinary and common, and others suggest the opposite. How do we begin to pull together our knowledge of the cosmos—from bacteria to the big bang—to explain whether or not we are special? And as we learn more about our place in the universe, what does it all imply for our efforts to find out if there are other living things out there? How do we take the next steps?

WHAT WE KNOW

IN THE 1600S TRADESMAN and scientist Antony van Leeuwenhoek used his hand-built microscopes to become the first human to see bacteria, a journey that took him into the alien world of the microcosm. In that remarkable descent, sliding down the ladder of physical dimensions, into the thriving universe within us, was one of the first clues that the components of our bodies, our arrays of molecular structures, exist at one extreme end of a spectrum of biological scales. Until van Leeuwenhoek's moment of surprise, I doubt that humans had the opportunity to think about this fact in anything more than a superficial way.

There are organisms on Earth that are physically larger and more massive than we are—just look at whales and trees. Yet we are much closer to the upper limit of scale than we are to the microscopic end of life's spectrum. The smallest reproducing bacteria are a couple of hundred-*billionths* of a meter across; the smallest viruses are 10 times as small as that. The human body is roughly 10 million to 100 million times larger than the simplest life we know of.

Among warm-blooded terrestrial mammals we are also on the large side but not quite at the extreme top. At the opposite end of scale, the smallest of our kin are the pygmy shrews, diminutive scraps of fur and flesh barely two grams in weight. They exist at the edge of feasibility, their bodies endlessly leaking heat that they can barely compensate for by voracious eating. But most mammals are closer to this size than to our size: so much so that the global average body weight of the mammalian population is 40 grams, or less than 1.5 ounces. Our complex-celled, intelligent bodies are at the boundary of the upper extremes, with comparatively few mammalian types bigger than us.

It is an undeniable observation that we exist at this border, this interface between the complex diversity of the biologically small and the limited options of the biologically large. Consider, too, our planetary system. It is unusual in certain respects. Our sun is not one of the most numerous types of star (most of which are less massive), our orbits are at present more circular and rather more widely spaced apart than most exoplanetary systems, and we do not count a super-Earth among our planetary neighbors. Such a world, a few times more massive than Earth, is represented in at least 60 percent of all systems but not our solar system. If you were an architect of planetary systems, you would consider ours to be an outlier, a little bit off from the norm.

Some of these characteristics stem from the fact that our solar system has escaped wholesale dynamical rearrangement, compared with the majority of planetary systems. This does not mean that we are assured a quiet and peaceful future—state-of-the-art gravitational simulations indicate that a few hundred million years along, a more chaotic period could overtake our system. And another five billion years into the future the sun will inflate with the onset of a spasmodic old age and quite drastically revise the properties of its array of planets. All indications are that today we also live at an interface or border in time, a transition between a period of stellar and planetary youth and one of encroaching decrepitude. Our existence in this period of relative calm is, in retrospect, not so surprising. As with so many other aspects of our circumstances, we live in a temperate place, not too hot or cold, not too chemically caustic or chemically inert, neither too unsettled nor too unchanging.

It is also now apparent that this astrophysically calm neighborhood extends well beyond our local galaxy. In terms of the universe as a whole, we exist in a period that is many times more ancient than the fast tumult of the young, hot cosmos. Everywhere the production of stars is slowing down. Other suns, and their planets, are forming at an average rate that is barely 3 percent of that 11 billion to eight billion years ago. The stars are slowly beginning to go out across the universe. And in grand cosmological terms, only six billion or five billion years ago the universe was decelerating from the big bang. Now we are again in a period of gentle transition. Dark energy, stem-

IN BRIEF

Earth orbits one of the hundreds of billions of stars in our galaxy, which in turn is one of hundreds of billions in the observable universe. This apparent insignificance fits with the Copernican principle that our planet is not the center of the cosmos but simply a mediocre member of a mediocre solar system.

Meanwhile there are reasons to think Earth and its life are special, perhaps even singular. Some evidence comes from the details of our planetary circumstances, as well as from the observation that certain fundamental constants of nature appear to be fine-tuned for life's existence.

Scientists must reconcile these conflicting ideas to understand where we fit—and whether we are alone—in the cosmos.

SCIENTIFIC AMERICAN ONLINE See a video on the potential for extraterrestrial life at ScientificAmerican.com/aug2014/scharf

Our species has sprung into existence within the barest instant of this universe's enormously long history, and it looks like there will be an even longer future that may or may not contain us. The quest to find our place, to discover our relevance, can seem like a monumental joke.

ming from the vacuum itself, is accelerating the growth of space, helping to quash the development of larger cosmic structures. But this means that life is ultimately condemned to a distant future of bleak isolation within an increasingly indecipherable universe.

Put all these factors together, and it is clear that our view of our inner and outer cosmos is highly constrained. It is a view from a narrow perch. Indeed, our basic intuition for random events and our scientific development of statistical inference might have been different under other circumstances of order or disorder, space and time. And the very fact that we are far isolated from any other life in the cosmos—to the extent that we have not spotted or stumbled across it yet—profoundly impacts the conclusions we can draw.

DEDUCTIONS

MUCH OF THE EVIDENCE we have supports the basic Copernican view that we are mediocre. Yet at the same time, there are specifics about our environment that say otherwise. Some of these qualities have led to the so-called anthropic principle, the observation that certain fundamental constants of nature appear "fine-tuned" in a way that causes the underlying properties of the universe to be balanced near a boundary that enables Earth and its life to exist. A little too far to either side, and the nature of the cosmos would be radically different. Tweak the relative strength of gravity, and either no stars form, no heavy elements are forged—or huge stars form and are quickly gone, leaving nothing of any import in their wake, no descendants, no pathway to life. Similarly, alter the electromagnetic force, and the chemical bonds between atoms would be too weak or too strong to build the diversity of molecular structures that allows such incredible complexity in the cosmos.

What do we make of all the contradictions? I would argue that the facts are pushing us toward a new scientific idea about our place in the cosmos, a departure from both the Copernican and anthropic principles, and I think it is well along the road to becoming a principle in its own right. Perhaps we could call it a cosmo-chaotic principle, the place between order (from the original Greek *kosmos*) and chaos. Its essence is that life, and specifically life like that on Earth, will always inhabit the border or interface between zones defined by such characteristics as energy, location, scale, time, order and disorder. Factors such as the stability or chaos of planetary orbits, or the variations of climate and geophysics on a planet, are direct manifestations of these characteristics. Too far away from such borders, in either direction, and the balance for life tips toward a hostile state. Life like us requires the right mix of ingredients, of calm and chaos—the right yin and yang.

Proximity to these edges keeps change and variation within reach but not so close that they overwhelm a system constantly. There are obvious parallels to the concept of a Goldilocks zone, which proposes that a temperate cosmic environment for a planet around a star exists within a narrow range of parameters. But for the existence of life, the hospitable zone may be much more dynamic—it need not be fixed in space or time. Rather it is a constantly drifting, twisting, flexing, multiparameter quantity, like the paths traced by a dancer's limbs.

If it is a universal rule that life exists only under these circumstances, it raises some intriguing possibilities about our cosmic significance. Unlike strict Copernican ideas, which stress our mediocrity and therefore suggest an abundance of similar circumstances across the cosmos, the notion that life requires a varying and dynamic alignment of parameters narrows the options. The opportunities for life implied by this new view also differ from anthropic ideas, which at their most extreme predict as little as one sole occurrence of life across all space and time. Instead this new rule actually identifies the places where life should occur and the potential frequency with which it does. It specifies the fundamental characteristics necessary for life within a virtual space of many waltzing parameters—it maps out the fertile zones.

Such a rule about life does not necessarily make living things some special part of reality. Biology may be the most complicated physical phenomenon in this universe—or in any amenable universe. But that is possibly as special as it gets: a particularly intricate natural structure that arises under the right circumstances, between order and chaos. And this conceptualization of where life fits into the grand scheme of nature leads directly to a way to resolve the conundrum between the persuasive, but unresolved, arguments that life must be abundant and that it is exquisitely rare. SA

MORE TO EXPLORE

Just Six Numbers: The Deep Forces That Shape the Universe. Martin Rees. Basic Books, 2001.

Caleb Scharf's Life, Unbounded blog: http://blogs.ScientificAmerican.com/life-unbounded

FROM OUR ARCHIVES

The Fate of Life in the Universe. Lawrence M. Krauss and Glenn D. Starkman; November 1999.

The Benevolence of Black Holes. Caleb Scharf; August 2012.

scientificamerican.com/magazine/sa

MORE TO EXPLORE For more recommendations and an interview with author Michael Harris, go to ScientificAmerican.com/aug2014/recommended

Our Devices, Ourselves

Four books this month investigate how our increasing dependence on mobile devices, social media and the online world is changing the way we think and feel.

The End of Absence: Reclaiming What We've Lost in a World of Constant Connection

by Michael Harris. Current, 2014 ($26.95)

The daily barrage of texts, tweets and e-mails brings us information, connection, entertainment. But it also takes something away, argues journalist Harris. "The loss of lack, the end of absence"—a deficit of silence and solitude—is the price we pay for our plugged-in lives, he writes. His book invites readers, especially those old enough to remember life before the Web, to hold on to downtime, daydreams and stillness. "For those of us who have lived both with and without the vast, crowded connectivity the Internet provides," Harris says, "these are the few days when we can still notice the difference between Before and After."

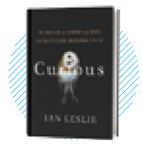
The Organized Mind: Thinking Straight in the Age of Information Overload

by Daniel J. Levitin. Dutton, 2014 ($27.95)

The influx of information streaming from our technology these days can make remembering what is important tougher than ever. Neuroscientist Levitin explains how our brains organize all the input and offers tips on decluttering one's thinking at work, in social interactions and with one's kids. "This is the story of how humans have coped with information and organization from the beginning of civilization," he says. It is also the story of how technology is changing many of our time-honored traditions for keeping an orderly mind.

Curious: The Desire to Know and Why Your Future Depends on It

by Ian Leslie. Basic Books, 2014 ($26.99)



The world is suffering a dearth in curiosity, as well as a lack of the innovation and progress it spawns, contends journalist Leslie. He places much of the blame on the Internet. "Digital technologies are severing the link between effort and mental exploration," he says. "By making it easier for us to find answers, the Web threatens habits of deeper inquiry." Instant access to Wikipedia and Google provides a quick burst of satisfaction that actually quells our inner hunger for understanding rather than seeding it. But this trend is not inevitable or irreversible, Leslie believes: "We can arrange our lives to stoke our curiosity or quash it."

Dataclysm: Who We Are (When We Think No One's Looking)

by Christian Rudder. Crown, 2014 ($28)

The unprecedented wave of personal data being collected by such sites as Facebook, Twitter and OkCupid raises privacy concerns and commercial hopes—as well as a unique opportunity for social science. OkCupid co-founder Rudder drills down into that last category via charts, graphs and intriguing analyses of human behavior gleaned from the wealth of social data now available. He finds, for example, that women with polarizing appearances (appealing to some, off-putting to others) are more likely to get dates than those who are conventionally attractive. Because this information is based not on surveys or artificial experiments but on human actions, "our privileged data exposes attitudes that most people would never cop to in public," Rudder writes.

Illustration by Neil Webb

Michael Shermer is publisher of *Skeptic* magazine (www.skeptic.com). His next book is *The Moral Arc*. Follow him on Twitter @michaelshermer

ClimeApocalypse!

Or just another line item in the budget?

In the year 2393 a historian in the Second People's Republic of China penned a book about how scientists, economists and politicians living in the 21st century failed to act on the solid science they had that gave clear warnings of the climate catastrophe ahead. As a result, the world experienced the Great Collapse of 2093, bringing an end to Western civilization.

So speculate historians of science Naomi Oreskes of Harvard University and Erik Conway of the California Institute of Technology in their book *The Collapse of Western Civilization: A View from the Future* (Columbia University Press, 2014), a short scientific-historical fantasy. During the second half of the 20th century—the "Period of the Penumbra"—a shadow of anti-intellectualism "fell over the once-Enlightened techno-scientific nations of the Western world … preventing them from acting on the scientific knowledge available at the time and condemning their successors to the inundation and desertification of the late twenty-first and twenty-second centuries."

Why the failure to act? The authors' future historian posits several causes: blind optimism; religion; reductionism that prevented scientists from understanding holistic systems; disciplinary narrowness that restricted cross-field communication between scientists; adherence to avoiding type I errors (believing a hypothesis is real when it isn't) over type II errors (not believing a hypothesis is real when it is); and insistence on a 95 percent confidence limit for statistical significance that caused scientists to dismiss as unproved climate effects caused by warmer weather, such as tornadoes and hurricanes. Between 1751 and 2012 more than 365 billion metric tons of carbon was released into the atmosphere, causing temperatures to increase, the historian notes. Another century of warming devastated the populations of Australia and Africa, and those of Europe, Asia and North America had to move inland from flooded coastal regions.

This science-historical fantasy is thought-provoking, but is it prescient? Global warming is, of course, real and caused by human activity. But predicting how much warmer it is going to get and what the consequences will be is extremely difficult because estimates include error bars that grow wider the further out the models run. The precautionary principle states that we should act, just in case. But act on what? Climate change is not our only problem, and we do not have unlimited resources. Which problem should we tackle and how much should we spend?

In the second edition (2014) of his book *How to Spend $75 Billion to Make the World a Better Place,* Bjørn Lomborg reports the findings of a study sponsored by his Copenhagen Consensus Center 2012 project in which more than 50 economists evaluated 39 proposals on how best to solve such problems as armed conflicts, natural disasters, hunger, disease, education and climate change. Climate change barely rated a mention in the top 10, which included, in order, malnutrition interventions, malaria treatment, childhood immunization, deworming of schoolchildren, tuberculosis treatment, research and development to increase crop yields, early-warning systems for natural disasters, hepatitis B immunization, and low-cost drugs for acute heart attack. Number 12 was R&D for geoengineering solutions to climate change, and number 17 was R&D for green energy technologies. The rest of the top 30 were related to disease, water and sanitation, biodiversity, hunger, education, population growth and natural disasters.

The ranking is based on a cost-benefit analysis. For example, an investment of $300 million "would prevent the deaths of 300,000 children, if it were used to strengthen the Global Fund's malaria-financing mechanism." Another $300 million would deworm 300 million children, and $122 million would lead to total hepatitis B vaccine coverage and thereby prevent another 150,000 annual deaths. Low-cost drugs to treat acute heart disease would cost just $200 million and save 300,000 people.

This doesn't mean we shouldn't do more about climate change. But what? Both books posit technological solutions: Lomborg's Copenhagen experts recommend spending $1 billion for research on planet-cooling geoengineering technologies; Oreskes and Conway have humanity saved by the creation in 2090 of a lichenized fungus that consumes atmospheric carbon dioxide. Whatever we do about climate, we should recognize that the world has many problems. If you are malnourished and diseased, what the climate will be like at the end of the century is not a high priority. Given limited resources, we should not let ourselves be swept away by the apocalyptic fear generated by any one threat. SA

SCIENTIFIC AMERICAN ONLINE
Comment on this article at ScientificAmerican.com/aug2014

Illustration by Simone Rein

The ongoing search for fundamental farces

Steve Mirsky has been writing the Anti Gravity column since a typical tectonic plate was about 34 inches from its current location. He also hosts the *Scientific American* podcast Science Talk.

Things That Go Bump

Strategies for collision avoidance, acceptance and observance

As a rule of thumb, animals avoid smacking into things. But rules of thumb, like the actual thumbs of unskilled carpenters, are made to be broken. And so researchers at Sweden's Lund University were recently surprised to find that the visual systems of some animals actually make collisions within their environment more, rather than less, likely.

The Lund scientists have a long-standing interest in how insects see the world, nay, the universe. Some members of the team were in on last year's Ig Nobel Prize–winning paper "Dung Beetles Use the Milky Way for Navigation," which appeared in the journal *Current Biology*. The beetles look up, see the stream of stars and think, "That's the way I roll."

The new Lundian research effort observed how bumblebees, representing flying critters, move through the dynamic fluid of air versus how zebra fish, in this corner for all the swimmers, find their way through the dynamic fluid of fluid.

As expected, the bees adjusted their flight to avoid contact with stuff. The fish, on the other fin, "move closer to the wall that provides the strongest visual feedback." That quote is from the write-up of the research in *Biology Letters,* "Control of Self-Motion in Dynamic Fluids: Fish Do It Differently from Bees." It's a good title, but it kind of gives away the ending, like if the movie had been called *The Hunger Games: Don't Worry, Kat Wins.*

Of course, bees zip around in a sun-dappled world of clear skies and vibrantly colored flowers, if Nasonex commercials have taught me anything. But fish often slog through a turbid seascape of limited visibility. So if they see seashells by the seashore, it seems like they'll swim toward them, accepting the risk of collision in return for having landmarks for just where the heck they are.

In summary then, bees fly around like Charles Lindbergh, looking down from up high while keeping clear of any obstacles in their paths. Meanwhile fish have evolutionarily adopted the strategy of those 15th-century European explorers who limited their voyages to slowly moving southward along Africa's western coast. Their motto: "I'd rather bump into a continent than be lost at sea."

Speaking of bumping into things, Utah State University scientists and government researchers have created a smartphone app for reporting incidents of that special breed of unhappy driving experience where one party ends up pumping out adrenaline and the other party shuffles off its mortal coil. The app is called the WVC Reporter, where "WVC" stands for "wildlife-vehicle collisions."

Wildlife agency folks and scientists currently try to tally the deaths by traveling around and writing down things they observe. A few states also have Web sites for reporting roadkill. But a smartphone-based and crowdsourced system of noting these frequent events could increase, by leaps and bounds (and I mean that), the data available to track the carnage.

And a bloody mess it is. The Utah squad, in a paper describing its app in the journal *PLOS ONE,* says that there are up to two million impromptu encounters between large animals and people behind wheels every year in the U.S. That figure, limited to big beasties, would not include the time I was a passenger in a Volkswagen Rabbit that hit an actual flesh-and-blood rabbit.

The Utah app inventors also cite a million road-killed vertebrates every 24 hours in the U.S., a daily vehicular-begotten, greasy-grimy, gopher-gutted *Guernica*. And some 200 humans wind up dead annually: Mack Truck versus mule deer is one thing, Mini Cooper versus moose quite another. So people have an enlightened self-interest in trying to reduce these highway lowlights.

If loads of us can use smartphones to play Angry Birds, maybe a few hundred thousand citizens can click on their mobile devices (not while driving) to efficiently help researchers turn dead possums into data points. Then we will know better where to install fencing and greenways that would keep America's car grilles fur-free. SA

SCIENTIFIC AMERICAN ONLINE
Comment on this article at ScientificAmerican.com/aug2014

Illustration by Matt Collins

SCIENTIFIC AMERICAN™
NYU
POLYTECHNIC SCHOOL OF ENGINEERING

PROFESSIONAL LEARNING

Learn from the Best

The Latest in Virtual Learning from the Leading Names in Science and Education

Grow your potential virtually — with interactive science courses from *Scientific American* and NYU Polytechnic School of Engineering. Our continuing education courses will provide you with the knowledge base to move ahead in your career, explore new areas and indulge your creativity.

Experience online convenience with a classroom feel. Our 1-week courses include a daily, pre-recorded, 30-minute interactive lecture partnered with a daily, live, 30-minute Q&A session.

Visit our website to learn more and to register:

www.scientificamerican.com/professional-learning

2014 courses include:

Quantum Mechanics and Information
August 4–8, 2014*

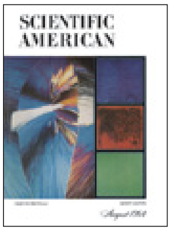
Cosmic Frontiers I & II
(I) August 18–22, 2014
(II) September 22–26, 2014

Feeding Our Planet
September 15–19, 2014

Wind Engineering
October 6–10, 2014

*Registration closes July 30th.

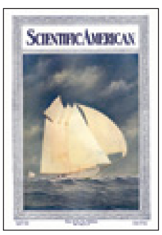
MORE TO EXPLORE Find original articles and images in the *Scientific American* archives at ScientificAmerican.com/magazine/sa



August 1964

Liquid Crystals

"Although their existence has been known for more than 70 years, substances that exhibit the liquid-crystal phase have until recently been regarded more as laboratory curiosities than as potentially useful or theoretically important objects of study. In the past few years, however, several investigators in this country and abroad have undertaken to reexamine the liquid-crystal phase. The first results of these new studies have helped to clarify the unusual molecular architecture of liquid crystals. They also point to a number of possible applications that arise from the remarkable ability of liquid-crystal substances to register minute fluctuations in temperature, mechanical stress, electromagnetic radiation and chemical environment by changing their color."



August 1914

The Great War

"Not since wars began has so great a military people, with such a sublime confidence in its invincible prowess, played for so great a stake as that for which the German hosts are now battling on sea and land. Should the Teuton win, he will hold all Europe in his 'mailed fist,' and the flag of his ships of war and commerce will float undisputed upon the Seven Seas, with nothing to stand between him and worldwide dominance but the great English-speaking republic of the New World! Had Germany shown a less ruthless spirit in flinging herself against the rest of Europe in a defiance so bold as to appear almost contemptuous, she might hope, in the event of disaster, for reasonable terms in the great final accounting. As it is, Europe, if victorious, will take a heavy toll."

Images and articles on World War I from our archives are at ScientificAmerican.com/wwi

HIDING BALDNESS: In Hungary, planting hair with gold-wire roots, 1914

Fix for Hair Loss

"A hair planting method employed by Dr. Szekely in Buda-Pesth is claimed to be a practical one. A gold wire 1/500 inch in diameter is bent to form a loop, barely visible to the naked eye, which is threaded with a woman's hair of the desired color and from 8 to 12 inches long. The wire is introduced into a short, fine Pravaz hypodermic needle and then bent and cut, forming a tiny hook. The needle is inserted normally, twisted and carefully withdrawn. The doubled hair is anchored by the hook in the subcutaneous tissue. As many as 50,000 hairs may be required for an entirely bald head [*see illustration*]. Even in this case little more than 15 grains of gold is consumed."

Superconductivity

"In studying the resistances of metals at temperatures that one may obtain with liquid helium, I foresaw that the resistance of mercury would still be easy to measure at 4.25 degrees Kelvin, but would diminish so as to become negligible at 2 deg. Kelvin (–271 deg. Centigrade). Experiments have verified this prediction so far as low temperatures are concerned, but they have also brought to light the fact that the disappearance of the resistance is sudden. The mercury at the temperature of the fall, here termed critical temperature (4.19 deg. Kelvin), passes in a disconnected way into a new state that is characterized by an extreme mobility of electricity. It may be well to term this condition, in which it is possible to maintain currents without appreciable electromotive force, the state of superconductivity.—H. Kammerlingh Onnes"

August 1864

California Ants

"That enemy of the hoarded sweets of the California housekeeper, the ant, is beyond counting in his annoyances this year. In the warmer districts of the State nothing eatable can be stored without attracting myriads of them, and the destruction they cause is really an important item. They have never within memory of the oldest settlers been so numerous in the lower levels of the Sacramento and San Joaquin as in 1864, and in the mines, residents inform us they invade in armies every pantry, kitchen and closet. The miners say they are laying up an early stock of comestibles to pass a long and heavy winter!"

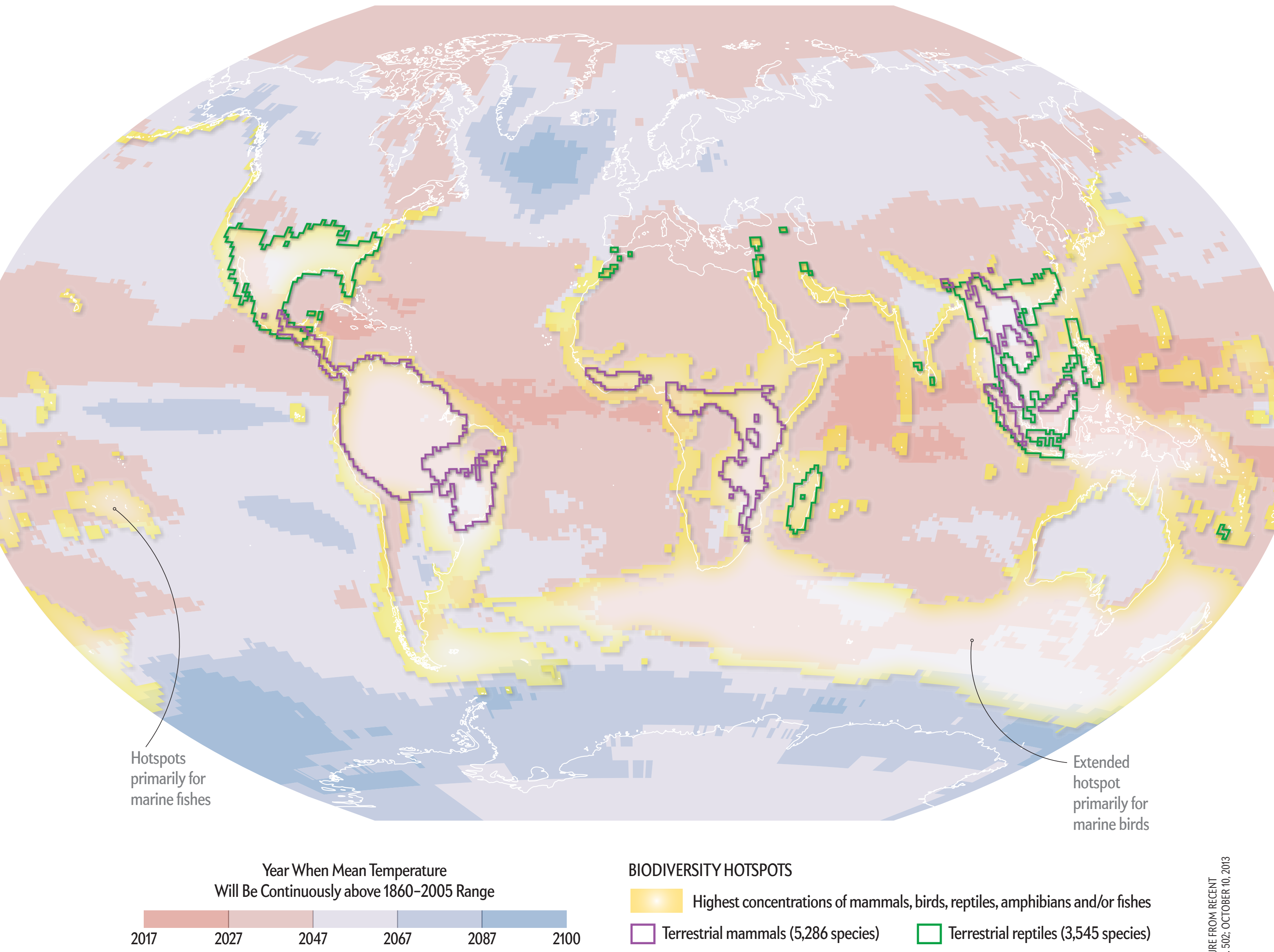
SCIENTIFIC AMERICAN, VOL. CXI, NO. 5; AUGUST 1, 1914

SCIENTIFIC AMERICAN ONLINE For the 100th anniversary of the Panama Canal, see a slide show at ScientificAmerican.com/aug2014/panama

SCIENTIFIC AMERICAN
How Reality Gets Created
Origins of Life's Complexity
Why Exercise Works Wonders
SCIENTIFIC AMERICAN
Special Report Learning in the Digital Age
SCIENTIFIC AMERICAN
SCIENTIFIC AMERICAN

Rising Temperatures Hit Species Hotspots

Animals across the tropics will bear the brunt of climate change



Within a few decades even the coldest years will be warm by historical standards. After 2047, the mean air temperature worldwide will exceed even the highest annual temperature from 1860 to 2005 if countries continue to emit carbon dioxide at the rates they do now. That "new abnormal" will begin even sooner than 2047 in certain locations, with the earliest occurrences (*dark red*) being across the tropics. That is precisely where species are least able to adapt to even small variations "because they are so used to a constant climate," says Camilo Mora of the University of Hawaii at Manoa, who led the study. Many biodiversity hotspots (*yellow*)—the places richest in species—lie in the tropics, so temperature rise could threaten a large number of land and ocean animals as soon as the late 2020s. —*Mark Fischetti*

SCIENTIFIC AMERICAN ONLINE
Specific hotspots for birds, fishes and other taxa can be seen at ScientificAmerican.com/aug2014/graphic-science

SOURCE: "THE PROJECTED TIMING OF CLIMATE DEPARTURE FROM RECENT VARIABILITY," BY CAMILO MORA ET AL., IN *NATURE*, VOL. 502; OCTOBER 10, 2013

Map by XNR Productions