others allowed first view of uncharted lands, and supported great leaps ahead.

The Oracle at Delphi once professed, “Make your own nature, not the advice of others, your guide in life”. Bill’s scientific life followed his nature, from dusty entomology libraries to steaming jungles.

This book traces not just Bill’s scientific ideas, but also his academic struggles to get his papers published, establish a name, and build a successful career. Early in his professorial days, at Silwood Park outside London, his publications were very few and had yet to garnish acceptance, much less fame. His lectures to undergraduates were legendary in their disjointedness and derailments, and he much preferred pulling bark off dead logs to participation in academic committees and service — and acted on his preferences. As Darwin was berated by his father for excessive natural history and outdoor pursuits, Hamilton suffered in mainstream academia, including the indignity of denied promotion — at least in part due to his preoccupations with the world of Nature rather than Man. He also fought with acceptance in journals — especially *Nature* – and against what he saw as insidious preemption of his core 1964 work. Fortunately, Richard Alexander at the University of Michigan arranged a professorship for Bill in Ann Arbor, where he spent seven highly productive years largely free from academic yokes and distraction, as his scientific prestige and impact soared. Professional success that grew beyond imagining brought great rewards, including a research professorship at Oxford — but Bill never really changed, and came fully to life only when immersed in some forest, savannah, or river, transported back to the days of Bates and Wallace. Understanding the puzzles of Nature remained a challenge, and an obsession, thoughout all of his days, but such trials were suffused with beauty and adventure as he bounced between the glorious oak wood of Wytham near his home, to the flooded Amazonian forest, and the sun bears, ground figs and fighting beetles of Borneo.

Nature’s Oracle deserves its place in the Pantheon of worthy biographies of biologists, most notably those of J.B.S. Haldane [5], Sir Ronald Fisher [6], and Sewall Wright [7], all of whom play cameo roles in Bill Hamilton’s chronicle. This biography differs, however, in that the author seeks a deep understanding of Bill’s personality, his motivations, and the soul that connects his life with life’s work. By my own account, as one of his graduate students, Bill’s psyche best reflects in how once he bent over his vast card catalogue of scrawled references, looked up, and opined, “These are the neurons of my brain”. Indeed, those were the synapses that linked boundless curiousity for the natural world, boyish enthusiasm, a Victorian-era love of exotic flora and fauna, a continual search for Nature’s patterns that emerged from exploration and collection, and an immutable sense of justice.

From the time I spent with Bill, and his circles of friends, I can fairly say that this book succeeds in accurately and effectively mixing individual with scientific narrative, and providing as clear a view as one could expect into Bill’s life. Sometimes the story jumps erratically across years, and readers without interests in evolution or behavior may lose incentive to read through, but the rewards remain — insights into the humble, sometimes tortured origins of major evolutionary ideas, and revelations on how to cultivate one’s own scientific creativity by being willing to explore beyond the trimmed hedge-rows of convention.

One of Bill’s later works described his “intended burial and why” [8], whereby the giant carrion beetles of Amazonia would disperse his transformed flesh and blood back to the beauties of Nature. This book serves as metaphor, to likewise disperse his ideas and life. The Oracle may be silenced, but his inspiration and words live on.

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Department of Biosciences, 8888 University Drive, Simon Fraser University, Burnaby BC V5A 1S6, Canada.
E-mail: crespi@sfu.ca

Q & A

Leon Lagnado

Leon Lagnado graduated in Physiology from University College London in 1985, and then did his Ph.D research with Peter McNaughton in Cambridge, investigating how retinal photoreceptors respond to light. He carried out post-doctoral work with Denis Baylor at Stanford University, where he developed his interest in the retina as a neural circuit. Returning to Cambridge in 1993, he joined the newly established Neurobiology Division at the MRC Laboratory of Molecular Biology where he began his work on the synaptic basis of visual processing in the retina. In 1998, he was awarded the Wellcome Prize in Physiology. He is currently a Group Leader at the LMB, but will soon be joining the University of Sussex where he will continue his work on the senses while also acting as Director of Sussex Neuroscience.

What turned you on to biology in the first place? I was turned on to science in general before I homed in on biology. Watching the moon landings at the age of six made a deep impression and I think that probably marks the beginning of my awareness of science as an exciting activity. I also remember that one of my favourite books as a child was *The Ladybird Book of Great Inventions*; it contains a beautiful illustration of Galileo peering at the heavens through his telescope — he is so excited that he is almost falling off his chair! This is a recurring motif in science: to discover new things it is often necessary to find a new way of looking. At school, my favourite subject was physics, but then I ended up studying medicine at UCL. Medicine was a mistake but UCL was a great experience. There I discovered two things: that it might be possible for me to pursue a life as a scientist (which I had not appreciated until then), and that experimental biology was both exciting and rewarding. I learnt these things from outstanding teachers such as David Attwell and Stuart Cull-Candy. In Stuart’s third year course on synaptic physiology we repeated some of Bernard Katz’s classical experiments

on neuromuscular transmission by recording miniature end-plate potentials using 35 mm cine cameras attached to old oscilloscopes. Watching mini's in real-time got me hooked!

If you were starting again knowing what you know now, would you still pursue the same career/research path? I would almost certainly want to be a professional scientist. Being provided with all the essentials of life while spending most of one's time chasing ideas is a privilege that very few of my species will ever have. It's hard to be more specific than this because I haven't really pursued a preconceived career path. I was incredibly lucky in finding opportunities to do what I wanted to do and perhaps the prime example was being able to start my own lab at the LMB. Sometimes I started things that I thought that I wanted to do only to find that they weren't really satisfying, but I'm not sure that I would change any of these mistakes — they were relatively painless and they are an essential part of the learning process.

What is the best advice you've been given? The most important advice has been to think for oneself and I've received it in many forms, most usually through reading. Bertrand Russell's opening to his essay "*On the Value of Scepticism*" puts it beautifully: "I wish to propose a doctrine which may, I fear, appear wildly paradoxical and subversive. The doctrine in question is this: that it is undesirable to believe a proposition when there is no ground whatever for supposing it true." What a simple idea! It is subversive because people who think for themselves will question received dogmas, especially religious or political. A more personal piece of advice was given to me by my post-doc supervisor, Denis Baylor: "*These* are the good old days". I wouldn't say that living for the moment was one of my strengths, so I try to remember this and make my lab an enjoyable place to work.

What advice would you offer someone wondering whether to start a career in biology? If you enjoy it, do it. But if science doesn't give you joy, at least sometimes, find something else to do. In terms of *how* to do science, I don't think that I would offer a firm opinion apart from try to find what you are good at and what gives you pleasure (hopefully they will coincide). Different people have different styles of science, reflecting their individual strengths and weaknesses. Some work in a general area using broad brush strokes, while others home in on a narrower question and keep chipping away. Some work in small groups, while others build empires. These different approaches are all an essential part of the mix that drives science forward. We also need good people willing to take on leadership/administrative roles because they can help create the environments in which science can flourish. I count myself lucky to have started my independent research under the watchful and encouraging eyes of Nigel Unwin and Richard Henderson — both scientists' scientists.

Do you have a scientific hero? I have many scientific heroes! I think the first was James Burke, who wasn't a practicing scientist but a science presenter on the BBC. He covered the moon landings and then a few years later made a TV series called "Connections" which traced the historical relationships between different scientific and technological discoveries. Inspiring! Amongst the recognized greats, my favourites are Galileo and Darwin. Their thinking revolutionized our understanding of the world and our place in it, and as a result they had to be brave and tolerant in the face of attacks from religious authority. Their incredible intellects were also contained within personalities which were warm and kind to family and friends. For me, Galileo and Darwin show the best of both the human mind and spirit.

A hero that I did have the opportunity to interact with was Alan Hodgkin, who won the Nobel Prize for his work on the biophysical basis of the action potential. My first task as a Ph.D student was to sit in a blacked out room and make notes on a chart recorder as he and his post-doc Brian Nunn recorded light responses from rod photoreceptors. Alan encouraged me to stick with science in the most subtle way: I was showing him some traces from one of my experiments and he pointed out that, if I were to do a post-doc in the US, I would have to date records with the month before the day. I took the hint!

What do you think are the big questions to be answered next in your field? My particular area of neuroscience, sensory processing, is extremely active. Many of us who work in this area would like to understand how circuits of neurons operate on incoming information, and to my mind the biggest challenge is to synthesize a proper understanding of the computational principles with the underlying neurobiology. Are there basic computations that different parts of the brain share in common? If so, how are they implemented by the cells and molecules? Getting at these questions requires methods for observing signals across complete populations of neurons, synapses and dendrites as they process information in real-time. There has been great progress in the last decade with the development of better microscopy techniques and fluorescent reporters, as well as the means of manipulating circuits using optogenetics. This is a large communal effort into which much money has been invested around the world, and the next decade will be exciting. I hope that my lab can contribute by focusing on the synapses that transmit signals between neurons.

What is your greatest ambition in research? To feel that I've made a useful contribution.

The relation between science and religion is often discussed in the media — what are your views?
For the large majority of scientists, religion has no direct impact on their research and this is not an issue that concerns them. But I don't believe that we should pretend that science and religion are 'compatible': they are actually diametrically opposed ways of thinking and acquiring knowledge. Science is revealing the incredible beauty of the world by a simple formula: the rational application of our communal common sense. In contrast, religion ultimately justifies its propositions on the basis of an individuals faith without reference to evidence, and so it is essentially anti-intellectual. Science is promulgated by our instincts to question and enquire while the different religions are promulgated by our needs for community and comforting formulas which get around death as the end of an individuals existence. Of course, science and religion can coexist (and often do in the same person), but this is more likely evidence of the agility of the human brain than, as some hopefully claim, because they deal with separate areas of understanding. The rational approach to acquiring knowledge and understanding has told us much more about what it is to be human than any religious book, and I think that all the evidence indicates that this will continue in the future.

I understand that polls of professional scientists indicate that many share broadly similar views to mine, but most shy away from publicly airing them because they don't want to be accused of being confrontational or intolerant. But the fundamental incompatibility of scientific and religious thinking is too important to skirt around and I am uncomfortable when professional scientists play along with those who try to pretend that there is no problem. Thank God for the likes of Richard Dawkins and Steve Jones, who have the patience and commitment to engage in these discussions on behalf of those of us who value rationalism and scepticism. If Dawkins didn't exist we would have to invent him.

MRC Laboratory of Molecular Biology, Hills Road, Cambridge CB2 2QH, UK.
E-mail: ll1@mrc-lmb.cam.ac.uk

Obituary

Carl R. Woese (1928–2012)

W. Ford Doolittle

Carl Woese died two days before this year began, in Urbana, Illinois, his academic home for nearly fifty years. Without the far-reaching ideas and prodigious datasets generated by Woese and his protégés, enthusiastic colleagues and hordes of more distant admirers, all of biology, but most especially microbiology and cellular evolution, would be immeasurably the poorer. Lynn Margulis, who died little more than a year before, once termed this cohort of evolutionary investigators "Woese's Army", and indeed Carl's following has that sort of character. If we sought reasons to endorse a "Great Man Theory" of (scientific) history and progress, we could find no better exemplar.

1977 was a very big year in biology, almost as important as 1953 or 1859, one might assert. Introns were discovered as 'intervening sequences' in the genes of eukaryotes, and prokaryotes were shown by Carl and his then-postdoc George Fox to be deeply divided into two groups, which Carl and George [1] called the 'urkingdoms' eubacteria and archaebacteria.

Why were Archaea (as archaebacteria are now called) as important as introns? First, because they drew attention to, vindicated, and ultimately led to independent tests for the whole ribocentric approach that Carl and his students had been developing over the previous decade as an objective and evolutionarily principled bacterial classification. At that time, this entailed the painstaking assembly of 'T1-catalogs' (lists of all G-terminated oligonucleotides) in 16S ribosomal (r)RNA, the molecule at the heart of all ribosome small subunits. The first catalogs took months (and intimidating amounts of ^{32}P as radioactive label) to assemble. Nowadays of course complete rRNA gene sequences are obtainable many orders of magnitude more cheaply and quickly. Classification *via* 16S rRNA phylogeny works well at all taxonomic levels, even down to the strain sometimes, and there are today more than 2.5 million rRNA sequences available, many being used for this purpose. 16S rRNA provides the framework within which all comparative prokaryotic physiology and genomics (three thousand genomes sequenced and counting) is currently carried out.

Second, for those who cared about evolution but not prokaryotic systematics, it was not just that the prokaryotic phylogenetic tree had a single deepest division (all bifurcating trees will), but that its two branches were so profoundly different at the molecular and cellular level. Their common ancestor must have been a primitive entity ('the progenote'), still "in the throes of evolving the genotype–phenotype coupling", Carl figured. This meant that comparative molecular biology could open a window into evolution's earliest stages, more than 3.5 billion years back. Many evolutionists, emboldened by this realization, have dedicated much of their careers to figuring out what life back then was like. Carl himself envisioned Bacteria, Archaea and Eukarya arising from an inchoate precellular community evolving through frequent gene transfer, each domain independently crossing what he called the 'Darwinian threshold'. Beyond this threshold, the increasing complexity and interconnectedness of the cellular machinery (especially ribosomes) became a barrier to information transfer: domain-specific molecular biologies emerged.

Third, for those who cared about neither systematics nor early evolution but acknowledged microbes' importance, Carl's approach would rewrite the book for microbial ecology. With the polymerase chain reaction (PCR), rRNA genes can be amplified from DNA purified straight from environmental samples. It becomes a non-problem that 90+ percent of microbes are uncultivatable, at least if the goal is to know 'who is there'. By now a very clear majority of prokaryotic species, even phyla, are known to exist just because their rRNA genes have been sequenced, not because anyone has cultured them or seen them under a microscope. Initially, only environmental microbiologists