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SCIENCE NEWS MAGAZINE
SOCIETY FOR SCIENCE & THE PUBLIC
JANUARY 24, 2015

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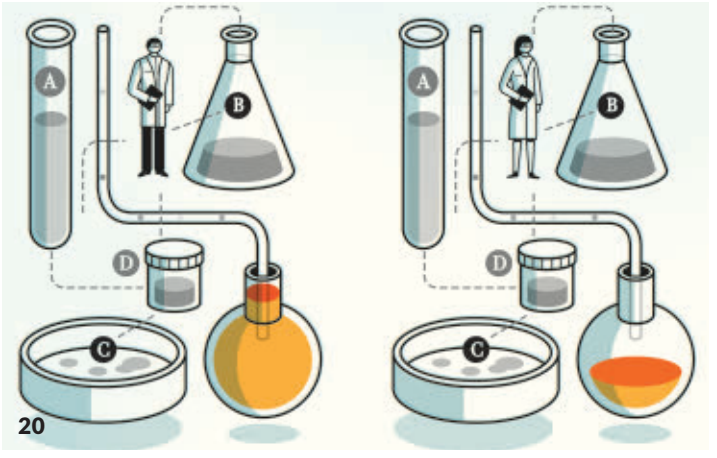

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COVER North America's basement rocks, far below layers of shale and sandstone, may be vulnerable to added pressure. *Nicolle Rager Fuller*

CLOCKWISE FROM TOP LEFT: HARRY CAMPBELL; SANTIAGO DAVID-RIVERA; A. MIKKELSEN/NATIONAL MUSEUM OF DENMARK

Science's self-criticism makes the enterprise stronger

Ever since John Ioannidis published his influential 2005 essay about the statistical problems plaguing science, there has been deepening concern about the enterprise. Are most scientific findings wrong? Have quality control and informed skepticism given way to publish-or-perish and headline grabbing? If science is self-correcting, why isn't it working?

In response to such concerns, many scientists (and scientific institutions) have become more self-reflective about how science works and how it might be improved, as Tina Hesman Saey reports on Page 20. In the first of a two-part series, Saey describes efforts to look specifically at one part of science's self-correction system: the ability to reproduce experimental findings. That's at the core of the scientific process. But it often doesn't work. Saey examines the reasons it sometimes fails and discusses possible solutions (such as hiring a company to repeat your findings for you, or requiring more detailed descriptions of methods). She also describes an emerging argument about what scientific reproducibility really means.

Some scientists believe that rather than actually replicating an experiment, step by step, it's more important to use a different experiment or approach to study the same question. From that perspective, current efforts to duplicate a study exactly may have less value than simply expanding research on any given issue. Because so many variables influence life and psychological sciences, this way of thinking about the problem may be especially important in these fields, Saey says.

Raising these issues poses another problem: Criticizing the scientific process can be seen as giving an opening to antiscience factions looking for reasons to plant doubt in the public mind. Scientific infighting looks bad from the outside. But self-criticism and self-skepticism have always been part of good science. Discussing the valid concerns without fueling the "all science is wrong" attitude is difficult. I think Saey does an admirable job of explaining the scope of the problem, and exploring responses to it. And she offers enough perspective to show the importance of acknowledging science's problems without exaggerating them. In the end, a dose of self-reflection, instead of shaking science's core, can help make it more robust. — *Eva Emerson, Editor in Chief*

SANDY SCHAFFER

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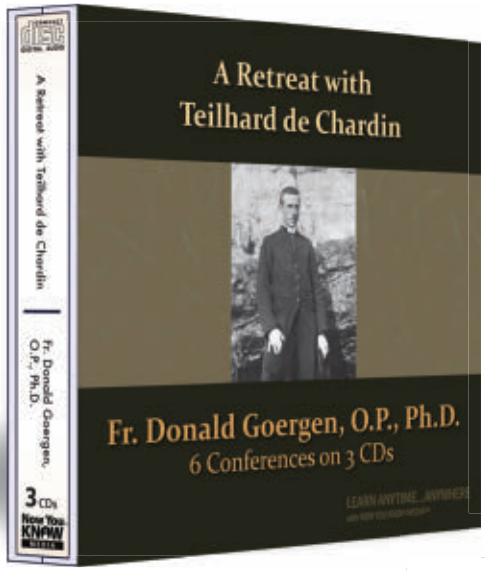

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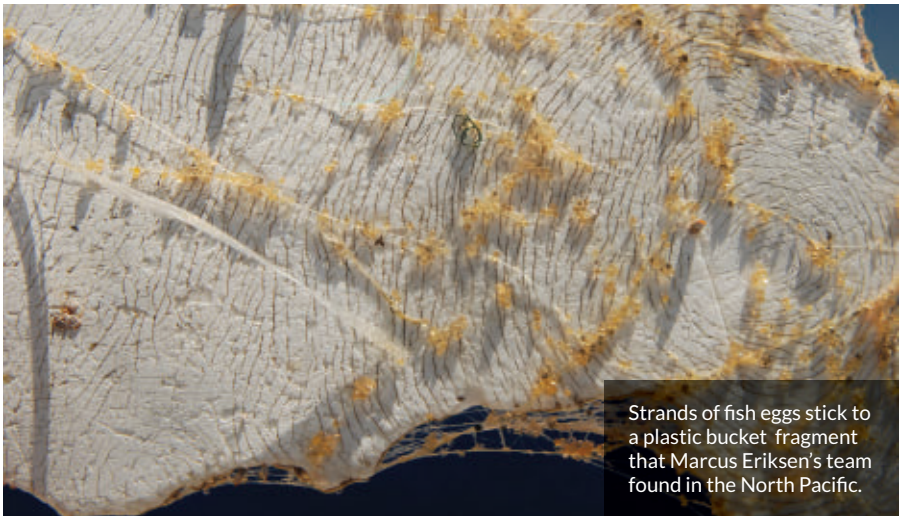
Excerpt from the January 23, 1965, issue of *Science News Letter*

50 YEARS AGO

Talking baby talk makes child learn two languages

Never use baby talk to young children, a speech expert warned parents in London. Otherwise, the children will have two languages to learn instead of one. "If mothers could only realize what harm they do they would never talk down to a child," said Mrs. Barbara Hicks, a fellow of speech and drama at the College of Music, London. "It's just as easy to say 'train' as to say 'puff-puff.'"

UPDATE: Hicks' advice was probably well-intentioned, but it's wrong, says psychologist and language researcher Erik Thiessen of Carnegie Mellon University. Little work has focused on the effects of nonsense words. Still, what has been done suggests that baby talk makes words easier for babies to pronounce and teaches general language concepts. Many studies indicate that the high-pitched, exaggerated vowels of "parentese" help babies learn to form words. As for a second language being harmful, research suggests that babies from bilingual families get a learning boost over children who hear only one language at home (*SN Online: 8/8/14*).



Strands of fish eggs stick to a plastic bucket fragment that Marcus Eriksen's team found in the North Pacific.

THE SCIENCE LIFE

The trash man

Marcus Eriksen has always had a thing for trash. As a teenager in New Orleans, he literally surrounded himself with it. He liked to dumpster-dive long before it became cool, spending hours at the local dump and watching a massive mechanical claw feed refuse to an incinerator.

But when Eriksen first considered dedicating his professional life to understanding global garbage and where it goes, he found few published studies.

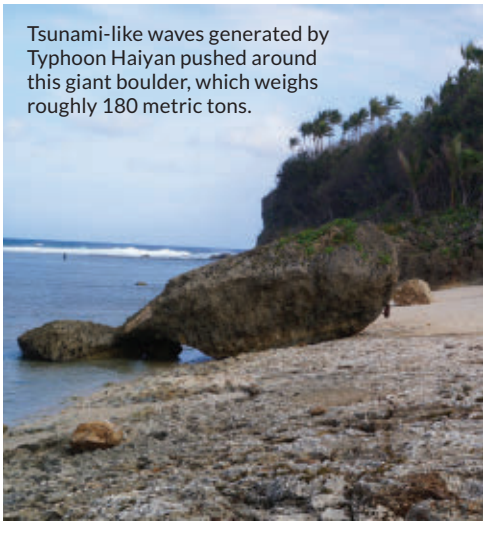
"I could count the research papers on ocean trash on two hands," Eriksen says. So in 2009, several years after finishing his Ph.D. in science education at the

THE -EST

Largest rock moved by a storm

SAN FRANCISCO — When Typhoon Haiyan made landfall in the Philippines in November 2013, its waves shoved a boulder weighing more than 25 adult African elephants. The boulder is the most massive known rock shifted by a storm, geoscientist Max Engel of the University of Cologne in Germany reported December 16 at the American Geophysical Union's fall meeting.

Engel and colleagues initially thought there was a language barrier when a local fisherman told them that the 9-meter-wide, 180-metric-ton rock moved during the storm. Comparing satellite photos taken before and after the storm, the researchers found that the boulder traveled about 45 meters along a beach.



Tsunami-like waves generated by Typhoon Haiyan pushed around this giant boulder, which weighs roughly 180 metric tons.

Based on videos recorded during the storm, the researchers think the typhoon created protracted, tsunami-like waves that pushed the hefty rock. The observations suggest that other boulder movements that scientists had associated with tsunamis might actually have been caused by superstorms, Engel said. *— Thomas Sumner*

FROM TOP: STIV WILSON; M. ENGEL

See more photos of floating plastic at **bit.ly/SN_plastic**

University of Southern California in Los Angeles, he and his wife, Anna Cummins, founded 5 Gyres, an institute devoted to studying plastic pollution in the sea.

Since then, Eriksen and his collaborators have sailed more than 35,000 miles, counting trash. On December 10 in *PLOS ONE*, the team published a new estimate of the ocean's floating plastic load: 5.25 trillion pieces spanning a range of sizes and together weighing almost 270,000 metric tons.

The researchers worked particularly hard to quantify the tiniest flecks of plastic, those smaller than a grain of rice. These specks constitute about 92 percent of the floating plastic particles, the team found, and a significant fraction of the total plastic mass that buoys to the ocean's surface.

Although that's a lot of trash, it's actually less than Eriksen and other scientists expected (*SN: 8/9/14, p. 9*). The smallest fragments either sink or get eaten, he says, and that's a problem.

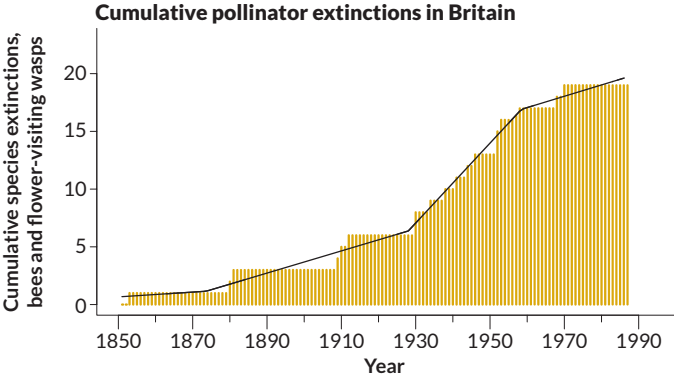
Marcus Eriksen (left) studies floating trash around the world. His team estimates that 5.25 trillion pieces of plastic are currently adrift in the ocean, where durable goods sometimes wash ashore intact, as seen on this beach in the Azores islands.

Microplastics at sea "are hazardous waste," Eriksen says. They absorb pollutants and cycle through the marine food web. "Paper is biodegradable, metals will oxidize, glass is benign — it's plastic that is a very different animal," he says.

Eriksen isn't content with simply tallying the damages. He also tries to raise awareness of the problem, sometimes in unconventional ways. In 2008, he sailed from Los Angeles to Hawaii on a raft made from the salvaged body of a Cessna airplane, buoyed by 15,000 plastic water bottles.

"It was more of an adventure than I bargained for," says Eriksen, who is 47. The 88-day voyage took nearly three times as long as expected, and he almost ran out of food. Then one day, Eriksen caught a fish — a foot-long rainbow runner.

The fish fed his hunger and his drive: When Eriksen cut open the rainbow runner, he found its belly full of plastic. — *Julia Rosen*



SCIENCE STATS

Bee losses followed World Wars

From 1851 to 1986, withering wildflower populations and booming agriculture may have joined forces to knock down pollinator populations in Britain. Researchers found that 19 species of bees and flower-visiting wasps died out in that time span, leaving about 500 pollinator species standing. Scientists also suspect that at least four other species have since gone extinct. The late 1920s through the late 1950s was an especially deadly period for Britain's pollinators, thanks to agricultural innovations like synthetic fertilizers and land use changes that trailed the two world wars. The findings appear in the Dec. 12 *Science*.

SOURCE: J. OLLERTON *ET AL*/*SCIENCE* 2014

HOW BIZARRE

Foul smells during sleep may help smokers quit

Call it the sweet stench of success. Smelling the aromas of rotting eggs and fish while sleeping might help smokers cut back, a study suggests.

Researchers pumped the stenches of rotten fish and eggs over smokers, along with the scent of cigarettes. People who inhaled the odors during one night while sleeping lightly reported smoking 34.4 percent fewer cigarettes in the following week than they had the week before. Those who received the smells during rapid eye movement sleep smoked 11.9 percent fewer cigarettes. Wakeful smokers who smelled the stinks along with cigarette smoke did not cut back.

The experiment, appearing in the Nov. 12 *Journal of Neuroscience*, fits with others finding that what people learn while asleep can influence their behavior for days (*SN: 12/29/12, p. 28*). — *Kate Baggaley*

GENES & CELLS

Hydrogen sulfide may lengthen life

Caloric restriction's benefits linked to amount of smelly gas

BY TINA HESMAN SAEY

Tapping into an ancient cellular energy source may help stave off the rigors of surgery and the ravages of age.

Hydrogen sulfide, a foul-smelling poisonous gas that microbes have been munching for eons, may be responsible for the health benefits and life-extending effects of reduced-calorie diets, scientists propose in the Jan. 15 *Cell*. Caloric restriction lengthens the life span of a wide variety of organisms, but scientists still don't know exactly how it works.

The new work, by James Mitchell of the Harvard School of Public Health and colleagues, suggests that cutting calories prompts cells to produce hydrogen sulfide. Animal cells can use the gas as a fuel, which makes tissues more resilient and prolongs the lives of lab organisms.

The researchers also found a more targeted way to trigger cells to make the smelly gas: cutting protein rather than overall calories from the diet. It may be that caloric restriction, at least in mice, actually works through the reduction in protein, specifically the sulfur-containing amino acids found in many proteins, say Mitchell and his colleagues.

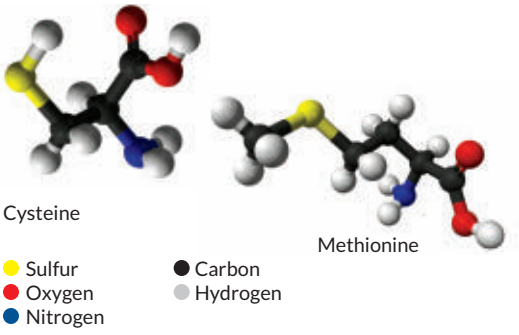
The finding provides a unifying mechanism that may help researchers make sense of previous caloric restriction studies, says Siegfried Hekimi, a geneticist at McGill University in Montreal. "It's the sort of paper you read and you're jealous you didn't do that work."

While investigating the role of antioxidants in caloric restriction, Mitchell's group stumbled upon hints that hydrogen sulfide is involved. Experiments involving mice and other organisms indicated that caloric restriction may work via increased hydrogen sulfide production, although the researchers don't fully understand what the gas does to protect cells.

The new study compared the abilities of mice on different diets to stave off liver damage following a surgery that temporarily cut off blood flow to the organ.

Reducing protein in the animals' diets increased hydrogen sulfide production in their livers. The gas seemed to stave off liver damage from surgery. Livers without that protection atrophy and produce distress signals that researchers can measure in the mice's blood. To Mitchell, that suggests that fasting before surgery might help people recover better, but he notes he has no data to support that idea yet.

In another experiment, the researchers fed mice a protein-deficient diet but replaced the lost protein calories with carbohydrates. No-protein mice staved off liver damage just as well as calorie-restricted mice did. That finding supports research from other groups indicating that cutting protein, not calories, produces the life-extending benefit of eating less (*SN: 4/5/14, p. 6*).



Cysteine and methionine are amino acids that contain sulfur. Cutting back on them causes cells to produce extra hydrogen sulfide.

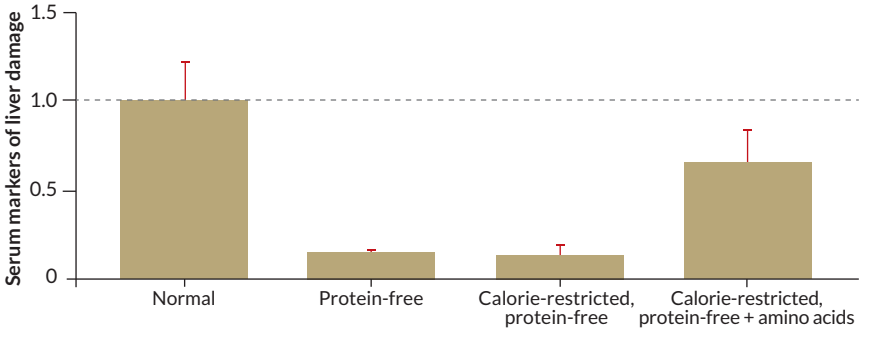
Next, Mitchell's group took another step toward explaining why reducing proteins is beneficial. Adding two sulfur-containing amino acids, methionine and cysteine, to the mice's protein-poor diets substantially reduced the liver protection. That result suggests that it is specifically the elimination of the two sulfurous amino acids that boosts cells' hydrogen sulfide production.

Cutting calories from the diets of mice, fruit flies, nematode worms and yeast led all of the organisms to produce more hydrogen sulfide, Mitchell and colleagues found. Worms that made more hydrogen sulfide lived longer, on average, than those making the normal amount of the gas. Caloric restriction can nearly double a nematode's life span, but when researchers blocked the worms from making hydrogen sulfide, their life span extension wasn't nearly as dramatic. Those results indicate that hydrogen sulfide is partly responsible for fighting aging in calorie-restricted organisms.

As for the oxidants' and antioxidants' role in caloric restriction: They aren't involved, the new work shows. Two opposing views had posited that caloric restriction either reduced the amount of oxygen radicals, which can damage cellular components, or actually increased their levels slightly. Evidence for the counterintuitive idea that oxygen radicals are beneficial came from experiments in which researchers gave animals an antioxidant called N-acetyl cysteine. The compound blocked caloric restriction's healthful effects. But the new study

Diet and damage Surgery causing liver damage in mice (left bar) causes less damage for mice on a protein-free diet (middle bars). But supplementing low-calorie, no-protein diets with the sulfur-containing amino acids methionine and cysteine erases much of that benefit (right bar).

SOURCE: C. HINE *ET AL*/*CELL* 2015



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shows that the oxidant erased caloric restriction's benefits not because it's an antioxidant, but because it has a sulfur-containing amino acid, Hekimi says.

The study "removes any question about [oxygen radicals] and antioxidants being involved in dietary restriction," Hekimi says.

Hydrogen sulfide's role in caloric restriction is "something we've never thought about," says Arlan Richardson, a molecular biologist at the University of Oklahoma Health Science Center in Oklahoma City. Raising hydrogen sulfide production is one of caloric restriction's effects that deserves more study, he says.

Richardson thinks hydrogen sulfide may alert cells and tissues to change their metabolism when fewer calories are available. But he's skeptical that the gas could be given to patients before surgery without poisoning them. "That window between benefit and toxicity might be pretty tight," he says. "It's a stinky gas, too. It smells like rotten eggs."

Mitchell has heard other comparisons, such as farts and brimstone, but to cells, hydrogen sulfide may smell like lunch.

When an organ's blood supply is cut off, such as during a heart attack, stroke or surgery, the tissue loses oxygen and its ability to produce energy. "We think hydrogen sulfide made by the cell can serve as a surrogate energy source," Mitchell says. "It's not very efficient, just enough to get by." But that meager sustenance may help sustain tissues during temporary oxygen loss, and perhaps to better rebound afterward.

Some microbes eat hydrogen sulfide, but animal cells were not previously known to use the gas as fuel. Human cells contain SQR, a protein thought to detoxify sulfur, but Mitchell's data indicate that it may allow cells to switch to hydrogen sulfide for energy production when oxygen isn't around. "It could be that these are really ancient methods for energy use that predate oxygen," he speculates. When oxygen became abundant, organisms might have developed ways to use it for more efficient energy production, but never entirely let go of hydrogen sulfide. ■

ATOM & COSMOS

Europa's geysers play hard-to-see

Further observations of Jovian moon fail to detect venting

BY ANDREW GRANT

SAN FRANCISCO — If Europa is venting its watery interior into space, it's doing so stealthily. Follow-up observations of Jupiter's icy moon failed to confirm the existence of powerful geysers observed by the Hubble Space Telescope in 2012, researchers reported December 19 at a meeting of the American Geophysical Union. The fruitless search, when combined with other recent results, suggests that Europa's plumes erupt weakly or sporadically, if at all.

The stakes are high for observing plumes on Europa. The moon's surface ice shell conceals a vast ocean that represents one of the potentially most habitable extraterrestrial environments in the solar system. Geysers would make the contents of that ocean, including water, minerals and perhaps even life, accessible to future spacecraft. "We're holding our breath to see if and when they get another observation," said planetary scientist Cynthia Phillips of the SETI Institute in Mountain View, Calif. "Until then, the geysers are in the intriguing but unproven category."

200
kilometers
Maximum height of plumes expelled by Europa, according to initial data from the Hubble Space Telescope

The first sign of geyser activity emerged in 2013 when scientists analyzing Hubble data detected ultraviolet radiation at the telltale frequencies emitted by hydrogen and oxygen atoms above Europa's southern hemisphere. Space scientist Lorenz Roth of the Southwest Research Institute in San Antonio and colleagues concluded that the moon was venting water into space (*SN: 1/25/14, p. 6*).

The discovery opened up the tantalizing possibility that Jupiter's most intriguing moon routinely expels samples of its shielded ocean (*SN: 5/17/14, p. 20*). Researchers were hopeful that follow-up observations would reveal active geysers similar to the plumes on Saturn's moon Enceladus, which have been erupting constantly since their discovery by the Cassini probe in 2005.

Yet nature has not made things so simple, Roth said. Multiple Hubble measurements made in January, February, November and December 2014 showed no signs of water surrounding Europa, he reported at the meeting. Some of those observations took place when the moon was at the same spot in its orbit as it was during the original detection.

Other evidence also casts doubt on the idea that Europa consistently propels water into space. A reanalysis of data obtained by Cassini as it whizzed by the Jupiter system en route to Saturn in 2001 revealed no signs of geysers, researchers reported at the meeting December 18. The findings also appear in a recent paper in the *Astrophysical Journal*. Study coauthor Amanda Hendrix, who works in Los Angeles for the Tucson-based Planetary Science Institute, said Cassini's ultraviolet sensor detected fewer neutral gas molecules around the moon than would be expected if Europa were venting water.

Despite the recent results, many scientists at the meeting expressed confidence in the initial Hubble detection. "I think there was definitely something going on there," Hendrix said. The typical output of Europa's plumes may be too feeble to detect from faraway instruments such as Hubble and Cassini, she said. Phillips speculates that Europa's geysers may resemble volcanoes on Jupiter's moon Io, which erupt intensely but sporadically, not as consistently as Enceladus' plumes.

Roth and his team plan to make about 45 follow-up observations with Hubble in 2015 in search of the elusive geysers. In the meantime, NASA is organizing a meeting in February to discuss whether the proposed Europa Clipper spacecraft could include an instrument that would scan the debris from potential geysers for signs of life. ■

These two cobalt-blue glass beads, found in 3,400-year-old graves in Denmark, came from ancient Egypt, probably via extensive European trade routes, a new chemical analysis concludes.

HUMANS & SOCIETY

Ancient Egyptian blue glass beads reached Scandinavia

Chemical analysis extends range of Bronze Age trade

BY BRUCE BOWER

Bronze Age bigwigs in what's now Denmark wore brightly colored glass beads made in the workshops of Egyptian pharaohs and Mesopotamian rulers, a new investigation finds.

Trade routes connected Egypt and Mesopotamia with Denmark by 3,400 years ago and remained active until at least 3,100 years ago, say archaeologist Jeanette Varberg of Moesgaard Museum in Højbjerg, Denmark, and her colleagues. Chemical analyses of blue beads previously found in Danish Bronze Age graves from that period show that the ornaments originated in glass workshops of Egypt's pharaohs and Fertile Crescent kings, the researchers report in the February *Journal of Archaeological Science*.

"This is the first evidence of ancient Egyptian glass outside the Mediterranean region," Varberg says. Mesopotamian glass was previously known to have reached as far north as France, she adds.

Egyptian and Mesopotamian glass beads probably reached societies more than 5,000 kilometers away in southern Scandinavia after passing through extensive sea- and land-based trading networks, says Boston University archaeologist Kathryn Bard, who did not participate in the new study.

Northern Europeans swapped amber for high-end glass objects, Varberg's group proposes. It's already known that Baltic amber, mined along the coasts of Denmark and nearby countries, reached Central European and Mediterranean sites more than 3,000 years ago. Baltic amber was used for a lion-shaped cup from that time previously discovered in Syria and for beads and scarabs found in Egyptian King Tutankhamen's tomb, Varberg says.

In addition, a roughly 3,300-year-old shipwreck discovered off the Turkish coast in 1982 included Baltic amber beads and glass items among its cargo of luxury items, indicating that these goods traveled along common trade routes.

Bright blue glass beads such as those from the ancient Danish graves "make perfect sense" as items that could have been exchanged for Baltic amber, comments archaeometallurgist Thilo Rehren, who directs a campus of University College London in Doha, Qatar. "These new results demonstrate that the globalization of trade is not a modern invention."

A chemical analysis pinpoints Mesopotamia as the source of this 3,400-year-old glass bead, featuring inlaid eyes of yellow and white glass.

Varberg's team analyzed 23 glass beads originally from 10 Danish Bronze Age graves that are now held at the National Museum of Denmark in Copenhagen. Chemical signatures were obtained by blasting microscopic craters on beads' surfaces with a tiny laser beam, enabling another device to identify the material's molecular structure. Results were compared with chemical signatures of 10 ancient Egyptian glass fragments, also studied by Varberg's team, and of Mesopotamian glass items previously assessed with the laser technique by other researchers.

Two Danish beads were made of Egyptian cobalt-blue glass. Cobalt in these finds contained concentrations of nickel, zinc and manganese typical of cobalt-colored glass items and fragments found at several ancient Egyptian workshops. One of the two beads came from the approximately 3,400-year-old grave of a woman who lay among an array of bronze ornaments. The glass bead and two amber beads were found next to the woman's upper right arm. The other Egyptian bead also came from a woman's grave.

Remaining beads displayed characteristics of Mesopotamian glass, including a relatively high concentration of copper and blue cobalt consisting of a distinctive blend of nickel, zinc and manganese. Most Mesopotamian beads also came from women's graves.

Many Bronze Age graves in Europe contain both amber and glass objects. The new evidence raises the possibility that ancient Egyptian religious beliefs — in particular, regarding the color yellow (seen in amber) as a sign of the sun's power, and blue (featured in glass beads) as symbolizing the sea that created the sun and life — influenced people in southern Scandinavia, Varberg speculates. ■

BOTH: A. MIKKELSEN/NATIONAL MUSEUM OF DENMARK

BODY & BRAIN

Flu shot response depends on gene

Targeting immune signaling protein may boost immunity

BY NATHAN SEPPA

Variant forms of a gene might tip off doctors to people who are naturally more or less likely to benefit from a flu vaccination. A new study of the gene variants' effect also suggests a novel approach to boosting immunity, possibly helping elderly or immune-compromised people who exhibit subpar responses to vaccines.

Variations in the interleukin-28B gene, which encodes an immune system signaling protein, might account for some of the differences in protection among people getting the flu shot. Some harbor a form of the gene that induces a cell to produce less of the signaling protein. That underproduction gins up a stronger antibody response from flu vaccines, researchers report in the December *PLoS Pathogens*.

"This is a very provocative finding and an interesting observation," says Octavio Ramilo, a pediatric infectious disease doctor at Ohio State University in Columbus. But it would need to be borne out in tests in animals and people to establish that revving up antibody production by undercutting interleukin-28B is a net gain — and doesn't diminish some other form of immune protection, he says.

The researchers tested immune cells from the blood of 196 immune-compromised transplant recipients recently vaccinated against the flu. Most had the common form of the *IL-28B* gene. Those with the variant form were nearly twice as likely to develop enough antibodies to trigger a strong response against flu.

In immune cells from some vaccinated healthy volunteers, the scientists added a protein particle designed to block the signaling action of the IL-28B protein. Antibody production increased substantially. When the researchers added extra IL-28B protein to a lab dish of similar cells, antibody production fell. The results suggest a drug that blocks IL-28B signaling might increase the efficacy of flu vaccines, says study coauthor Deepali Kumar of the University of Toronto.

John Belmont of Baylor College of Medicine in Houston and his team reported in *eLife* in 2013 that at least 20 genes come in variant forms that influence flu vaccine responses. These different forms might provide clues to the variability in vaccine response, but any effect would probably stem from a combination of traits. "It is not likely that testing a single [genetic] variant would allow one to predict who will be a poor responder to flu vaccine," Belmont says. ■

BODY & BRAIN

Priming the elderly for flu vaccination

Transplant antirejection drug improves antibody production

BY NATHAN SEPPA

For older people, the sniffling, coughing, fever and aches of the flu aren't just a nuisance. Influenza infections can turn deadly. Researchers now report a new strategy for fighting the flu that might improve the odds in this high-risk group.

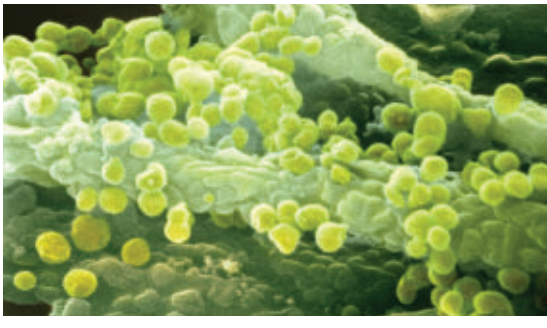
Low doses of a drug called everolimus taken before a flu shot by people age 65 or older bumped up their immune response to the vaccination by an average of 20 percent, scientists report in the Dec. 24 *Science Translational Medicine*. Everolimus is used to fend off rejection in transplant recipients and fight certain cancers.

Previous research with a similar drug in mice improved the immune protection from flu shots and extended their survival. The new study tries to extend those findings to humans, says study coauthor Joan Mannick, an infectious disease physician at Novartis Institutes for Biomedical Research in Cambridge, Mass.

Everolimus is an analog of the drug rapamycin. Both compounds inhibit a powerful signaling protein in cells called mammalian target of rapamycin, or mTOR. Animal research suggests that mTOR can affect immunity.

In humans, immune function declines with age. So Mannick and colleagues gave a low, medium or high dose of everolimus pills to 159 older people in Australia or New Zealand for six weeks. Two weeks afterwards, each received a flu shot, as did 59 others not given the mTOR-blocking drug. Four weeks later, blood tests showed that those given a low- or medium-sized dose of everolimus generated one-fifth more antibodies to the flu than controls.

"Aside from the potential applications to improve vaccine efficacy in elderly people, this study provides the first good evidence that an mTOR inhibitor can improve at least some aspects of age-related decline in humans," says Matt Kaeberlein, a molecular biologist at the University of Washington in Seattle who wasn't involved in the study. "It's pretty convincing that this transient treatment with an mTOR inhibitor can have an effect." But it remains unknown whether this apparent benefit is specific to flu defense or might apply more broadly.



This electron micrograph shows influenza virus particles (round) on a cell membrane.

NIBSC/SCIENCE SOURCE

Curiously, people entering the study with little flu immunity seemed to benefit the most from the primer drug regimen.

"I think a good deal more work is required before using a rapamycin analog routinely to boost flu vaccine responses," says chemist David Harrison of the Jackson Laboratory in Bar Harbor, Maine, also not involved in this study. ■

LIFE & EVOLUTION

Crows may have the knack of analogy

Birds pass lab test for picking out similar relationships on cards

BY SUSAN MILIUS

Two hooded crows in a lab have wowed their human colleagues by passing a test designed to see whether animals can grasp analogies.

The test presents a sample card showing two symbols, such as two triangles or a plus sign paired with a circle, that may be alike or different in shape, color or size, says study coauthor Edward Wasserman of the University of Iowa in Iowa City. A crow also sees two other cards with completely different symbols and has to pick the one that best exemplifies the relationship — sameness or difference — shown in the sample card.

The crows managed to pick the correct card about three-quarters of the time, Wasserman and his colleagues report December 18 in *Current Biology*.

The triumph of the crows at this test adds new evidence to a growing revolution in attitudes toward animals' mental processes. Research has been exploding that suggests animals, without language or a fancy human forebrain, have ways of dealing with what humans consider abstract concepts, Wasserman says. "We have been grossly wrong: underestimating animal intelligence."

Some apes plus baboons have also passed tests as difficult as this one, with just two symbols for determining sameness or difference, Wasserman says. He eventually trained pigeons to do a simple version of the task but had to hype up the samples with clusters of 16 icons to create blatant sameness and difference. "This is quite a chore for pigeons," he says.

Hooded crows have passed a challenging lab test designed to see whether animals can think in terms of analogies.

What especially interested him was that the crows scored well the first time they tried the task. The birds, working in the lab of Wasserman's coauthors at Lomonosov Moscow State University in Russia, had learned how to take easier

HUMANS & SOCIETY

Culture affects tones of voices

Schizophrenia's hallucinations tend to positive in some places

BY BRUCE BOWER

People with schizophrenia may hear either hostile voices goading them to jump off a bridge or a mother's soothing words of advice, depending on the cultures in which they live, a new study suggests.

In the United States, schizophrenia's recognized symptoms include hallucinations of disembodied voices that hurl insults and make violent commands. But in India and Ghana, schizophrenia patients often report positive relationships with hallucinated voices that they recognize as those of family members or God, says an international team led by Stanford University anthropologist Tanya Luhrmann. The findings appear in the January *British Journal of Psychiatry*.

"Learned cultural expectations about the nature of mind and self may encourage Americans with schizophrenia to pay more attention to negative, hostile voices," Luhrmann says.

Much evidence shows that Westerners think of the mind as a fortress guarding private thoughts and of schizophrenia as a broken brain. Americans with schizophrenia in the study — who often referred to hallucinated voices as unreal and as symptoms of a brain disease — homed in on the strangest, most antagonistic voices in their minds, Luhrmann suspects.

Indians and Africans in the study spoke little of their psychiatric diagnosis. Their social worlds emphasize relationships over individuality and the possibility of supernatural contacts with spirits. Many patients in both regions regarded most hallucinated voices as familiar people who couldn't be controlled but who were sensible and likable.

Hearing voices, an experience reported by some mentally healthy people as well as those with schizophrenia (*SN: 4/7/12, p. 22*), "may be a partially learned and malleable skill," says medical anthropologist Kim Hopper of Columbia University.

Luhrmann, working with two psychiatrists in India and one in Ghana, recruited 20 people in each country receiving treatment for schizophrenia. All reported hearing voices. Interviews with the patients included questions about their voices' identities, what the voices said and whether the patients conversed with their voices.

Among U.S. patients, 14 heard voices that told them to hurt other people or themselves, and five described hearing voices as akin to being in a war or a battle. None reported predominantly positive voice-hearing experiences.

In India, 13 patients heard voices of kin or spouses offering guidance, scolding or giving commands to do household tasks. These voices were regarded as good, even if sometimes demanding or frightening. Only four people heard voices that regularly or occasionally commanded them to hurt someone.

In Ghana, 16 patients reported hearing God or another deity and 10 described

TANYA OBOZOVA

versions of the test, picking one of two cards that had symbols of the same size, shape or color as a reference sample. When the Moscow researchers first challenged the crows using a reference sample with symbols not shown on any of the choice cards, the crows did well the first time.

A strong case that crows can deal with analogies could spark new questions about the evolution of analogical reasoning, says comparative psychologist Timothy Flemming of Portland State University in Oregon. If the ability shows up in a bird, on a branch in the tree of life distant from the primates, then biologists can look for shared evolutionary forces that might have led not-very-related ancestors to converge on a similar power.

The new test can't detect what mental processes the bird uses to get the right answers, Wasserman cautions. Bird minds quite possibly would not use the same approaches that humans use. ■

voices as entirely or mostly positive. Others heard bad voices but insisted that good voices — usually God's — were more powerful. Only two people said that voices told them to kill or to fight.

Most patients in each country, including the United States, were religious, so something else about their backgrounds must have influenced the tendency to hear positive or negative voices, Luhrmann says.

Cultural differences help to explain why schizophrenia tends to be more severe and long-lasting in the United States than in India, Luhrmann proposes. Evidence on schizophrenia's course in Ghana is too sparse for comparison.

The new findings lend support to a controversial treatment approach in the West, called the Hearing Voices movement, which for more than 20 years has taught people to interact with hallucinated voices as people. If this approach continues to catch on, a growing number of people with schizophrenia will become skilled at interacting constructively with their voices, Hopper predicts. ■

LIFE & EVOLUTION

In darkness, rock ants tend to left

Directional bias may aid search for habitats, evading predators

BY SUSAN MILIUS

Rock ants show a lefty bias when picking which way to turn in strange, dark places.

Tiny, crevice-dwelling *Temnothorax albipennis* ants don't have hands, of course, but in lab tests, a tendency similar to handedness shows up in choosing the direction to turn when exploring, says Edmund Hunt of the University of Bristol in England. The ants also tend to follow a wall, but when willing to step away from it, show a leftist bias, he and colleagues report December 24 in *Biology Letters*.

Hunt, trained as a physicist, has turned to ant colonies to explore how simple rules for behaving can create complex outcomes. When rock ants need to find a new home, they have to explore strange places not unlike laboratory mazes. Clusters of explorers crowding into various crevices eventually reach a quorum in one of them and choose it for the colony.

A bias for turning in the same direction might offer explorers some advantages of traveling near nest mates, Hunt speculates. Clusters of ants may fare better than a loner if they happen upon a predator. And clustering may speed the process of reaching the vital number of exploring scouts in a particular crevice that tips the decision to "Yes, we'll take it."

A tendency in a population of animals to turn in the same direction might make searching for food more efficient, muses evolutionary biologist Scott Kight of Montclair State University in New Jersey. Such a tendency suggests that the underlying nervous system is not symmetrical, and that the sides specialize in particular functions. Evolution may have favored the specialties, or a behavioral bias may be a side effect of growing up lopsided. "Perhaps it is simply what animals with asymmetric nervous systems do," he says.

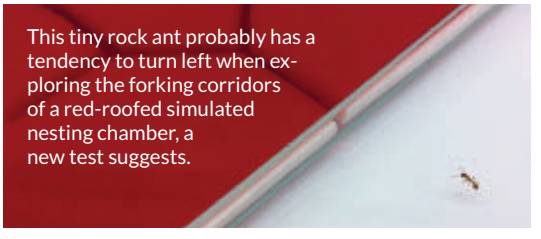
Brain hemispheres specialized for different functions were long thought to be a unique marvel of humankind, says Lesley Rogers of the University of New England in Armidale, Australia. Her discovery that chicks show lateralized behavior plus similar discoveries with rats and songbirds in the '70s and '80s dented human pride a bit. "Now it seems that lateralized brain function is very common, regardless of the overall brain size," she says.

Tendencies to favor one side of the body for some functions have also shown up in insects. For a few hours after learning an odor cue task, bees typically remember the scent only if sniffed with the right-side antenna, Rogers and colleagues found. Six hours later, the bees have switched to long-term memory, available only if sensing the odor with the left antenna.

Among rock ants, experiments had identified a navigational bias in suggesting that travelers favor their right eyes when scanning landmarks. To see if rock ants show any directional bias when choosing which direction to turn in unfamiliar passages, Hunt and colleagues sent ants into a simulated dark nest with a wall enclosing an open center. Of those that turned, 35 ants went left; 19 went right.

In a more complicated lab setup, one ant at a time moved into a corridor that forked and then forked again. When the researchers corrected for ants that could have just been following the walls, the team found more lefties than righties.

When ants venture into an unknown corridor, their focus on scanning for landmarks with the right eye may give way to vigilance and wariness, Hunt says. Confronting danger might be a left-side thing, as it seems to be in some other kinds of ants. ■



This tiny rock ant probably has a tendency to turn left when exploring the forking corridors of a red-roofed simulated nesting chamber, a new test suggests.

E.R. HUNT

GENES & CELLS

Insect-eating bats implicated as Ebola outbreak source

Tree in Guinea harbored suspects in infection of 2-year-old who was first victim in epidemic

BY TINA HESMAN SAEY

The epicenter of the Ebola epidemic may be a hollow tree in Guinea.

Emile Ouamouno, a 2-year-old boy who is thought to be the first person to contract Ebola in this outbreak, often played with other children in the hollow tree near his home in the village of Meliandou, Guinea. That tree was inhabited by small insect-eating free-tailed bats of a species (*Mops condylurus*) that previous research has suggested may harbor Ebola, Fabian Leendertz of the Robert Koch Institute in Berlin and colleagues report in the January *EMBO Molecular Medicine*.

Many species of bats may spread the deadly virus, which has infected over 20,000 people and killed more than 8,000 in the ongoing West African outbreak. Insect-eating bats often roost in houses, and people may encounter the animals more frequently as settlements push deeper into previously wild areas. To Leendertz, that suggests that the next Ebola outbreak "can start anywhere" in Africa where the bats live.

This hollow tree once housed insect-eating bats that may have been the source of the Ebola epidemic. The first known person to contract Ebola in the outbreak was a toddler who often played in the tree.

F. LEENDERTZ

The case against the insectivorous bats is not a slam dunk. The boy was infected and died in December 2013. By the time Leendertz's group arrived in April to track the outbreak's source, the hollow tree had burned and the bats were gone. Villagers reported that when the tree caught fire on March 24, it started a "rain of bats." None of the bat species in or around the village were found to carry Ebola.

"Although [the evidence] is largely circumstantial, it's a start for sure," says Tony Schountz, an immunologist at Colorado State University in Fort Collins who studies viruses in bats and rodents. Discovering which bat species harbor viruses will enable public health officials to teach local people how to avoid contact with the bats. "We have a good chance of modifying human behavior," he says. "We have no chance of changing the bats."

Getting rid of bats is not the solution. "We need those bats," Leendertz says. Bats eat the insects that spread malaria. Fruit bats pollinate many fruit crops, such as mangoes, bananas and guava.

Leendertz and colleagues from several different scientific disciplines traveled to Meliandou hoping to find the animal source, or reservoir, and learn more about how the disease might have spilled over into humans. The researchers talked to villagers, conducted wildlife surveys and collected samples from bats and material in the village. The investigation led the team to conclude that fruit bats, the prime suspects for spreading Ebola, were probably innocent. Leendertz says he can't completely rule out fruit bats, but thinks the insect-eaters are a more likely source of the initial transmission to people.

For one thing, Meliandou is not located near fruit bat roosting sites where the child might have come in contact with an infected animal or tainted fruit, and there is no evidence that the family ate fruit bats. The village is not typical of the rainforest hamlets where Ebola outbreaks have started in the past, Leendertz says. "There is no rainforest around." Instead the village, composed of 31 houses, is surrounded for kilometers by rice fields and cocoa and coffee plantations.

But children often knock small, smelly, long-tailed bats that villagers call "lolibelo" from trees or roosting spots under roofs and grill the mouse-sized bats over fires. Because the boy was the first to catch Ebola, Leendertz thinks it is more likely that he got it from one of the little bats, rather than larger bats that his mother might have prepared for the family, since she didn't contract the virus first.

"This sort of deep epidemiology is important," says Raina Plowright, an infectious disease ecologist at Montana State University in Bozeman. Without an anthropologist and other specialists on the team, "the hypothesis of kids playing in roosting places might not have been considered," she says.

Researchers have only indirect evidence that bats are reservoirs of Ebola, Plowright says, but the data suggest that the animals probably do harbor the virus. It will be important to learn whether the virus is present in bats at low levels all the time or if certain environmental factors trigger periodic outbreaks that might then affect people.

Leendertz isn't surprised that his team failed to find the Ebola virus in bats near the village. "We're trying to trace a virus in an extremely large, multispecies population ... in which the virus is extremely rare." He and his team hope to learn more about how Ebola is transmitted among wild bats. ■

BODY & BRAIN

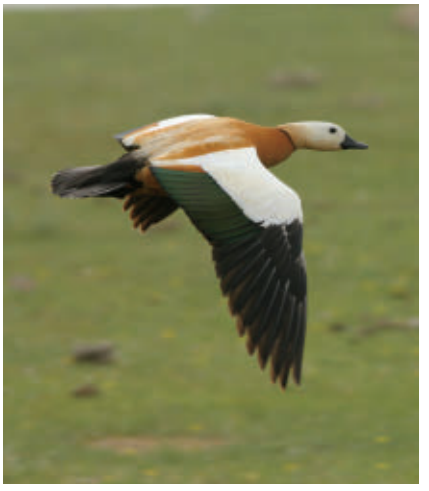
Bird flu follows avian flyways

Wild geese may fly with the flu on their wings, new research suggests. Scientists have suspected that wild birds spread the H5N1 avian influenza virus, but the evidence has been inconclusive. A new study combines GPS tracking data of four species of wildfowl with genetic analysis of the virus and finds that H5N1 spreads along migratory flyways. Human outbreaks of the disease also coincide with migration time of the birds, Huaiyu Tian of Beijing Normal University and colleagues report December 22 in the *Proceedings of the National Academy of Sciences*. Since 2003, 676 people have been infected with the virus and 398 have died. Bar-headed geese and ruddy shelducks (one shown) spend the winter in India, Nepal, Bangladesh and Myanmar. Then they fly the Central Asian flyway to breed in China's Qinghai Province. Along that route, H5N1 epidemics spread at a rate of 607.26 kilometers per month, close to the birds' migration speed of 573.19 kilometers per month, the researchers found. In East Asia, swan geese and northern pintails migrate along at least two flyways, the researchers discovered. Genetic patterns in the virus matched well with the migratory routes, suggesting that wild birds could be important for spreading H5N1 in Asia. — *Tina Hesman Saey*

GENES & CELLS

Contamination blamed in STAP debacle

The discredited stem cells known as STAP cells were ultraflexible because they were really embryonic stem cells, a new report contends. In January 2014, researchers claimed in two papers published in *Nature* that they had made stem cells by briefly dipping adult cells in a dilute acid bath or by giving the cells a squeeze (*SN: 2/22/14, p. 6*). The research was soon called into question, and an investigation by RIKEN, the Japanese research institute where much of the work was done, found lead author Haruko Obokata guilty of manipulating images and plagiarizing parts of the text. The papers were



COURTESY OF CHAO ZHAO

retracted in July (*SN: 7/26/14, p. 7*). After months of failing to replicate her work, Obokata resigned and RIKEN said it would cease efforts to re-create the cells. On December 26, RIKEN issued a report saying that what the researchers claimed were STAP cells were really embryonic stem cells contaminating the lab dishes. The contamination probably wasn't accidental, but exactly who was responsible for it could not be determined. The investigators found Obokata guilty of two more counts of misconduct for fabricating data. The report may close the book on a yearlong saga that has marred stem cell science (*SN: 12/27/14, p. 25*). — *Tina Hesman Saey*

EARTH & ENVIRONMENT

Nylon goes green

Whether the world is better off from the invention of panty hose is debatable. But a new route toward making nylon — the polymer of many a sheer stocking — is decidedly better for the planet. Using ozone bubbles and ultraviolet light, chemists can now make a precursor to nylon without the typical exhaust of greenhouse gas. The finding appears in the Dec. 19 *Science*. Nylon is usually made from adipic acid, a zigzag molecule of six carbons bedecked with hydrogens and a few oxygens. To get adipic acid, scientists react hexagon-shaped carbon molecules with corrosive nitric acid. That reaction gives off nitrous oxide, which can harm the Earth's ozone layer and, molecule-for-molecule, has nearly 300 times the planet-warming capacity of carbon dioxide. Human activity produces more than 8 million metric tons of nitrous oxide each year and up to 8 percent of that comes from making nylon. To avoid this problem, chemists Kuo Chu Hwang and Arunachalam Sagadevan of the National Tsing Hua University in Hsinchu, Taiwan, replaced the nitric acid with bubbles of ozone, O_3, and ultraviolet light. The ultraviolet light breaks the ozone gas into O_2 and a highly reactive oxygen atom. Lone oxygen atoms then repeatedly attack and latch onto a hexagon-shaped carbon molecule, cyclohexane, until the ring breaks open, forming adipic acid. — *Beth Mole*

BODY & BRAIN

Old product might help smokers quit

A compound called cytisine, used in Eastern Europe since the 1960s as a smoking-cessation drug, worked better than nicotine replacement therapy in a quit test, researchers report in the Dec. 18 *New England Journal of Medicine*. Scientists in New Zealand randomly assigned 1,310 smokers to get cytisine tablets or nicotine patches, gum and lozenges. After one month, 40 percent of the people on cytisine and 31 percent of those on nicotine had quit. At two months, it was 31 percent and 22 percent, and at six months, cytisine still held an edge with 22 percent of the volunteers having quit compared with 15 percent of those using the nicotine products. Among those who failed the test, the median time to relapse was 53 days in the cytisine users and 11 days in the nicotine group. Cytisine is a natural plant compound that works like the quit-smoking drug varenicline, marketed as Chantix, by attaching to a protein receptor molecule on neurons. This attachment blocks nicotine from binding to the receptor and triggering its trademark effects. Like Chantix, cytisine causes side effects in some users. In this trial, 31 percent of people taking cytisine reported side effects compared with 20 percent of those on nicotine. The most frequent problems were nausea, vomiting and sleep disruptions. — *Nathan Seppa*

Carbon Quakes

An escape hatch from global warming may do some harm while doing good

By Charles Petit

The shaking in the nation's midsection has been intense enough in the last few years to break chimneys and scatter dishes. Those alarming earthquakes are in places where such things have been about as common (and as welcome) as laughing hyenas. Their cause: injection of watery waste fluids deep underground as part of natural gas and oil retrieval.

This worries some scientists who have high hopes for a way to curb global warming by getting rid of carbon dioxide that comes from, among other things, combustion of coal, gas and oil. These CO_2 emissions may be accelerating Earth toward a climate calamity as the land and seas warm and weather zones shift. One promising strategy for curbing climate change is to pump much of the CO_2 from fossil fuel–fired power plants into deep underground storage where everybody hopes it will remain for millennia.

But in an ironic symmetry, in which a proposed solution to a problem shares one of its side effects, deep geological storage of CO_2 might produce as many or more quakes than are now being triggered by oil- and gas-related wastewater disposal. Especially if it is performed on the vast scale many hope to see.

To study the basic mechanism involved, scientists are delving deeply into the stresses and strains that have built up over the ages in the Earth's crust. What they have found is that it is remarkably easy to trigger earthquakes, even in regions that historically have been seismically silent or nearly so.

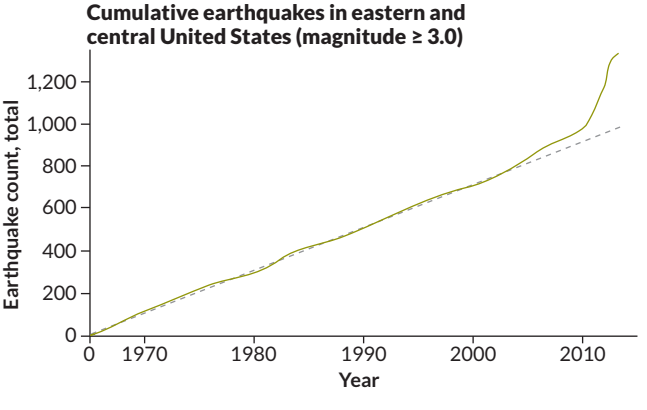
"We have faults that are accumulating stress over thousands to hundreds of thousands of years, even in Iowa," says Stanford University geophysicist Mark Zoback. "So when you inject water or gas or any fluid it can set some of them off."

In the central and eastern United States from 1970 to 2000, geologists recorded a yearly average of only 20 quakes of at least magnitude 3.0 — enough to sway a hanging lamp. Then the count rose: Between 2010 and 2013, 450 such temblors hit — a rate about five times higher than normal for those parts of the country.

"There have been hundreds of earthquakes in Oklahoma alone. That state is making magnitude 3s faster than we are in California," says a leading expert on earthquake mechanics, William Ellsworth, in his office at the U.S. Geological Survey's regional center in Menlo Park, a few kilometers east of the mighty San Andreas Fault. "It is unprecedented."

If asked to explain the quake upsurge, many Americans may guess fracking. Not quite, but fracking shares a family resemblance to the prime culprit. Formally called hydraulic fracturing, fracking has allowed drillers to make money off sandstones

Human-induced earthquakes After decades of a steady earthquake rate (dotted line) in the central and eastern United States, activity began to rise in about 2009 and jumped to five times the normal rate by 2013, probably due to human activity. SOURCE: W.L. ELLSWORTH/*SCIENCE* 2013



ARCHER DANIELS MIDLAND

Archer Daniels Midland corn processing plant in Decatur, Ill.

and shales that had been considered too "tight" for the gas and oil to flow freely into wells (*SN: 9/18/12, p. 20*). Fracking is an old process that has only recently entered wide use. It drives networks of fissures into this type of formation, one patch at a time. It hammers brief pulses of very high-pressure water or other fluids plus grit and chemicals into the shale so that oil and gas can migrate more easily. Fracking is not seismically silent, but its quivers, mostly hovering around or below magnitude 2.0, are imperceptible at the surface.

The immediate reason for the nerve-rattling quakes of magnitude 4.0 or 5.0: New oil and gas fields have gone into production, often after fracking gets them started. Flowing up through the new wells is more than gas and oil. "Flowback" of fracking fluid often comes up too. Plus, a barrel of crude may reach the surface mixed with more than a barrel of additional undrinkable, very salty water that has accumulated down deep over eons.

Industry's response for many decades has been to gather the foul liquid from many extraction wells and deliver it to a relatively few high-volume wastewater injection sites: More than 1 million wells nationwide send their wastewater to about 30,000 disposal sites. It is typically pumped nonstop and driven at high pressure into deep aquifers a mile or more down to mix with the saline waters already there. In most cases, the water injection works without incident. But at times, "things have gone off the rails," Ellsworth says (see "When the Earth moves," Page 17).

For all the huffing and chuffing of heavy equipment for months on end, the energy in these human-made earthquakes does not come from the work being done to shove fluids far underground, Ellsworth says. The potential energy for earthquakes is already down there.

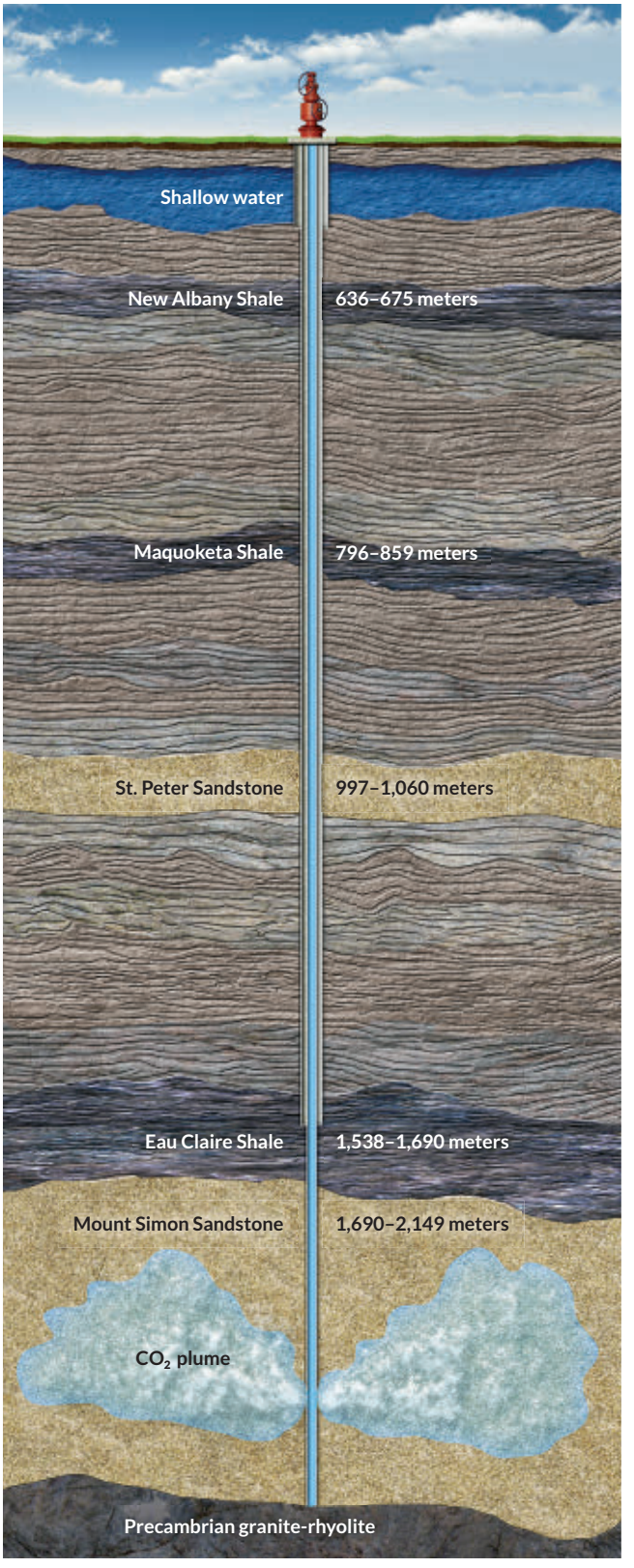
In recent decades geologists have come to suspect that North America's basement rocks are near the breaking point. Faults, many inactive for thousands to millions of years, lace much of the bedrock and strata all around the globe. In places where such deep, long-immobile faults exist, "it does not take much to set them off," Ellsworth says.

The zone of unnaturally high pressurization extends well beyond the plume of newly pumped-in fluid. If this high pressure encounters a fault that's close to failing, even in a layer of rock that is largely impervious to fluid entry, fluid already in the nearby formations may worm its way into the fault zone of crushed rock. It tends to unclamp the fault, lowering its resistance to slippage, perhaps enough for it to yield to the stress it had long withstood.

That is roughly how geologists explain the rise in oil and gas field quakes. They are examples of what is formally called induced seismicity, or quakes triggered by human activity.

Deep storage test

But residents of Decatur, Ill., are not feeling any perceptible quakes. Decatur, a busy industrial town among the rolling hills and cornfields 180 miles southwest of Chicago, is home to the



Injection site geology At a Decatur, Ill., test site, CO_2 is pumped through several impermeable boundaries of shale and into a thick layer of sandstone just above Precambrian granite-rhyolite rock.
SOURCE: A. ALVI *ET AL/OILFIELD REVIEW* WINTER 2012/2013

NICOLLE RAGER FULLER

nation's biggest test of deep carbon storage. Decatur is considered a safe test site in part because no significant fault is anywhere near it.

The North American headquarters and processing plant of the giant agribusiness company Archer Daniels Midland, or ADM, dominates Decatur's skyline. Trainloads of corn arrive there to become animal feed, cooking oil, corn syrup, sweeteners and more.

The possible escape hatch from global warming under test in Decatur is found in a row of outdoor fermentation tanks, each more than 15 meters high. They turn 3.3 million metric tons (130 million bushels) of ADM corn into 1.3 billion liters of ethanol for blending with gasoline. Leftover mash becomes food for livestock, the used-up yeast fish food. And out the top comes about 2,700 tons per day of nearly pure CO_2.

This plant's CO_2 is not part of the world's CO_2 problem in the same way that CO_2 from fossil fuel combustion is. The corn as it grew took carbon from the air, so putting it right back as CO_2 balances the carbon ledger. Still, to stash such "biogenic" CO_2 away permanently offsets some fossil CO_2 emissions and, more importantly, paves the way toward isolating CO_2 arising from coal and natural gas combustion.

The ADM plant is the centerpiece of a two-phase experiment. The first, the Illinois Basin–Decatur Project, finished a three-year run in November. It sent about one-third of the fermentation CO_2 about 2,100 meters underground into a formation called the Mount Simon Sandstone. Named for a hill near Eau Claire, Wis., where it has an outcrop, the formation underlies most of Illinois and rests directly on the continent's granite shield or basement rock. Money for the recent Decatur test came largely in a $67 million grant from the Department of Energy. Additional funding is from ADM and the carbon services division of the big oil service contractor Schlumberger.

Under a second DOE grant of $141.4 million plus $66.5 million from ADM and other partners, phase two will drill a second well and triple the amount of CO_2 diverted down deep. To begin in 2015, that phase should render the plant's ethanol works nearly free of CO_2 emissions.

It is the first major proof-of-concept in the United States for the "S" part of what's called Carbon Capture and Sequestration (alternatively, Storage). CCS is a central strategy under consideration by climate policy analysts for curbing global warming. Tests of the more challenging job of taking CO_2 from the hot exhausts of gas- and coal-fired power plants are under way elsewhere (*SN: 9/6/14, p. 22*).

Robert Finley, an Illinois State Geological Survey researcher and director of the first phase of the Decatur project, says it illustrates every step of how to bury CO_2 deep underground for thousands of years or more. "This is the real deal," he says. His agency and the USGS maintain seismographic arrays near the well.

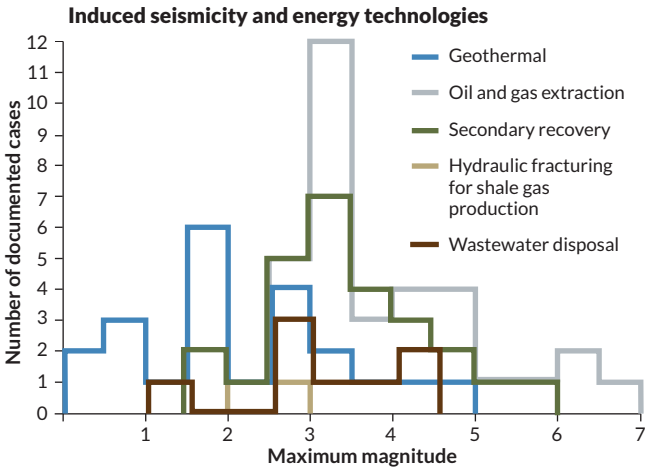
So far, ADM has pumped 1 million tons of CO_2 into the ground over three years. That may seem like a lot. But it is nothing compared with what will be needed to dent the planet's greenhouse gas emissions. A million tons of CO_2 is about a fourth what the average coal plant emits yearly. The United States has more than 400 coal plants. To reduce American emissions by a billion tons — about 20 percent of the total from all sources including combustion of coal, natural gas and oil — would take thousands of injection facilities like Decatur's. Annual worldwide emissions from all sources now run at nearly 40 billion tons. About 5.27 billion come from the United States, and fossil fuel-fired power plants account for about 40 percent of it.

In October, just before phase one ended, Scott McDonald, ADM's biofuels development manager, stands in a cornfield near the plant and points to a fenced enclosure. A concrete lid with some electronic boxes on top covers a monitoring well near the injection site. Inside, geophones — which detect seismic vibrations — dangle more than 1.6 kilometers down. The gear allows engineers and earth scientists to monitor the growth of the underground plume of CO_2 — now about 402 meters wide. The detectors map the tiny shudders and other signals of high-pressure CO_2 squeezing its way into the sandstone. Inside a nearby shed a monitor displays a series of jagged lines. Earthquakes? "No, that's just normal noise," McDonald says. "We get hundreds of seismic signals a month, but not so far today. We never feel them."

The largest yet recorded was about a magnitude 1.0. "To call these events earthquakes is an overstatement," says geologist Finley.

Inside the plant's CO_2 compression hall, ear protection is a must. Elaborate plumbing splays across the floor and walls. The place looks a little like the engine room of a large ship. Some pipes have the girth of a horse. Two 2,424-kilowatt, four-stage, six-cylinder reciprocating compressors as big as tractor-trailers dominate the room. Large dehydrators remove water vapor from the CO_2. The main pumps and an array of smaller compressors and blowers boost the purified

Shake it up Several energy technologies have caused quakes of varying magnitudes; oil and gas extraction has caused the most quakes and highest magnitudes. Little data (two events around a magnitude 1) exist on the seismic impact of CO_2 injection. SOURCE: NATIONAL RESEARCH COUNCIL 2012



When the Earth moves

The oil and gas industry operates more than 30,000 deep disposal wells injecting wastewater far below freshwater sources. In addition, many oil drillers increase yield by pumping in high-pressure, near-liquid CO_2 that mixes with oil to make the oil flow better. Most of the time it works as planned. But problems can crop up.

WASTEWATER INJECTION

Rocky Mountain Arsenal, Colo. | 1962–1966
A 3.7 kilometer waste disposal well drilled under U.S. Army supervision was followed by a rising tempo of earthquakes through the mid-1960s; a magnitude 5.0 quake in 1967 broke windows at the arsenal and closed schools in Denver; a magnitude 5.3 quake in August 1967 caused $500,000 in damage in Denver. Once water injection stopped, seismic activity gradually subsided. The episode, followed by experiments at a Chevron oil field in Colorado where scientists could turn quake activity up and down by changing pressure in injection wells, established scientifically that deep fluid injection may lead to earthquakes.

Raton Basin | 2001–Present
Sixteen magnitude 3.8 and greater quakes, including a 4.6 quake followed by a 5.3 six hours later in August 2011, struck after wastewater injections began in oil and gas fields of southern Colorado and New Mexico. Wells in the area inject unusually large amounts of wastewater; two wells about two kilometers from the source of the largest quakes were pumping many thousands of barrels of wastewater per month into underlying reservoirs.

Dallas-Fort Worth, Texas | October 2008–May 2009
A storm of small quakes, mostly of magnitude 3.3 or less, quivered through the region. They all had their origin about 400 meters from a well that started pumping brine into deep formations several weeks before the quakes began.

Prague, Okla. | November 6, 2011
The largest earthquake in the state's history, a magnitude 5.7 on the Wiltzetta Fault, destroyed 14 houses and injured two people. A 2014 report from the U.S. Geological Survey pinned it on a long history of wastewater injection in the area, saying a smaller magnitude 5.0 quake very close to the injection wells transferred stress to the larger fault, causing its failure.


2011 quake damage in Sparks, Okla., near the Wiltzetta Fault.

SUE OGROCKI/AP PHOTO

Youngstown, Ohio | December 31, 2011
A magnitude 4.0 earthquake, the first-ever recorded for the community, struck near an injection well shortly after it began pumping.

CO_2 INJECTION FOR ENHANCED OIL RECOVERY

Cogdell Oil Field, near Snyder, Texas | 2006–2011
This area has seen flurries of small earthquakes blamed on wastewater injection. However, a distinct series of more than 90 quakes, 18 with magnitude 3.0 or above, including a 4.4, stands out. It began within two years of the start of deep injection of large volumes of supercritical CO_2 and methane to stimulate oil flow. The link to CO_2 — or possibly methane — presents a geology puzzle. Similar gas injection in nearby, seemingly identical oil fields was followed by no quake increase. — *Charles Petit*

CO_2 to 9.8 megapascal pressure at a temperature of 35° Celsius. Nearby, a larger hall houses twice as much equipment waiting quietly for the second phase expansion due sometime this year.

Such conditions put CO_2 in what physicists call a supercritical state. It is neither fully liquid nor gas, but instead a fluid with a density about 60 percent that of water that flows like gas. About 90 meters of pipe wind through the plant to the injection well. Topping it is a modest stack of lumpy blue valves and other plumbing about 2.7 meters high with large round handles.

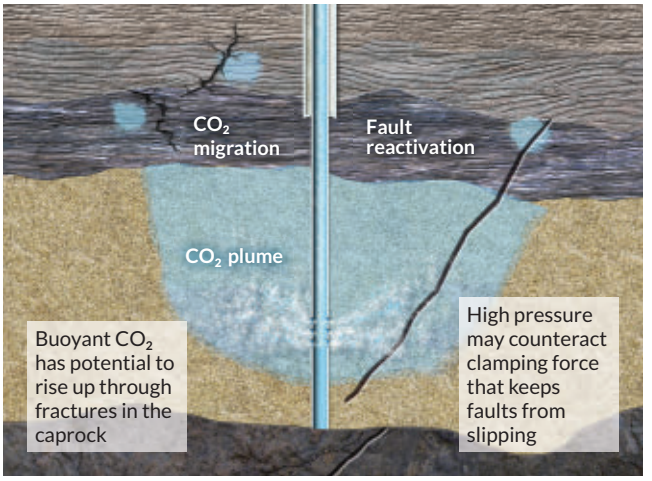
Below the plant, the Illinois Basin's sediments fill a wide dimple in ancient crystalline granite-rhyolite. The basin spans most of Illinois and much of Indiana to the east and Kentucky to the southeast, plus small parts of Missouri and Tennessee.

As it dives into the basin, the CO_2 travels only about 45 meters to reach the deepest freshwater aquifer in the area. Continuing down to 450 meters is a coal seam. At about 600 meters begins the New Albany layer of shale — the first of three caprock layers that geologists say is impervious to any CO_2 that might try to work its way back out. A second shale cap, the Maquoketa, lies at around 800 meters. At roughly 900 meters is an oil-bearing shale layer. At 1,500 meters comes the Eau Claire Shale, 150 meters thick and the main seal on the CO_2. After that, the well casing enters the 500-meter-thick Mount Simon Sandstone. The final stretch of well casing is 13 percent chrome stainless steel alloy to resist corrosion. A series of perforations let the CO_2 out below 2,100 meters. Beneath that the

well penetrates the continental basement bedrock of the North American craton, Precambrian granite-rhyolite battered by scars accumulated over billions of years.

The CO_2 arrives with a pressure a few hundred pounds per square inch higher than is natural so deep. It flows down the final, 10-centimeter-diameter stretch of injection pipe at about 1,100 liters per minute. To the uninitiated, such injection may seem impossible. Finley shows off pieces of drill core from the Mount Simon Sandstone. Some are crumbly and look porous enough but many are pinkish hunks of rock that look and feel like concrete sidewalk. How can fluids be forced into such sturdy material for years on end?

The reason is pore space, the interconnected gaps between irregularly shaped mineral grains. The Mount Simon formation is about 22 percent pore space by volume. By one calculation, Mount Simon Sandstone has room for at least several centuries of all CO_2 emissions from the Upper Midwest. The USGS estimates that it and similar formations around the nation could handle 500 times America's present annual CO_2 emissions.



Pressure concerns Down deep, where CO_2 is injected, high pressure spreads far beyond the injected fluid. As pressure rises, rock grains are pushed apart. This has potential to cause unwanted mechanical changes, including escape of CO_2 (through existing or new fractures or leaky faults) as well as quakes due to fault failure. SOURCE: J. RUTQVIST/*GEOTECH. GEOL. ENG.* 2012; STEVE HICKMAN/USGS

Hidden faults

Sheer forces from the continental margins are wrenching the Illinois Basin, trying to drag the northern parts to the east northeast and the southern ones to the west southwest. Most of the tiny microseismic events seen since the Decatur sequestration pumps turned on tend to move in directions that relieve this stress — even if movements have only been a few fractions of a millimeter along cracks perhaps 10 meters long. Careful advance scrutiny by state and federal researchers revealed no perceptible significant faults near Decatur.

Microseismicity under Decatur is mostly at or below the boundary of the continental bedrock that begins 76 meters under the injection zone. More buoyant than water, supercritical CO_2 has not moved downward, but the pressure clearly has.

So far, it seems, so good. However, some suspect that CO_2 sequestration cannot work. A prime reason is that not every injection site, not for wastewater and presumably not for CO_2, can be guaranteed to be far from hidden faults.

Stanford's Zoback says the standard calculations that have convinced some that immense volumes of CO_2 can be buried safely in the pore space of deep formations reflect "science that could be done by a fourth grader. They are leaving out one important fact," he says. "Those pores are already filled with saline water. Where are you going to put that?"

In a paper he coauthored in the *Proceedings of the National Academy of Sciences* in 2012 and in testimony before Congress, Zoback offered another, larger reason for doubt. He argues that inevitable quakes from CO_2 injection, while fairly small, may well open paths, or fractures, through low-porosity caprock. Movement on faults that extend through caprock, he says, could let most of the stored CO_2 escape in coming centuries. That would gradually torpedo the point of injecting it.

He also believes the cost of equipment able to store billions of tons of CO_2 will prevent its construction any time soon. "By the time we bury billions of tons of carbon it will be too late for the climate."

Jonny Rutqvist of the Lawrence Berkeley National Laboratory in California and colleagues, in a series of recent papers, have modeled multiple scenarios of how sustained, large-scale deep injections of CO_2 might work out. While some earthquakes big enough to alarm local people (magnitude 3.0 to 4.5 at most) appear inevitable, very few would be large enough to damage buildings. Most CO_2 for injection could be piped to reservoirs far from population centers. Plus, their studies suggest that if such reservoirs are under several independent layers of impervious caprock, very few if any quakes would open paths for significant CO_2 to escape.

It will take a long time, he says, to get a full-scale global sequestration program going, plenty of time for a "learn-as-you-go" approach that could be modified or even abandoned if necessary.

If technical barriers fall and if restrictive regulations or government incentives change and give companies, including operators of gas- and coal-fired power plants, a good business reason to install carbon capture and sequestration equipment, then perhaps CO_2 sequestration will become an immense industry in its own right. And perhaps the occasional rumble underfoot may, aside from rattling nerves, be a reassuring sign that humankind is sending fossil carbon in CO_2 waste back underground where we found it. ■

Explore more

- U.S. Geological Survey. "Man-made earthquakes update": bit.ly/SN_USGSquakes

Charles Petit is a freelance science writer based in Northern California.

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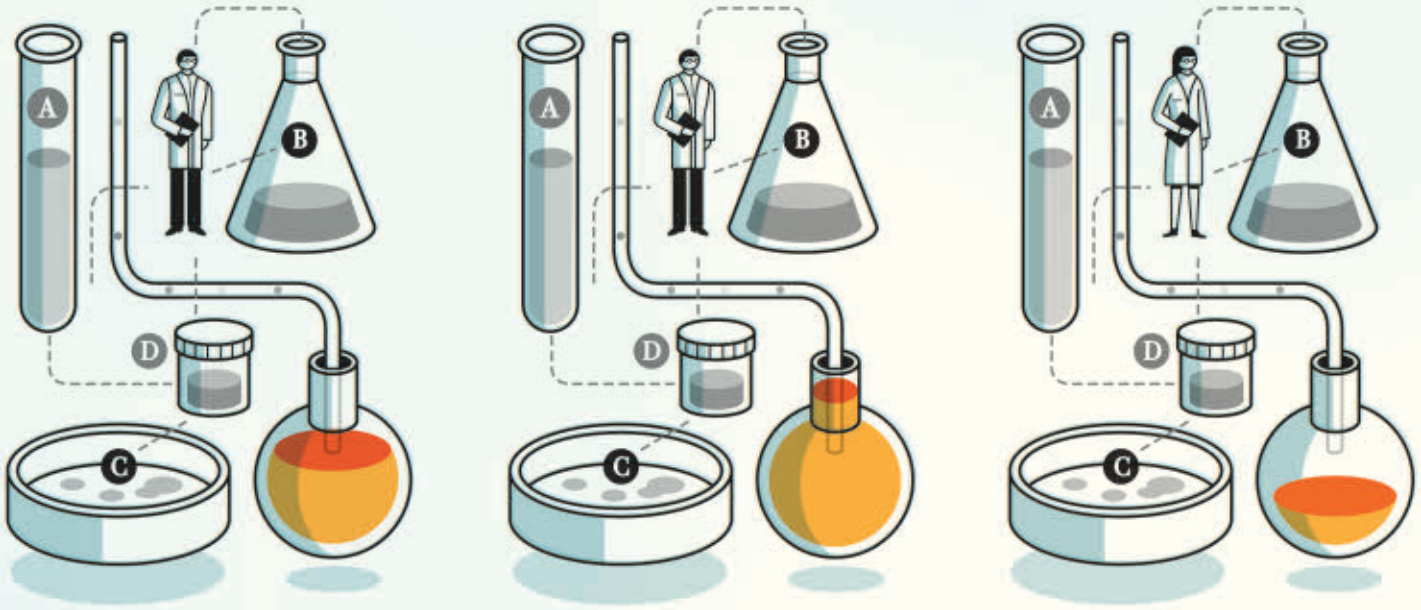
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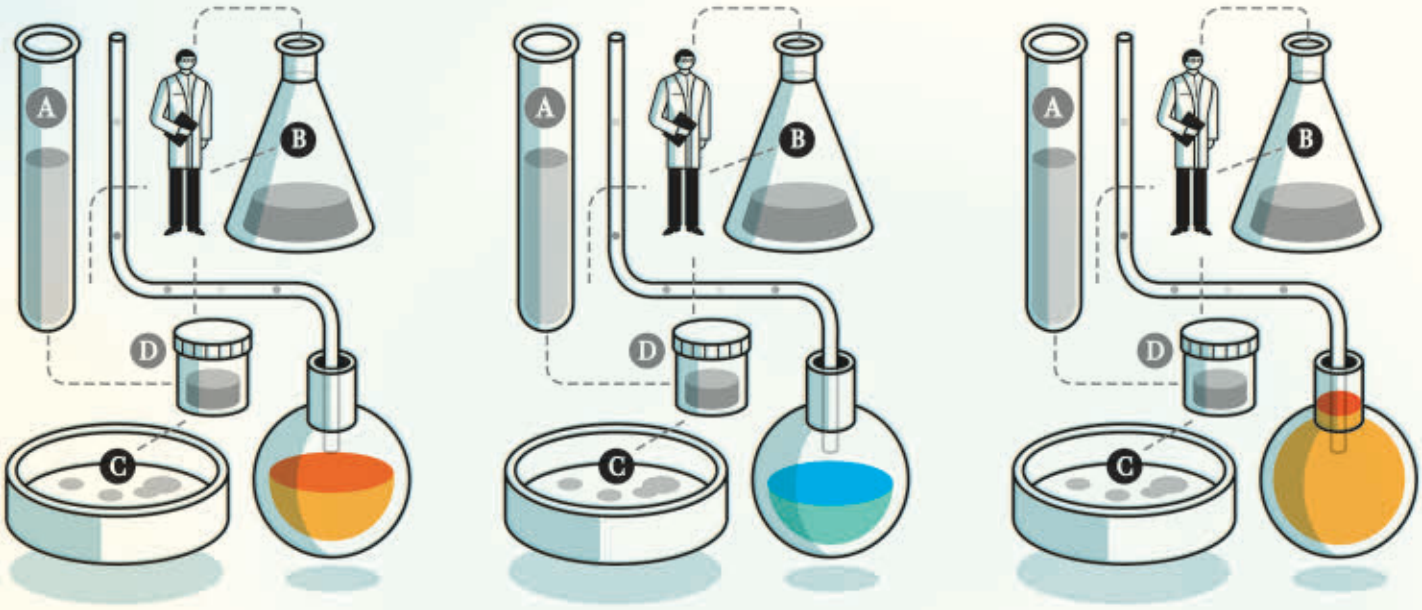
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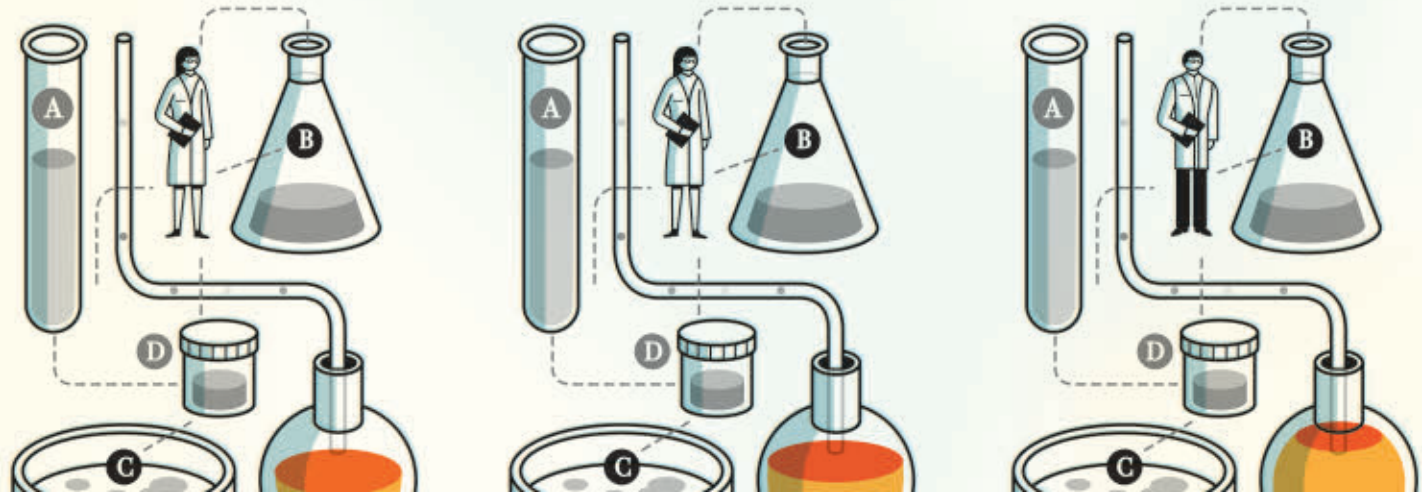
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Repeat Performance

Too many studies, when replicated, fail to pass muster

By Tina Hesman Saey

R. Allan Mufson remembers the alarming letters from physicians. They were testing a drug intended to help cancer patients by boosting levels of oxygen-carrying hemoglobin in their blood.

In animal studies and early clinical trials, the drug known as Epo (for erythropoietin) appeared to counteract anemia caused by radiation and chemotherapy. It had the potential to spare patients from the need for blood transfusions. Researchers also had evidence that Epo might increase radiation's tumor-killing power.

But when doctors started giving Epo or related drugs, called erythropoietic-stimulating agents, to large numbers of cancer patients in clinical trials, it looked like deaths increased. Physicians were concerned, and some stopped their studies early.

> "We're always in a gray area between perfect truth and complete falsehood."
>
> GIOVANNI PARMIGIANI

At the same time, laboratory researchers were collecting evidence that Epo might be feeding rather than fighting tumors. When other scientists, particularly researchers who worked for the company that made the drug, tried to replicate the original findings, they couldn't.

Scientists should be able to say whether Epo is good or bad for cancer patients, but seven years later, they still can't. The Epo debate highlights deeper trouble in the life sciences and social sciences, two fields where it appears particularly hard to replicate research findings. Replicability is a cornerstone of science, but too many studies are failing the test.

"There's a community sense that this is a growing problem," says Lawrence Tabak, deputy director of the National Institutes of Health. Early last year, NIH joined the chorus of researchers drawing attention to the problem, and the agency issued a plan and a call to action.

Unprecedented funding challenges have put scientists under extreme pressure to publish quickly and often. Those pressures may lead researchers to publish results before proper vetting or to keep hush about experiments that didn't pan out. At the same time, journals have pared down the section in a published paper devoted to describing a study's methods: "In some journals it's really a methods tweet," Tabak says. Scientists are less certain than ever that what they read in journals is true.

Many people say one solution to the problem is to have independent labs replicate key studies to validate their findings. The hope is to identify where and why things go wrong. Armed with that knowledge, the replicators think they can improve the reliability of published reports.

Others call that quest futile, saying it's difficult — if not impossible — to redo a study exactly, especially when working with highly variable subjects, such as people, animals or cells. Repeating published work wastes time and money, the critics say, and it does nothing to advance knowledge. They'd prefer to see questions approached with a variety of different methods. It's the general patterns and basic principles — the reproducibility of a finding, not the precise replication of a specific experiment — that really matter.

It seems that everyone has an opinion about the underlying causes leading to irreproducibility, and many have offered solutions. But no one

OPPOSITE: HARRY CAMPBELL

Replication anxieties

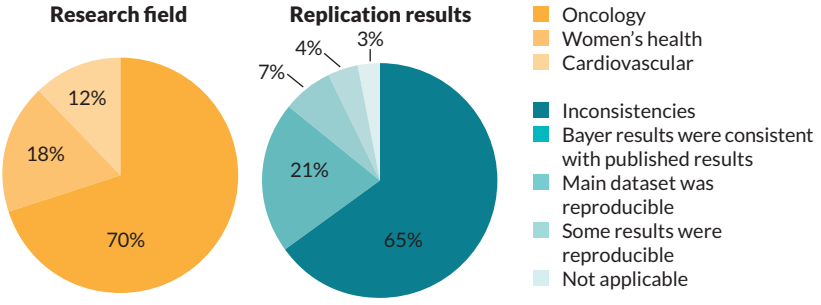
THIS ISSUE

"Repeat Performance"
Too many discrepancies in research results is sparking self-reflection among scientists

NEXT ISSUE, FEBRUARY 7

"Big Data, Big Challenges"
With move toward massive datasets, opportunities for chaos and errors multiply

Wrong answers The Bayer pharmaceutical company tried to repeat studies in three research fields (gold chart), mostly cancer studies. Almost two-thirds of the redos (dark teal) produced results inconsistent with the original findings.
SOURCE: F. PRINZ *ET AL/NATURE REVIEWS DRUG DISCOVERY* 2011



really knows entirely what is wrong or if any of the proffered fixes will work.

Much of the controversy has centered on the types of statistical analyses used in most scientific studies, and hardly anyone disputes that the math is a major tripping point. An influential 2005 paper looking at the statistical weakness of scientific studies generated much of the self-reflection taking place within the medical community over the last decade. While those issues still exist, especially as more complex analyses are applied to big data studies, there remain deeper problems that may be harder to fix.

Taking sides

Epo researchers weren't the first to find discrepancies in their results, but their experience set the stage for much of the current controversy.

Mufson, head of the National Cancer Institute's Cancer Immunology and Hematology Etiology Branch, organized a two-day workshop in 2007 where academic, government and pharmaceutical company scientists, clinicians and patient advocates discussed the Epo findings.

A divide quickly emerged between pharmaceutical researchers and scientists from academic labs, says Charles Bennett, an oncologist at the University of South Carolina.

Bennett was part of a team that had reported in 2005 that erythropoietin reduced the need for blood transfusions and possibly improved survival among cancer patients. But he came to the meeting armed with very different data. He and colleagues found that erythropoietin and darbepoetin used to treat anemia in cancer patients raised the risk of blood clots by 57 percent and the risk of dying by about 10 percent. Others found that people with breast or head and neck cancers died sooner than other cancer patients if they took Epo.

Those who argued that Epo was harmful to patients cited cellular mechanisms: tumor cells make more Epo receptors than other cells. More receptors, the researchers feared, meant the drug was stimulating growth of the cancer cells, a finding that might explain why patients were dying.

Company scientists from Amgen, which makes Epo drugs, charged that they had tried and could not replicate the results published by the academic researchers. After listening to the researchers hash through data for two days, Bennett could see why there was conflict. The company and academic scientists couldn't even agree on what constituted growth of tumor cells, or on the correct tools for detecting Epo receptors on tumor cells, he says. That disconnect meant neither side would be able to confirm the other's findings, nor could they completely discount the results. The meeting ended with a list of concerns and direction for future studies, but little consensus.

"I went in thinking it was black and white," Bennett says. "Now, I'm very much convinced it's a gray answer and everybody's right."

From there, pressure continued to build. In 2012, Amgen caused shock waves by reporting that it could independently confirm only six of 53 "landmark" papers on preclinical cancer studies. Replicating results is one of the first steps companies take before investing in further development of a drug. Amgen will not disclose how it conducted the replication experiments or even which studies it tried to replicate. Bennett suspects the controversial Epo experiments were among the chosen studies, perhaps tinting the results.

Amgen's revelation came on the heels of a similar report from the pharmaceutical company Bayer. In 2011, three Bayer researchers reported in *Nature Reviews Drug Discovery* that company scientists could fully replicate only about 20 to 25 percent of published preclinical cancer, cardiovascular and women's health studies. Like Amgen, Bayer did not say which studies it attempted to replicate. But those inconsistencies could mean the company would have to drop projects or expend more resources to validate the original reports.

Scientists were already uneasy because of a well-known 2005 essay by epidemiologist John Ioannidis, now at Stanford University. He had used statistical arguments to contend that most research findings are false. Faulty statistics often indicate a finding is true when it is not. Those falsely positive results usually don't replicate.

Academic scientists have had no easier time than drug companies in replicating others' results. Researchers at MD Anderson Cancer Center in

Houston surveyed their colleagues about whether they had ever had difficulty replicating findings from published papers. More than half, 54.6 percent, of the 434 respondents said that they had, the survey team reported in *PLOS ONE* in 2013. Only a third of those people were able to correct the discrepancy or explain why they got different answers.

"Those kinds of studies are sort of shocking and worrying," says Elizabeth Iorns, a biologist at the University of Miami in Florida and chief executive officer for Science Exchange, a network of labs that attempt to independently validate research results.

Over the long term, science is a self-correcting process and will sort itself out, Tabak and NIH director Francis Collins wrote last January in *Nature*. "In the shorter term, however, the checks and balances that once ensured scientific fidelity have been hobbled. This has compromised the ability of today's researchers to reproduce others' findings," Tabak and Collins wrote.

Myriad reasons for the failure to reproduce have been given, many involving the culture of science (see "12 reasons research goes wrong," page 24). Fixing the problem is going to require a more sophisticated understanding of what's actually wrong, Ioannidis and others argue.

Two schools of thought

Researchers don't even agree on whether it is necessary to duplicate studies exactly, or to validate the underlying principles, says Giovanni Parmigiani, a statistician at the Dana-Farber Cancer Institute in Boston. Scientists have two schools of thought about verifying someone else's results: replication and reproducibility. The replication school teaches that researchers should retrace all of the steps in a study from data generation through the final analysis to see if the same answer emerges. If a study is true and right, it should.

Proponents of the other school, reproducibility, contend that complete duplication only demonstrates whether a phenomenon occurs under the exact conditions of the experiment. Obtaining consistent results across studies using different methods or groups of people or animals is a more reliable gauge of biological meaningfulness, the reproducibility school teaches. To add to the confusion, some scientists reverse the labels.

Timothy Wilson, a social psychologist at the University of Virginia in Charlottesville, is in the reproducibility camp. He would prefer that studies extend the original findings, perhaps modifying variables to learn more about the underlying principles. "Let's try to discover something," he says. "This is the way science marches forward. It's slow and messy, but it works."

Parmigiani says both paths toward truth are important. At any rate, researchers will never get science completely right, he contends. "We're always in a gray area between perfect truth and complete falsehood," he says. The best researchers can do is edge closer to truth.

But Iorns and Brian Nosek, a psychologist and one of Wilson's colleagues at the University of Virginia, are among those who think exact duplication can move research in the right direction.

In 2013, Nosek and his former student Jeffrey Spies cofounded the Center for Open Science, with the lofty goal "to increase openness, integrity and reproducibility of scientific research." Their approach was twofold: provide infrastructure to allow scientists to more easily and openly share data and conduct research projects to repeat studies in various disciplines in science.

Soon, Nosek and Iorns' Science Exchange teamed up to replicate 50 of the most important (defined as highly cited) cancer studies published between 2010 and 2012. On December 10, 2014, the Reproducibility Project: Cancer Biology

Survey says ... Academic researchers have trouble duplicating other researchers' published results, a survey from MD Anderson Cancer Center suggests. Researchers, especially junior faculty members and trainees, often don't resolve discrepancies and tend not to publish conflicting reports. SOURCE: A. MOBLEY *ET AL*/*PLOS ONE* 2013

Questions	% Answering Yes			
	Total	Senior Faculty	Junior Faculty	Trainee
Have you ever tried to reproduce a finding from a published paper and not been able to do so?	54.6%	66.2%	48.7%	48.5%
Did you contact the authors who published the findings?	78.0%	79.5%	81.0%	73.1%
Were the differences in results ever resolved?	33.3%	37.5%	23.1%	30.8%
Did you publish the results that disagreed with those in the literature?	33.3%	48.2%	28.9%	17.6%
Did you have difficulty publishing the contradictory results?	43.8%	30.8%	61.5%	66.7%

kicked off when three groups announced in the journal *eLife* their intention to replicate key experiments from previous studies and shared their plans for how to do it.

Iorns, Nosek and their collaborators hope the effort will give scientists a better idea of the reliability of these studies. If the replication efforts fail, the researchers want to know why. It's possible that the underlying biology is sound, but that some technical glitch prevents successful replication of the results. Or the researchers may have been barking up the wrong tree. Most likely the real answer is somewhere in the middle.

Neuroscience researchers realized the value of duplicating studies with therapeutic potential early on. In 2003, the National Institute of Neurological Disorders and Stroke contracted labs to redo some important spinal cord injury studies that showed promise for helping patients. Neuroscientist Oswald Steward of the University of California, Irvine School of Medicine heads one of the contract labs.

Of the 12 studies Steward and colleagues tried to copy, they could fully replicate only one. And only after the researchers determined that the ability of a drug to limit hemorrhaging and nerve degeneration near an injury depended upon the exact mechanism that produced the injury. Half the studies could not be replicated at all and the rest were partially replicated, or produced mixed or less robust results than the originals, according to a 2012 report in *Experimental Neurology*.

Notably, the researchers cited 11 reasons that might account for why previous studies failed to replicate; only one was that the original study was wrong. Exact duplications of original studies are impossible, Steward and his colleagues contend.

Acts of aggression

Before looking at cancer studies, Nosek investigated his own field with a large collaborative research project. In a special issue of *Social Psychology* published last April, he and other researchers reported results of 15 replication studies testing 26 psychological phenomena. Of 26 original observations tested, they could only replicate 10. That doesn't mean the rest failed entirely; several of the replication studies got similar or mixed results to the original, but they couldn't qualify as a success because they didn't pass statistical tests.

Simone Schnall conducted one of the studies that other researchers claimed they could not replicate. Schnall, a social psychologist at the University of Cambridge, studies how emotions affect judgment.

She has found that making people sit at a sticky, filthy desk or showing them revolting movie scenes not only disgusts them, it makes their moral judgment harsher. In 2008, Schnall and colleagues examined disgust's flip side, cleanliness, and found that hand washing made people's moral judgments less harsh.

M. Brent Donnellan, one of the researchers who

12 reasons research goes wrong

Barriers to research replication are based largely in a scientific culture that pits researchers against each other in competition for scarce resources. Any or all of the factors below, plus others, may combine to skew results.

Pressure to publish

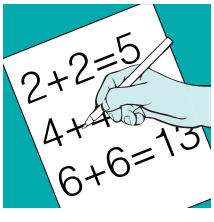
Research funds are tighter than ever and good positions are hard to come by. To get grants and jobs, scientists need to publish, preferably in big-name journals. That pressure may lead researchers to publish many low-quality studies instead of aiming for a smaller number of well-done studies. To convince administrators and grant reviewers of the worthiness of their work, scientists have to be cheerleaders for their research; they may not be as critical of their results as they should be.

Impact factor mania

For scientists, publishing in a top journal — such as *Nature*, *Science* or *Cell* — with high citation rates or "impact factors" is like winning a medal. Universities and funding agencies award jobs and money disproportionately to researchers who publish in these journals. Many researchers say the science in those journals isn't better than studies published elsewhere, it's just splashier and tends not to reflect the messy reality of real-world data. Mania linked to publishing in high-impact journals may encourage researchers to do just about anything to publish there, sacrificing the quality of their science as a result.

Tainted cultures

Experiments can get contaminated and cells and animals may not be as advertised. In hundreds of instances since the 1960s, researchers misidentified cells they were working with. Contamination led to the erroneous report that the XMRV virus causes chronic fatigue syndrome, and a recent report suggests that bacterial DNA in lab reagents can interfere with microbiome studies.



Bad math

Do the wrong kinds of statistical analyses and results may be skewed. Some researchers accuse colleagues of "p-hacking," massaging data to achieve particular statistical criteria. Small sample sizes and improper randomization of subjects or "blinding" of the researchers can also lead to statistical errors. Data-heavy studies require multiple convoluted steps to analyze, with lots of opportunity for error. Researchers can often find patterns in their mounds of data that have no biological meaning.

Sins of omission

To thwart their competition, some scientists may leave out important details. One study

attempted to replicate Schnall's 2008 findings, blogged before the replication study was published that his group made two unsuccessful attempts to duplicate Schnall's original findings. "We gave it our best shot and pretty much encountered an epic fail as my 10-year-old would say," he wrote. When Schnall and others complained that the comments were unprofessional and pointed out several possible reasons the study failed to replicate, Donnellan, a psychologist at Texas A&M University in College Station, apologized for the remark, calling it "ill-advised."

Schnall's criticism set off a flurry of negative remarks from some researchers, while others leapt to her defense. The most vociferous of her champions have called replicators "bullies," "second-stringers" and worse. The experience, Schnall said, has damaged her reputation and affected her ability to get funding; when decision makers hear about the failed replication they suspect she did something wrong.

"Somehow failure to replicate is viewed as more informative than the original studies," says Wilson. In Schnall's case, "For all we know it was an epic fail on the replicators' part."

The scientific community needs to realize that it is difficult to replicate a study, says Ioannidis. "People should not be shamed," he says. Every geneticist, himself included, has published studies purporting to find genetic causes of disease that turned out to be wrong, he says.

Iorns is not out to stigmatize anyone, she says. "We don't want people to feel like we're policing them or coming after them." She aims to improve the quality of science and scientists. Researchers should be rewarded for producing consistently reproducible results, she says. "Ultimately it should be the major criteria by which scientists are assessed. What could be more important?"

Variable soup

Much of the discussion of replicability has centered on social and cultural factors that contribute to publication of irreplicable results, but no one has really been discussing the mechanisms that may lead replication efforts to fail, says Benjamin Djulbegovic, a clinical researcher at the University of South Florida in Tampa. He and long-time collaborator mathematician Iztok Hozo of Indiana University Northwest in Gary have been mulling over the question for years, Djulbegovic says.

They were inspired by the "butterfly effect," an illustration of chaos theory that one small action can have major repercussions later. The classic example holds that a butterfly flapping its wings in Brazil can brew a tornado in Texas. Djulbegovic hit on the idea that there's chaos at work in most biology and psychology studies as well.

Changing even a few of the original conditions of an experiment can have a butterfly effect on the outcome of replication attempts, he and Hozo reported in June in *Acta Informatica Medica*. The two researchers considered a simplified case in which 12 factors may affect a doctor's decision on

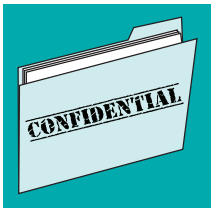
found that 54 percent of research papers fail to properly identify resources, such as the strain of animals or types of reagents or antibodies used in the experiments. Intentional or not, the result is the same: Other researchers can't replicate the results.

Biology is messy

Variability among and between people, animals and cells means that researchers never get exactly the same answer twice. Unknown variables abound and make replicating in the life and social sciences extremely difficult.

Peer review doesn't work

Peer reviewers are experts in their field who evaluate research manuscripts and determine whether the science is strong enough to be published in a journal. A sting conducted by *Science* found some journals that don't bother with peer review, or use a rubber stamp review process. Another study found that peer reviewers aren't very good at spotting errors in papers. A high-profile case of misconduct concerning stem cells revealed that even when reviewers do spot fatal flaws, journals sometimes ignore the recommendations and publish anyway (*SN: 12/27/14, p. 25*).



Some scientists don't share

Collecting data is hard work and some scientists see a competitive advantage to not sharing their raw data. But selfishness also makes it impossible to replicate many analyses, especially those involving expensive clinical trials or massive amounts of data.

Research never reported

Journals want new findings, not repeats or second-place finishers. That gives researchers little incentive to check previously published work or to try to publish those findings if they do. False findings go unchallenged and negative results — ones that show no evidence to support the scientist's hypothesis — are rarely published. Some people fear that scientists may leave out important, correct results that don't fit a given hypothesis and publish only experiments that do.

Poor training produces sloppy scientists

Some researchers complain that young scientists aren't getting proper training to conduct rigorous work and to critically evaluate their own and others' studies.

Mistakes happen

Scientists are human, and therefore, fallible. Of 423 papers retracted due to honest error between 1979 and 2011, more than half were pulled because of mistakes, such as measuring a drug incorrectly.

Fraud

Researchers who make up data or manipulate it produce results no one can replicate. However, fraud is responsible for only a tiny fraction of results that can't be replicated.
— *Tina Hesman Saey*

> "We need a balance of innovation and verification."
>
> **BRIAN NOSEK**

how to treat a patient. The researchers focused on clinical decision making, but the concept is applicable to other areas of science, Djulbegovic says. Most of the factors, such as the decision maker's time pressure (yes or no) or cultural factors (present or not important) have two possible starting places. The doctor's individual characteristics — age (old or young), gender (male or female) — could have four combinations and the decision maker's personality had five different modes. All together, those dozen initial factors make up 20,480 combinations that could represent the initial conditions of the experiment.

That didn't even include variables about where exams took place, the conditions affecting study participants (Were they tired? Had they recently fought with a loved one or indulged in alcohol?), or the handling of biological samples that might affect the diagnostic test results. Researchers have good and bad days too. "You may interview people in the morning, but nobody controls how well you slept last night or how long it took you to drive to work," Djulbegovic says. Those invisible variables may very well influence the medical decisions made that day and therefore affect the study's outcome.

Djulbegovic and Hozo varied some of the initial conditions in computer simulations. If initial conditions varied between experiments by 2.5 conditions or less, the results were highly consistent, or replicable. But changing 3.5 to four initial factors gave answers all over the map, indicating that very slight changes in initial conditions can render experiments irreproducible.

The study is not rigorous mathematical proof, Djulbegovic says. "We just sort of put some thoughts in writing."

Balancing act

Failed replications may offer scientists some valuable insights, Steward says. "We need to recognize that many results won't make it through the translational grist mill." In other words, a therapy that shows promise under specific conditions, but can't be replicated in other labs, is not ready to be tried in humans.

"In many cases there's a biological story there, but it's a fragile one," Steward says. "If it's fragile, it's not translatable."

That doesn't negate the original findings, he says. "It changes our perspective on what it takes to get a translatable result."

Nosek, proponent of replication that he is, admits that scientists need room for error. Requiring absolute replicability could discourage researchers from ever taking a chance, producing only the tiniest of incremental advances, he says. Science needs both crazy ideas and careful research to succeed.

"It's totally OK that you have this outrageous attempt that fails," Nosek says. After all, "Einstein was wrong about a lot of stuff. Newton. Thomas Edison. They had plenty of failures, too." But science can't survive on bold audacity alone, either. "We need a balance of innovation and verification," Nosek says.

How best to achieve that balance is anybody's guess. In their January 2014 paper, Collins and Tabak reviewed NIH's plan, which includes training modules for teaching early-career scientists the proper way to do research, standards for committees reviewing research proposals and an emphasis on data sharing. But the funding agency can't change things alone.

In November, in response to the NIH call to action, more than 30 major journals announced that they had adopted a set of guidelines for reporting results of preclinical studies. Those guidelines include calls for more rigorous statistical analyses, detailed reporting on how the studies were done, and a strong recommendation that all datasets be made available upon request.

Ioannidis offered his own suggestions in the October *PLOS Medicine*. "We need better science on the way science is done," he says. He helped start the Meta-Research Innovation Center at Stanford to conduct research on research and figure out how to improve it.

In the decade since he published his assertion of the wrongness of research, Ioannidis has seen change. "We're doing better, but the challenges are even bigger than they were 10 years ago," he says.

He is reluctant to put a number on science's reliability as a whole, though. "If I said 55 to 65 percent [of results] are not replicable, it would not do justice to the fact that some types of scientific results are 99 percent likely to be true."

Science is not irrevocably broken, he asserts. It just needs some improvements.

"Despite the fact that I've published papers with pretty depressive titles, I'm actually an optimist," Ioannidis says. "I find no other investment of a society that is better placed than science." ■

Explore more

- Timothy M. Errington *et al*. "An open investigation of the reproducibility of cancer biology research." *eLife*. December 10, 2014.

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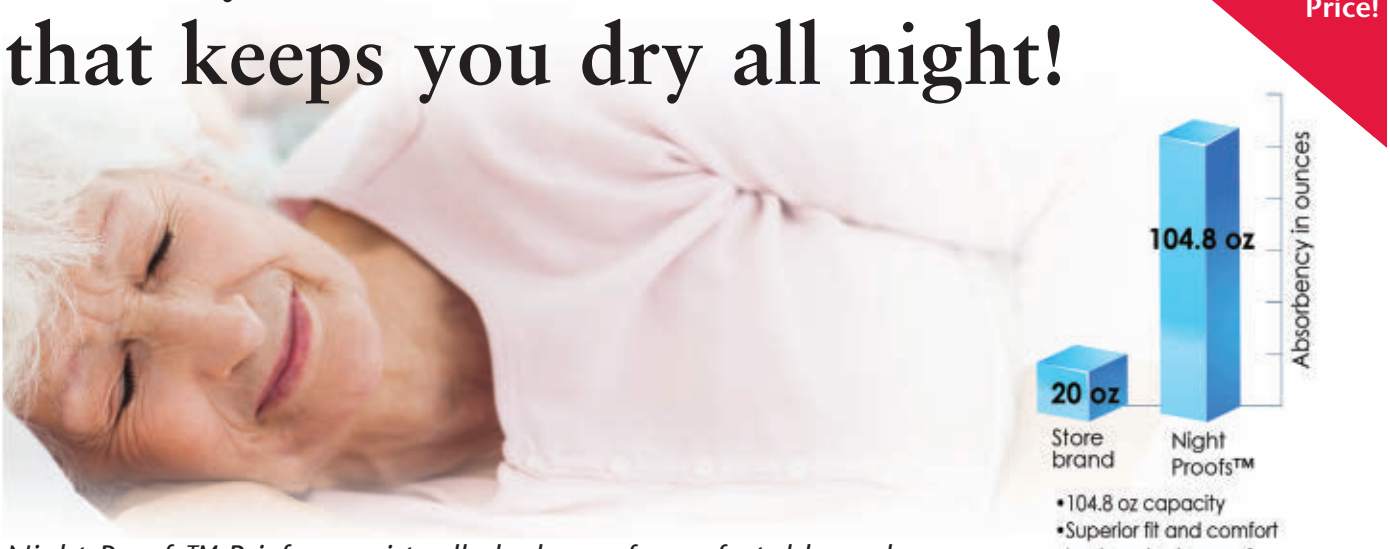

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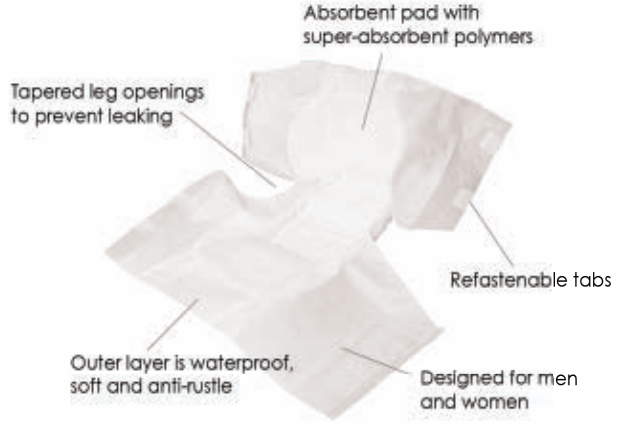

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Benedict Cumberbatch plays the British mathematician and World War II code breaker Alan Turing in *The Imitation Game*.

FILM

The Imitation Game entertains at the expense of accuracy

Ordinarily the life of a mathematician isn't ideal fodder for a major Hollywood movie. But when that mathematician is Alan Turing — the British genius who inspired the modern computer, protected Allied soldiers from Nazi attacks with his code-breaking prowess and was a closeted gay man — you've got yourself a film with Oscar buzz. (Casting Benedict Cumberbatch as the lead doesn't hurt either.)

Overall, the movie is fun and gripping. It features a brilliant performance from Cumberbatch. But like so many Hollywood biopics, it takes some major artistic license — which is disappointing because Turing's actual story is so compelling.

The film mainly takes place during the early years of World War II, when the German war machine is dominating Britain. Frustratingly, the British can intercept German communications but can't understand them. The Germans had encoded their communiqués on Enigma machines, encryption devices that could substitute letters in a message using any of about 150 quintillion possible settings. The filmmakers effectively portray a race against the clock as Turing struggles to perfect his crazy idea for a machine that could break the Enigma code.

In reality, Turing had already outlined the concept of a computing machine in a 1936 paper (*SN: 6/30/12, p. 26*) and had built a cipher machine while at Princeton in the late 1930s, says Turing biographer Andrew Hodges. By mid-1940, Hodges says, Turing and his team at Bletchley Park in Milton Keynes, England, were routinely decoding German Air Force messages with code-breaking machines, or bombes. Within another year the cryptanalysts, who included Joan Clarke (played by Keira Knightley), had deciphered the all-important naval messages that strategized U-boat attacks.

The film skips the biggest real-life drama, Hodges says. In February 1942, the Germans adopted a more complex Enigma machine for naval communications. "It was a major crisis," Hodges says. Turing and American partners ran multiple bombes in parallel and used electronic components to speed up the code-breaking process. Finally, in early 1943, the Allies succeeded in cracking the code.

The consequences of the 1942 Enigma upgrade went far beyond the war. The introduction to electronics, Hodges says, offered Turing a practical means for incorporating his 1936 conceptual ideas into a revolutionary machine — the digital computer. "The scientific story is much bigger than just the Enigma problem," Hodges says. "It was a great movement in which ideas and new technology came together."

The Imitation Game ignores much of this history. It also includes an egregious, historically inaccurate story line in which Turing fails to report a Soviet spy to avoid being outed as gay.

Nonetheless, the acting, suspense and a surprising amount of humor make it a movie worth seeing. Just take some time after the movie to read up on Turing's actual immense contributions to the war and modern computing. — *Andrew Grant*

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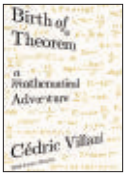

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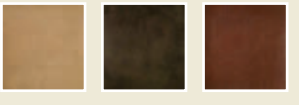

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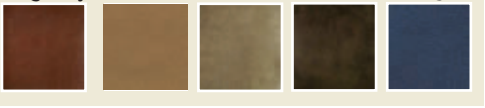

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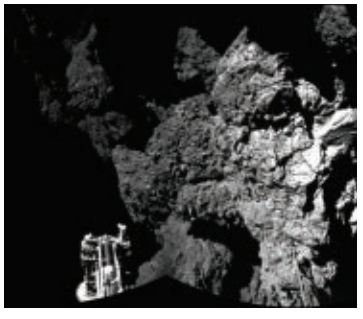
SOCIAL MEDIA

On a comet far, far away



"Probably the most lonely view in the solar system right now."

@cabbageleek on Twitter, in response to Philae's first photos from the surface of comet 67P (*SN: 12/13/14, p. 6*).

Concerned about cocoa

High doses of a cocoa antioxidant boost blood flow in the hippocampus, an important brain area for learning and memory. In "Cocoa antioxidant sweetens cognition in elderly" (SN: 12/27/14, p. 5)*,* ***Bethany Brookshire*** *described how these molecules, called flavanols, also improve older people's ability to tell complex visual patterns apart.*

Commenters on the medical journal site PubMed expressed concerns that the study did not meet standards for clinical trial reporting. Before performing a study with human volunteers, scientists must register their experiments on ClinicalTrials.gov, an online database maintained by the National Institutes of Health. But **Hilda Bastian** and others pointed out that the experiment described in the cocoa study didn't match the one submitted to the website: The researchers reported giving high and low doses of flavanols to participants, while the clinical trial initially set out to compare high doses of flavanols to no flavanols at all.

Study author **Scott A. Small** of Columbia University says that he and his team have submitted an update to ClinicalTrials.gov and that the submission is awaiting approval. As for the flavanol doses, **Small** says that the beverage used to deliver the high dose contained a number of other components, such as potassium, caffeine and calcium. The low-flavanol beverage had all the same components, he says, and was included to show that only the flavanols had an effect on cognition. "The levels of flavanols in the low-flavanol condition were so low that they have no known effect on the body," he explains.

Monitoring Mount Nyiragongo

Geologists are keeping an eye on Mount Nyiragongo, an active Congolese volcano that sits perilously close to a growing city. Violent conflicts in the area make this important job difficult, as ***Thomas Sumner*** *reported in "War zone volcano"* (SN: 12/13/14, p. 26)*.*

Researchers occasionally descend into the sweltering crater of the volcano to scoop up fresh lava samples for study. That's very exciting, **Tom Ostwald** wrote in an e-mail, but "is it really necessary to get 'em while they're hot? It would seem that any lava with an accurate birth date would suffice."

A freshly deposited lava sample offers benefits beyond just a known birth date, explains **Sumner**. "The rising magma fueling Nyiragongo contains a baseline mix of the radioactive isotopes the researchers use to date flows. This mixture will vary depending on whether radioactive daughter products in the magma are whisked away as gas. Without this information from a newborn rock, the researchers couldn't tell if a certain pair of isotopes in a lava sample had reached equilibrium over several years or whether they'd already been in balance when they were first spat from the volcano."

He adds that this baseline is especially important for shorter-lived isotopes such as polonium-210, which has a half-life of just 138 days.

Playing with science

In "Evolve and Linkage turn science into games" (SN: 12/27/14, p. 32)*,* ***Tina Hesman Saey*** *and a competitive group of* Science News *staffers tested out a pair of biology-based card games.*

"I love hearing about others who are creating science-based games," wrote **John J. Coveyou**. "Are there any other science-themed games that I should know about?"

One reader-supplied suggestion was Go Extinct, developed by STEAM Galaxy Studios. "Like Go Fish, but with species," explained **Andy Hall**. "Light on the science concepts, but it does teach a bit about the tree of life, and the rules are easy — which is a big plus."

Commenter **jmcnichols** added another game to the list: "Evolution is similar in theme to Evolve but looks more polished. I can't speak for the game-play differences but Evolution had plenty of strategy. It doesn't teach about evolution either, but uses the relationships between species in an interesting way."

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Delicious bird or poisonous caterpillar?

The orange chick of an Amazonian bird looks a lot like a toxic caterpillar. Now a rare peek into a nest suggests the chick may act the part, too.

Adults of the bird called the cinereous mourner (*Laniocera hypopyrra*) are gray with a few brownish spots on the shoulders. "Boring," acknowledges Gustavo Londoño of Universidad Icesi in Cali, Colombia. Yet the chicks, which are frail and reside in leafy nests that look like open cups, boast vivid, attention-grabbing color (above). A recent survey suggests that some 80 percent of cup nests in the region get attacked, Londoño says.

The chicks' appearance, however, may discourage predators. A 1982 paper proposed that fluff disguises chicks as less desirable moss-covered fruits. And in 2012, another team proposed that chicks might resemble toxic orange caterpillars from the region (inset) — at least as far as the researchers could tell by examining two museum specimens of baby mourners.

Watching and photographing a live chick in a cup nest in Peru supports that idea, Londoño and his colleagues report in the January *American Naturalist*. In addition to sporting a caterpillar-esque coat, the chick waved its head from side to side when the nest was disturbed. That's peculiar for a baby bird, but it's a very caterpillar thing to do.

These nest observations are only the second published for the cinereous mourner, and they fit with the proposal that mourners exhibit Batesian mimicry. In this classic evolutionary bit of fakery, never before seen in bird nestlings, vulnerable organisms increase their chances of survival by imitating dangerous or inedible neighbors. — *Susan Milius*

MAIN: SANTIAGO DAVID-RIVERA; INSET: WENDY VALENCIA

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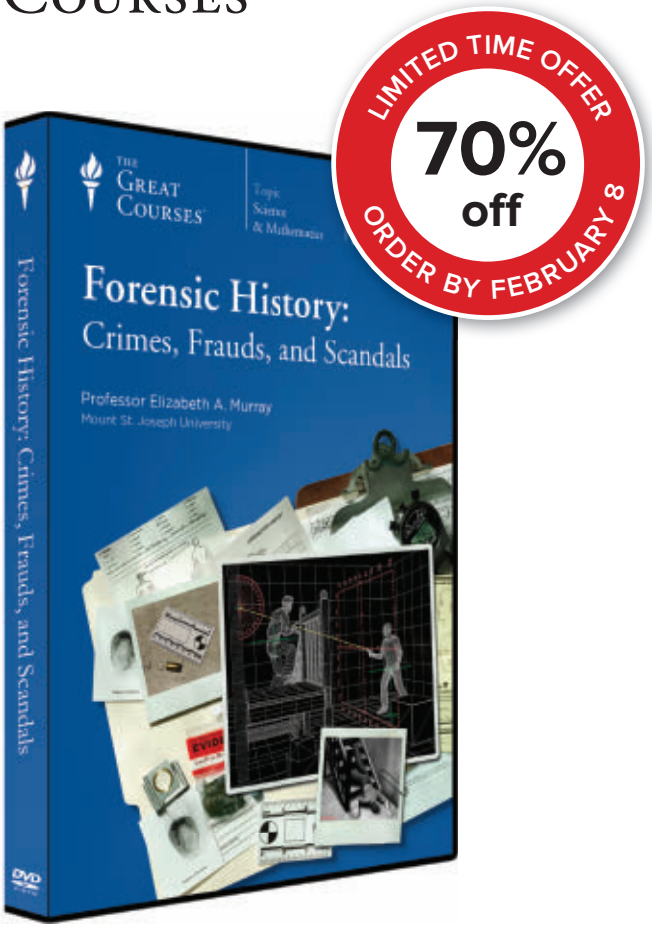

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