METEOROLOGY

The brainstormers

Alan Thorpe enjoys a hymn to some of the founders of the science and institutions of weather forecasting.

It is thanks to the efforts of an international community of meteorologists and atmospheric scientists that accurate forecasts of major weather systems can be made reliably up to about a week ahead (see P. Bauer *et al. Nature* **525,** 47–55; 2015). Many researchers contributed to the revolution in weather sciences in the first half of the twentieth century, so it is perhaps invidious to single out a few.

Science historian James Fleming focuses on three: Norwegian Vilhelm Bjerknes, Swede Carl-Gustaf Rossby and American Harry Wexler. The first two I expected; the third I was intrigued to learn more about. Fleming devotes about 60 pages to each man's life and work, and mentions many others and their impacts, mostly on US weather forecasting.

To the cognoscenti, the essentials of Bjerknes's and Rossby's science will be familiar. Fleming's fascinating account clarifies why these two were giants of leadership. Bjerknes created the 'Bergen school' of meteorology, which used rigorous scientific principles to understand and predict the evolution of weather features such as fronts and cyclones. The school included his son Jacob among many talented, mainly Scandinavian, scientists. Rossby established university schools of meteorology in Stockholm and Chicago, and at the Massachusetts Institute of Technology in Cambridge. The breadth of Wexler's role emerges through his contributions to the development of techniques and operational weather forecasting, particularly in the United States.

Inventing Atmospheric Science: Bjerknes, Rossby, Wexler, and the Foundations of Modern Meteorology
JAMES RODGER FLEMING
MIT Press: 2016.

Between the birth of Bjerknes — the oldest — in 1862 and the death of Wexler, the youngest, in 1962, there passed a formative and innovative century. As Fleming reveals, their lives were linked, with Bjerknes teaching Rossby and Rossby, Wexler.

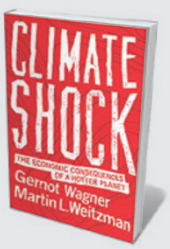
In 1904, in 'Weather forecasting as a problem in mechanics and physics', Bjerknes set the agenda for applying the laws of physics to the atmosphere to predict the weather (V. Bjerknes *Meteorol. Z.* **21,** 1–7; 1904). His vision was to use a sufficiently accurate knowledge of the state of the atmosphere and the laws that govern its evolution to forewarn people about weather to come. His motivation was to make his mark in what was for him a new field of science — he began his career working with his father, a physicist at the University of Oslo, on fluid analogies for the electromagnetic field. He was eager, too, to provide practical advice on hazards that affected mariners, farmers and the public.

Fleming notes the absence of a book-length biography of Rossby, and I hope that this will be rectified soon. To me, he is a first among equals. As well as building institutions, he established important principles, such as the conservation of potential vorticity — used to understand the development of rotation in cyclones and other weather systems — and the large-scale atmospheric wave patterns named after him. He was a leader in developing techniques such as experiments that simulate the atmosphere in a rotating tank of water, as well as aircraft soundings and the use of radiosondes, or radio-based measurements using weather balloons. A polymath with a high public profile, he was pictured on the cover of *Time* magazine in December 1956, with the title "Weatherman".

Wexler's contributions include making the first research flight into a hurricane, using radar to track storm systems, working

NEW IN PAPERBACK

Highlights of this season's releases



Climate Shock: The Economic Consequences of a Hotter Planet
Gernot Wagner and Martin L. Weitzman (Princeton University Press, 2016)
Global, long-term, irreversible, uncertain: four words used by economists Gernot Wagner and Martin Weitzman in their timely warning on the impacts of climate change. It is not enough to simply hope that we are wrong about worst-case scenarios; the authors' most extreme predictions include a 20-metre sea-level rise and average global temperatures reaching 6 °C above pre-industrial levels. Wagner and Weitzman urge us to act now to insure Earth against uncertainty.

towards space observations and developing the use of computers in meteorology.

From the findings of these three men, Fleming expertly weaves a tapestry of broader developments, from early uses of computers and satellites to numerical predictions with supercomputers. He explores intentional weather modification, radioactive fallout, rocketry, air pollution and electromagnetism. For example, the air movements made apparent when researchers tracked the fallout from nuclear-bomb tests in the 1950s provided insight into atmospheric circulation.

The penultimate chapter covers what Fleming calls the birth of atmospheric science in the late 1950s, coinciding with planning for the International Geophysical Year in 1957–58. In 1956, Rossby proposed enlarging the definition of meteorology to include elements such as atmospheric chemistry and relevant biological processes. Much of what we regard as contemporary developments, such as the understanding of atmospheric composition or geoengineering, were in the minds of 1950s researchers, Fleming points out.

Modifying the reflectivity of the planet to avoid harmful climate change was discussed by Wexler and others as early as 1958. In a 1962 speech, Wexler said: "We are in weather control now whether we know it or not." Fleming also focuses on the importance of committees in planning developments such as the creation of the US National Center for Atmospheric Research in 1960, and the role of top researchers in leading these committees.

A historical account has to have boundaries, and Fleming barely hints at what came after 1960. I found the discussion of Edward Lorenz's work on chaos that led to aspects of probabilistic forecasting disproportionately brief.

What shines through *Inventing Atmospheric Science* is the commitment of three men to applications of research to society, and their desire to advance our understanding of weather. This is an inspirational story, very well told. ■

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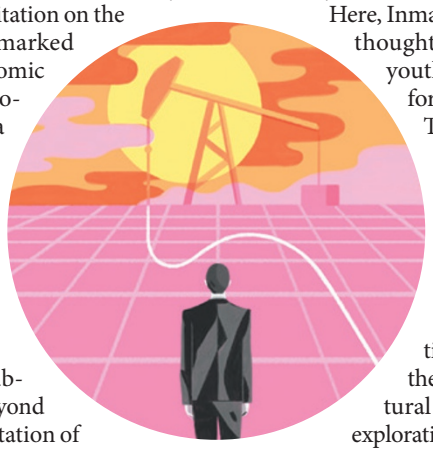
ENERGY

Oilman at the peak

Gregor Macdonald applauds a biography of prescient geologist and energy theorist Marion King Hubbert.

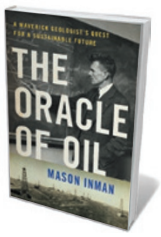
A scientist's work does not always intersect neatly with the events of their time, but that was the good fortune of US geologist and oilman Marion King Hubbert (1903–89). After labouring for decades to perfect forecasting of the oil-production limit, he saw his efforts validated in the energy crises of the early 1970s. His approach would later be known as Hubbert peak theory.

Journalist Mason Inman's meticulous biography *The Oracle of Oil* follows Hubbert from his youth on the plains of Texas through the Great Depression, the Second World War and the rise of US President Ronald Reagan in 1981. But its scope is much more expansive. In Hubbert's story, Inman has found a meditation on the booms and busts that marked twentieth-century economic growth. Hubbert's iconoclastic career forms a perfect arc, from oil's troubling oversupply in the 1920s to its relative scarcity after the peak of US production in 1971, when the US economy suffered oil shocks.



As Inman shows, Hubbert's impact extends beyond oil: it is an early manifestation of ecological economics. At the end of his career, Hubbert remained concerned about nuclear waste; was convinced that high rates of growth were environmentally destructive; and conjectured that solar power might be the most viable energy solution. With regard to growth or sustainability, Hubbert's work is an overlooked contribution to US economic history.

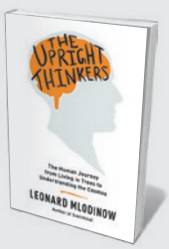
Arriving at the University of Chicago in Illinois in 1924 with little money but no shortage of ambition, Hubbert saw geology as a wide-open field, and gate-crashed it. With precocious brilliance, he began to identify gaps and disorganization in its practices, and published his first paper, on fault classifications, as an undergraduate. In 1930, he was head-hunted by Columbia University in New York City to direct a new effort in geophysics.



The Oracle of Oil: A Maverick Geologist's Quest for a Sustainable Future
MASON INMAN
W. W. Norton: 2016.

Here, Inman's biography reveals its thoughtful design, tracing the youthful roots of Hubbert's formidable achievements. The undergrad pondering Earth's folds one summer later becomes a breakthrough geologist, solving complex scaling problems. The boy surrounded by oil rigs becomes a Shell executive, aggressively pursuing the hydrological and structural complexities of oilfield exploration. The young man who questioned religious faith becomes a nonconformist US Geological Survey (USGS) researcher, insisting that popular forecasts are built less on data than on optimism.

Inman's direct, explanatory style is well suited to describing the evolution of Hubbert's thinking. At Columbia, Hubbert began to ponder the S-curve of growth that has long fascinated observers of economies, biology and natural-resource extraction. He perfected his technique over decades, from rough ▶



The Upright Thinkers
Leonard Mlodinow (Vintage, 2016)
Carrier pigeons once toted stock prices. Today, instant messaging manages the job. Theoretical physicist Leonard Mlodinow explores how the most human of desires, a thirst for knowledge, grew from Neanderthal hunger pangs to measuring our planet's orbit around the Sun.

Why Information Grows
César A. Hidalgo (Penguin, 2016)
Economies are computers and information is at war with entropy, claims statistical physicist César Hidalgo. He shows how the scientific imagination needs knowledge and resources to grow, such as the Chilean copper that 'feeds' electronics (see Philip Ball's review: *Nature* **521,** 420–421; 2015).

estimates of ultimately recoverable US oil reserves to his eventual winning model: an advanced calculation that incorporated past production, yield per foot of exploration and the tricky variable of reserve growth.

Inman does not, however, cite the work of UK economist William Stanley Jevons, whose 1865 warning about the economy's over-reliance on coal prefigures the Hubbert story. Jevons died in 1882, so never saw his prediction come true: British coal output peaked in 1913. Hubbert, by contrast, was feted with numerous awards, including the Rockefeller Service Award in 1977, and broad coverage in *The New York Times* when his previous reports for the government and the USGS were acknowledged for their accuracy.

Hubbert's forecast was not the end of the US oil story. After his death, production continued to languish, in accordance with his forecast. But with fracking, the United States lifted oil production as recently as last year to levels close to the 1970 peak. Oil production is now falling again owing to a price bust — global supply capabilities were created for demand that failed to materialize. Inman does a fine job of handling this recent history.

The Oracle of Oil offers valuable insights beyond energy. In the demand-side bust of the 1930s, it shows Hubbert thinking deeply about the surplus of labour created partly, in his view, by the effects of powerful oil married to the newest machines: cars, construction equipment and aircraft. Hubbert was co-founder of Technocracy, a group of New York intellectuals aiming to prevent future economic dislocations. Two publications by keen observers of the low-growth problem — Thomas Piketty's *Capital in the Twenty-First Century* (Seuil, 2013) and Robert Gordon's 2012 paper 'Is US Economic Growth Over?' (see go.nature.com/wblxig) — also explore this territory of limits and sustainability.

In Inman's work, the oilman emerges as a restless and prescient figure concerned with the environment. In writing the first biography of Hubbert, Inman has retrieved, if not rescued, the story of a scientist who has much to offer to today's energy conundrum. ■

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NEUROSCIENCE

Listening in on yourself

Douwe Draaisma is intrigued by a study examining both 'the voice within' and verbal auditory hallucinations.

Thinking about thinking is a curious exercise. Most of us probably agree that much of our own thought process takes the form of inner speech. But would we also agree that we hear an inner voice? If not, why would we call it talking at all? Can we experience and observe inner speech simultaneously, or would this be like "trying to turn up the gas quickly enough to see how the darkness looks", as US psychologist William James asked himself in 1890? Each of these questions may lead one into a philosophical forest, dense and dark.

Side-stepping such conceptual intricacies, psychologist Charles Fernyhough convincingly explores inner speech from a practical perspective. In *The Voices Within*, he discusses how people with aphasia (a speech and language disorder that stems from brain damage) may lose their sense of inner speech; how deaf people 'talk to themselves' (mostly in sign language, some by lipreading); how more than 60% of children have had silent conversations with imaginary friends; and whether people who stutter experience their inner speech as fluent (they do). Silent self-talk, evasive as it is to introspection, turns out to be a robust and quintessential part of memory, thought and imagination.

Fernyhough's sources are equally wide-ranging. He draws on internal monologues

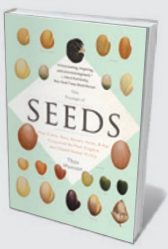
The Voices Within: The History and Science of How We Talk to Ourselves
CHARLES FERNYHOUGH
Profile: 2016.

in Gustave Flaubert's 1856 novel *Madame Bovary* and reports of self-talk by professional cricketers. He mentions physicist Richard Feynman having an argument with himself, and Joan of Arc insisting that God talked to her in French, not Latin. Today, Fernyhough directs Hearing the Voice, a research project at Durham University, UK, funded by biomedical charity the Wellcome Trust.

SILENT SELF-TALK TURNS OUT TO BE A ROBUST PART OF MEMORY.

When I'm invited to write a review, I know from experience that it is wise to switch my inner speech from Dutch, my native language, to English, which I routinely use for scientific communication. Most bilingual people have no trouble identifying the language that they are thinking in. But I would be hard-pressed to say whether I talk to myself at a natural speed or in an abbreviated way, much less whether the stream of my thoughts flows equally fast (or slow) in both languages. Most people say that they have the definite impression that their inner speech unfolds faster than actual speech.

Spirals in Time: The Secret Life and Curious Afterlife of Seashells
Helen Scales (Bloomsbury, 2016)
From beachcombing to shipwreck diving, marine biologist Helen Scales shares her love of molluscs, many of which convert seawater into protective homes. Shells, she reveals, have served as everything from jewellery to calcareous currency.



The Triumph of Seeds
Thor Hanson (Basic, 2016)
Biologist Thor Hanson sows the ultimate celebration of seeds and how they conquered Earth. Kernels can be crafty: unripe fruit, for instance, tastes bitter to deter predators from dispersing the seeds too soon (see Sandra Knapp's review: *Nature* **519,** 288–289; 2015).

Referring to the ideas of philosopher Eric Schwitzgebel, Fernyhough points out that this leaves several questions open. Is internal speech faster because it is unhampered by slower motor processes, or because we don't think in full sentences? According to twentieth-century Russian psychologist Lev Vygotsky, inner speech develops as children's conversations 'go underground', often as a result of social encouragement. In the process, they begin to think in 'pure meanings', causing telegraphic inner speech. This condensation, in turn, could help to explain the paradoxical sensation that inner speech feels faster, but never rushed. Sped up or condensed? To this day, there are no consensual methods or techniques to decide between the two.

Fernyhough also presents several interviews with participants in his Durham research project, itself an offshoot of the Hearing Voices Movement founded in 1987 by Dutch psychiatrist Marius Romme and now expanded to 23 countries. At present, the United Kingdom has 180 support groups for voice-hearers. Some people report hearing intrusive voices, often whispering or shouting abuse, and seek relief by joining a local group. Most people who experience verbal auditory hallucinations have had a diagnosis of schizophrenia or have experienced childhood abuse — but, as Fernyhough points out, not all. Clinically relevant as they are, these chapters expose a tension in *The Voices Within*: it is still a matter of controversy whether hearing voices has much to do with the quiet self-talk of ordinary thinking.

Fernyhough tries to bridge this gap with a model that he dubs dialogic thinking, which conceptualizes inner speech as an internalized conversation between different voices. He hypothesizes that if a patient fails to identify a particular utterance as a fragment of some inner dispute, he might experience this fragment as coming from an external source — a hallucination. But many voice-hearers also experience inner speech, and can distinguish between the two. It remains to be seen whether the experience of hearing voices will really offer a window on inner speech.

We have come a long way from US psychologist John Watson's behaviourist speculation that inner speech is simply covert motor action in the speech apparatus. New methods have invited new distinctions. Neuroimaging studies by Fernyhough and his colleagues suggest that speaking internally when instructed activates Broca's area in the brain (associated with producing speech), and deactivates Heschl's gyrus (associated with auditory perception). Spontaneous, free-flowing inner speech, on the other hand, involved the opposite pattern of neural activation. This is but one of many promising avenues of research, and *The Voices Within* is full of them. Profound and eloquent (he is a novelist too), Fernyhough presents an intriguing array of fresh findings and perspectives. He makes a persuasive case that one of the most intimate and private of our mental activities has a social origin. We talk to ourselves because we talked to others first. ■

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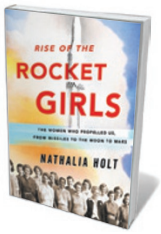
Infested: How the Bed Bug Infiltrated Our Bedrooms and Took Over the World
Brooke Borel (University of Chicago Press, 2016)
Bed bugs (*Cimex lectularius*) are perfectly adapted for bloodsucking. Toothed mandibles pierce their victims' skin and inject saliva proteins that widen the blood vessels and prevent clotting, reveals Brooke Borel in her creepy exposé of the household pest.

Life's Greatest Secret: The Race to Crack the Genetic Code
Matthew Cobb (Profile, 2016)
Anecdotes abound in zoologist Matthew Cobb's history of the quest to unravel the genetic code. Cobb updates the story with a look at gene-editing tool CRISPR and its role in gene therapy, agriculture and the control of invasive species.

SPACE SCIENCE

The women who launched NASA

Jennifer Light savours the history of a doughty band of 'human computers'.



Rise of the Rocket Girls: The Women Who Propelled Us, from Missiles to the Moon to Mars
NATHALIA HOLT
Little, Brown: 2016.

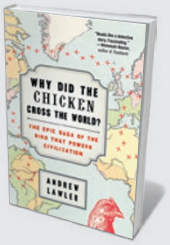
Data is having its moment in the sun. It used to be an incidental detail in stories about personalities and institutions in the history of science and engineering, politics and culture. Now, the construction of databases and details of data analysis are featured events. Even the 2015 film *Spotlight*, which dramatizes a journalistic investigation into sexual abuse in the Catholic Church, has an extended scene in which the protagonists compile a spreadsheet. Number crunchers, once stereotyped as missing the bigger picture, now are the big picture.

Natalia Holt's *Rise of the Rocket Girls* reveals how, from the 1940s, a group of 'crunchers' operated in near secrecy at NASA — their anonymity as much to do with their gender as with the status of data. These women staffed NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California, as human computers and, later, programmers. Most held degrees in mathematics or science. Their work, Holt reveals, was innovative, yet was considered less important than other JPL outputs. Holt documents the work of previously unknown figures such as Barbara Canright, Susan Finley and Helen Ling, who supplied crucial calculations that helped to launch missiles, bombers and the first US satellite; to control lunar missions; and even to navigate today's Mars rovers. Intercut with the human stories, Holt carefully lays out practical problems — such as the need to minimize fuel weight while ensuring that a rocket could reach escape velocity — and how mathematics helped to solved them.

Here, maths is dramatic, not mundane. Calculating is a physical, even athletic, act. Holt describes Canright's experience: "Her right index finger was lined with thick red and white calluses, the result of clutching a pencil for hours a day. Her grip on the pencil often made her hand perspire, leaving pucker marks across the graph paper." The women held "computing races" to solve complex mathematical problems in their down time. But as Holt shows, 'doing the maths' was often a matter of life and death. She describes Marie Crowley's work on the ideal size and shape of a rocket's nozzle opening: the faster a nozzle can clear exhaust, the more thrust the rocket generates. On one occasion, as engineers were about to run a test based on her calculations, Crowley realized that she had forgotten to take a square root. Her phone call came too late and the rocket failed — luckily, no one was hurt. Often rushed and never double-checked in those seat-of-the-pants days, the calculations were a source of anxiety for the women.

The drama of data is not the book's main rationale. Holt's larger interest is that it was women who did the calculating. The book is organized chronologically, with photographs of starring figures at the start of each section. In keeping with larger currents in historical studies of databases and data analysis, Holt argues that these women's calculations played an under-appreciated part in NASA's towering achievements. She bases her chronicle on interviews with several JPL data crunchers, members of their families and lab engineers, as well as a reading of scholarly and archival literature on the space programme.

The book does not show equal mastery of research on gender and labour in technical fields: Holt provides more data than analysis. She depicts the human computers' life stories vividly, but her reflections on larger themes are limited. One is the relationship between people and machines. For example, Holt mentions the women's limited use of calculation aids. They often found it faster to do hand calculations than to work with a Friden calculating machine. Even in the late 1950s, when JPL acquired an IBM 704 — an early mass-produced computer — the crunchers (and engineers) were



Why Did the Chicken Cross the World?
Andrew Lawler (Atria, 2016)
With 20 billion chickens roaming Earth at any one time, this beleaguered bird truly merits Andrew Lawler's illuminating eulogy. It shows how the red junglefowl (*Gallus gallus*) strutting in a Borneo jungle became an economic mainstay (see Ewen Callaway's review: *Nature* **515,** 490–491; 2014).

Most Wanted Particle
Jon Butterworth (The Experiment, 2016)
Experimental physics becomes accessible as well as astounding in this insider's account of the hunt for the Higgs boson, detected in 2012. Explaining fermions, jet algorithms and particle-accelerator malfunctions with ease, Jon Butterworth puts a lively spin on atomic science.

wary of machines "that had too many glitches to be trustworthy". The speed and accuracy of later models threatened to make the mathematicians' roles redundant, but the women staved off obsolescence for some time by redefining their official jobs as programmers. Holt misses an opportunity here to make the connection between the experiences of JPL's human computers in relation to the rise of automation, and today's widespread anxieties over the 'age of artificial intelligence'.

Personal anecdotes include details of the family arrangements that the women had to make in an era when marriage and children meant leaving the workforce. These will fascinate general readers and provide valuable primary source materials for future academics. Yet Holt does not contextualize the JPL crunchers' experience in the broader history of women in science and technology. She does observe that the proportion of JPL technical jobs held by women — 15% in the 1990s — was partly due to women organizing the hiring process. Yet although the figure was higher than elsewhere in NASA, it was still remarkably low. And in the same way that NASA failed to celebrate these women's contributions, it also overlooked the evidence in favour of including women in the astronaut corps. As space curator Margaret Weitekamp has detailed in *Right Stuff, Wrong Sex* (Johns Hopkins University Press, 2004), the benefits of sending women to space included their small size compared to men, which meant that they would need less food and water.

Engagement with such studies would have helped Holt to analyse how typical the JPL programmers' experience was for women in technical fields, and to explicate her original findings more clearly. Many scholarly studies describe the exodus of women at other institutions from programming by the 1950s. By contrast, Holt notes, some of the early female crunchers stayed at JPL well into the twenty-first century, some in managerial roles. That raises questions about what made JPL different and, crucially, about retaining women in technical fields today. That story remains to be written. ■

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GENETICS

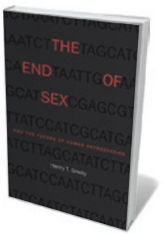
Coitus defunctus

Lori Andrews assesses Henry Greely's treatise on how technology will oust reproductive intimacy.

For millennia, people have been trying everything from magic to medicine to influence the traits of their children. Recommendations from relatives and advice columns have, across time, included: put a knife under your bed if you want a boy; eat sweets while pregnant if you want a girl; place headphones on your pregnant belly and play Jacopo Peri's *Euridice* to ensure that your future child will appreciate opera.

Current genetic technologies offer parents more-precise means of predicting and perhaps shaping the traits of their children. Embryos created through *in vitro* fertilization (IVF) can be analysed using pre-implantation genetic diagnosis (PGD); their entire genomes can even be sequenced. And the gene-editing technique CRISPR–Cas9 is expected to one day offer couples a chance to repair and enhance the genes of their embryos.

In *The End of Sex and the Future of Human Reproduction*, lawyer and bioethicist Henry Greely does an enviable job of explaining the scientific underpinnings and legal regulation of current reproductive and genetic technologies. The central focus of his book is his prediction that a new technology will develop — one that he dubs "Easy PGD". Greely envisions a situation in which a woman will not have to undergo treatment with hormones and have her eggs removed to produce an embryo for testing — as is done in the course of IVF. Instead, some of her skin cells will be removed and coaxed by stem-cell technologies to turn into eggs. The eggs will then be fertilized by sperm from her partner to create as many as 100 embryos. In this scenario, parents will be able to choose which embryos to have implanted in the woman's uterus on the basis of hundreds of traits (or more) revealed by whole-genome sequencing.



The End of Sex and the Future of Human Reproduction
HENRY T. GREELY
Harvard University Press: 2016.

THE PROCESS OF DECISION-MAKING WOULD BE DAUNTING.

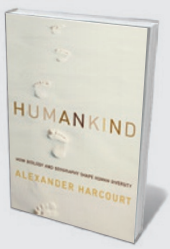
Greely makes three claims about this putative Easy PGD. First, it will replace sex as a way to create babies. Second, it will be more socially acceptable than current PGD and prenatal genetic-testing technologies. And third, it will be free to the user.

All three claims are problematic.

Greely assumes that people will elect to create children with Easy PGD rather than through sex because of the desire to control the traits of their children. But if people were so keen to choose embryos on the basis of their genotypes, all couples who use IVF would submit their embryos to genetic testing (given that this would involve no extra risk to the woman). In the United States, only 5% of such couples do so.

Greely also speculates that couples will rush to use stem cells to create embryos because such an approach would be less ▶

Birth of a Theorem: A Mathematical Adventure
Cédric Villani (Vintage, 2016)
Tackling the 140-year-old Boltzmann equation (with Clément Mouhot) led mathematician Cédric Villani to win a share in the 2010 Fields Medal. Documenting this quest, Villani encapsulates the despair and elation that maths can incite (see Amir Alexander's review: *Nature* **519,** 31–32; 2015).



Humankind: How Biology and Geography Shape Human Diversity
Alexander Harcourt (Pegasus, 2016)
Biogeographer Alexander Harcourt ponders the myriad forces that led to the amazing diversity of *Homo sapiens* as we spread across the globe. He thinks that coastal migration once prevailed: harvesting seafood was easier than hunting.

invasive than IVF. But there is no proof that the risks to women presented by IVF (such as ovarian hyperstimulation syndrome and pelvic infection) are a substantial deterrent when it comes to couples who use the procedure: globally, more than 400,000 children are born through IVF each year. Nor is there any evidence that couples would embrace an untested stem-cell procedure, with unknown risks to the resulting child.

Even if Easy PGD were risk-free, the process of decision-making would be daunting. Whole-genome sequencing would provide prospective parents with hundreds or thousands of bits of information about each embryo. The *BRCA1* tumour-suppressor gene alone consists of more than 81,000 base pairs. Of the hundreds of *BRCA1* mutations that have been reported, some are associated with an increased risk of developing breast cancer or ovarian cancer; others are not, and the significance of many is not yet known.

If the test reports a mutation of unknown significance in any of an embryo's 20,000 genes, parents might end up discarding a perfectly healthy embryo, or — if they have the embryo implanted anyway — worrying throughout the child's life about the potential manifestation of a horrible condition. Even the mutations that are associated with disease will be hard to make sense of. What does a person do with the knowledge that a certain embryo will develop into someone who has a breast-cancer risk 30% higher than that of the general population, double the baseline risk of developing Alzheimer's disease, and a 45% possibility of achieving a higher college admission score than another embryo with an equally complex data set?

Greely claims that Easy PGD will be more socially acceptable than current genetic testing of embryos and fetuses because, unlike existing approaches, it does not involve abortion. Yet whether the embryos are derived from skin cells or seeded with gametes, right-to-life advocates will oppose the termination of embryos that could be implanted to create children. Furthermore, many more embryos would be discarded using Greely's proposed Easy PGD than are now destroyed in the course of IVF and PGD.

Greely's final claim is that Easy PGD will be free. Using assumptions, including that it will cost US$1,000 to create 100 embryos from skin cells, $60 per embryo for genetic diagnosis, and $500 for genetic counselling, he estimates that it will cost about $11,000 for the entire procedure. According to Greely, at that cost, "the procedure should pay for itself for health reasons". But current genetic technologies also save future health costs, and these techniques are not always covered by health-care systems. In fact, it is extremely difficult for women below a certain income bracket to access them.

Greely imagines the slogans that clinics will use to tout Easy PGD: "You want the best for your child; why not have the best child you can?" But after exploring Greely's claims in detail, Easy PGD seems more likely to be an expensive technology of unknown risks that would present parents with hard-to-interpret information about as many as 100 embryos. The idea of Easy PGD should make us uneasy indeed. ■

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Pressed for Time: The Acceleration of Life in Digital Capitalism
Judy Wajcman (University of Chicago Press, 2016)
Sociologist Judy Wajcman sagely analyses the disparate experience of time as technology has evolved. Despite the common belief that smartphones heighten stress, she argues that we are not victims of machines, but masters of their role in our lives.

The Cosmic Cocktail: Three Parts Dark Matter
Katherine Freese (Princeton University Press, 2016)
What is the Universe made of? Physicist Katherine Freese chronicles the cracking of this beguiling enigma, from the eccentric, ski-jumping Fritz Zwicky (who coined the term dark matter) to particle-smashing physics (see Francis Halzen's review: *Nature* **509,** 560–561; 2014). **Emily Banham**