ripple in incandescent waves".

Roberts's personal anecdotes bring the struggle of one scientist, in service of the sea, into sharp focus. I can just imagine his cheery face as he dressed down the head of the Marine Stewardship Council for sanctioning fisheries with questionable sustainability. I would like to have been there.

About two-thirds of the way through, with the statement "I am an optimist", Roberts starts to introduce solutions to his litany of seemingly intractable problems. In the subsequent chapters, he discusses aquaculture, pollution abatement and his signature research achievement: marine protected areas. These are all fields in which tremendous strides have been made, some by Roberts himself, to help the future oceans and the human communities that rely on them.

Yet Roberts cannot help pointing out that the problems are still huge. This is partly because some of the easiest apparent fixes — such as aquaculture — can do more harm than good in practice. But it may also be partly down to Roberts's need to keep the parlous state of the ocean in the public and governmental eye. Environmental problems can become so polarized in society that any excuse to downplay or deny them is trumpeted by special-interest groups — a reaction that surfaces with greater and greater frequency.

Back at the World Oceans Summit, Steve McCormick, president of the philanthropic Gordon and Betty Moore Foundation, declared that there has never been a time in ocean conservation like now, when the solutions to ocean problems are laid before us and some of the challenges, particularly overfishing, are conquerable. *Ocean of Life*, in detailing sobering facts about the ills that afflict the largest biosphere on Earth, is a call to action. At the heart of this book is a deep love of the ocean and a profound concern for its viability as a resource for us all. ■

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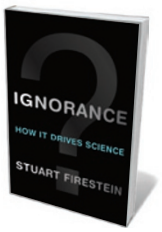
PHILOSOPHY

What we don't know

Michael Shermer enjoys a reminder that cutting-edge research is a step into the unknown.

At a press conference in 2002, Donald Rumsfeld, then US secretary of defence, used epistemology to explain US foreign entanglements and their unintended consequences. "There are known knowns; there are things we know we know. We also know there are known unknowns; that is to say, we know there are some things we do not know. But there are also unknown unknowns, the ones we don't know we don't know," he said.

It is this last category that is the focus of Stuart Firestein's sparkling and innovative look at ignorance, and how it drives the scientific process. Firestein is a neurobiologist at Columbia University in New York, where he teaches a wildly popular course on ignorance, inviting scientists to tell students not what they know, but what they don't. He muses, would you rather earn an A or an F in a class called Ignorance?



MARTIN O'NEILL

Ignorance: How it Drives Science
STUART FIRESTEIN
Oxford University Press: 2012. 256 pp. £14.99, $21.95

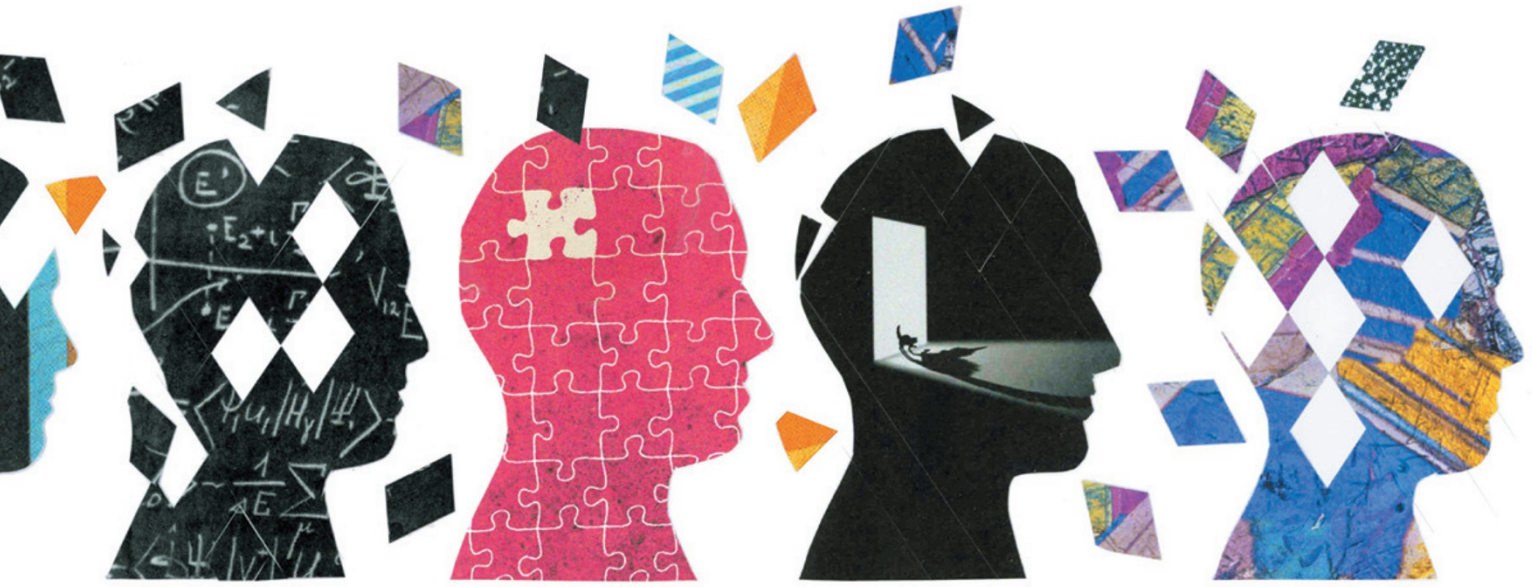
Firestein introduces the concept of ignorance by contrasting the public's perception of science — as a systematic process — with a scientists' understanding that it is more haphazard. Most people think of science as a stepwise algorithm, in which researchers grind through experiments that churn out data sets that are analysed statistically and published in peer-reviewed journals: part of an endless cycle of observation, hypothesis testing and adjustment.

In reality, as mathematician Andrew

NEW IN PAPERBACK

Highlights of this season's releases

Changing Planet, Changing Health: How the Climate Crisis Threatens Our Health and What We Can Do About It
Paul R. Epstein and Dan Ferber (University of California Press, 2012; $24.95)
Public-health expert Paul Epstein and science journalist Dan Ferber confront an under-recognized and crucial issue: the effects of climate change on health. Too great a focus on immediate concerns, such as cost, is threatening the planet's basic life-support systems, they argue. Reviewer Tony McMichael called it "an excellent corrective for climate-change myopia" (*Nature* **472,** 292–293; 2011).



Wiles says in the book, science consists of "groping and probing and poking, and some bumbling and bungling". A switch is discovered and a light comes on. It is like looking for the proverbial black cat in a dark room.

It is in the dark that cutting-edge science takes place. To make discoveries, researchers need to look beyond the facts — to where they run out, says Firestein. Scientists should "forget the answers, work on the questions". That is good advice, because the mountain of facts is now so vast that we cannot hope to learn, let alone remember, them.

It has been estimated that, from the beginning of civilization — 5,000 years ago or more — until 2003, humanity created a total of five exabytes (billion gigabytes) of information. From 2003 to 2010, we created this amount every two days. By 2013, we will be doing so every ten minutes, exceeding within hours all the information currently contained in all the books ever written.

So it isn't that we need more knowledge; it is that we need to distinguish between what we know and what we don't know, through what Firestein calls "controlled neglect". Researchers must selectively ignore vast quantities of facts and data that block creative solutions, and focus on a narrow range of possibilities.

Ignorance includes an important discussion about scientific errors and their propagation in textbooks. I admit that I passed one on in my last book, *The Believing Brain* (Times Books, 2011): I repeated as gospel the 'fact' that the human brain contains about 100 billion neurons. Firestein reports that it is actually around 80 billion, and that the number of glial cells is an order of magnitude smaller than most textbooks state.

The 'neural spike' recorded by neuroscientists as a fundamental unit of brain activity, Firestein reminds us, is an artefact of our measuring devices and ignores other forms of neural activity. Even the famous and widely printed 'tongue map', which shows sweet flavours sensed on the tip of the tongue, bitter on the back and salt and sour on the sides, is wrong — the result of a mistranslation of a German physiology paper. These and other errors arise as a result of our lack of scepticism towards the knowledge we have.

TO MAKE DISCOVERIES, RESEARCHERS NEED TO LOOK BEYOND THE FACTS.

To Rumsfeld's categories, Firestein adds one more: unknowable unknowns, or "things that we cannot know due to some inherent and implacable limitation". He puts history in this category, but I would not. When history is defined as anything that happened before the present, it includes much of astronomy, geology, archaeology, palaeontology and evolutionary biology — fields with hypotheses that can be tested with as much rigour as experiments in the lab.

I worry, too, that too much emphasis on ignorance opens the door to creationists, climate deniers and others with political agendas who wish to challenge mainstream scientists. Acknowledging our ignorance is good, but we should also recognize the well-supported theories that science has confidently given us.

As scientific knowledge grows, so does our awareness of how much we don't know. "Ignorance works as the engine of science because it is virtually unbounded," explains Firestein, "and that makes science much more expansive". We should remember that when a sphere becomes bigger, the surface area grows. Thus, as the sphere of scientific knowledge increases, so does the surface area of the unknown. Firestein's book reminds us that it is at this interface that we can claim true and objective progress. ■

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e-mail: mshermer@skeptic.com

Animal Architects
James L. Gould and Carol Grant Gould (Basic Books, 2012; $16.99)
James and Carol Gould, an ethologist and a science writer, challenge the idea that a good builder needs a human brain. They show how the constructive skills of termites and birds become built in. (See Tore Slagsvold's review: *Nature* **446,** 730; 2007.)

Not Exactly: In Praise of Vagueness
Kees van Deemter (Oxford Univ. Press, 2012; £11.99)
Computer scientist Kees van Deemter makes the case for vagueness, saying that the idea of 'true' and 'false' statements defies classical logic because language is imprecise. (See Andrew Robinson's review: *Nature* **463,** 736; 2010).