

## CHAPTER 2

# REACHING OUT

It's not done until you give it back.

— Emerging Scientist, Ecosystems Ecology

I put some of my best papers in journals that maybe would be considered second string [because] I would rather my work reach a dirty fingernails control person than a theoretical evolutionary biologist.

— Senior Scientist, Ecology

The scientists in this study who “reached out” in their field, beyond their disciplinary field, fell into three camps: those who wrote for the public, those who chose to collaborate in writing across disciplinary fields or subfields, and those who wrote for a generally science-literate audience (ranging from undergraduate texts to journals that targeted a wide range of disciplines, such as *Science* or *Nature*). Almost all of those who wrote for the public believed that science had a strongly social, cultural, or economic imperative. Richard and Cameron’s narratives in this chapter illustrate this point, in that both were passionate about the potential impact of science on the national economy and wellbeing, and both felt a social responsibility to communicate both the beauty and purpose of science to a community that supported them. Richard, in particular, argues something very similar to Randy Olson’s (2009, p.8) comments about the public’s attitude to science, possible implications of the anti-science movement, and the responsibility of scientists to do something to address a real threat:

A backlash has developed against science, in disciplines ranging from evolution to global warming to mainstream medicine. An entire anti-science movement has emerged that truly does threaten our quality of life. Large groups of people are fighting against hard, cold, rational data-based science and clinical medicine. . . . Major groups are now arguing against certain childhood vaccinations . . . that have been responsible for eradicating terrible diseases. It is a genuine threat to society. In the midst of this conflict, communication is not just one element in the struggle to make science relevant. It is *the* central element.

Those who chose to write across disciplines were likely to be motivated by both a broader vision of the nature of science, and sometimes a desire to invigorate

their careers in new ways. An exception to this is James who was one of only two participants who had started his career with two distinct (but connected) disciplinary interests.

For most of the writers in this study who reached across traditional disciplinary boundaries, writing for the public or across disciplines was an emotionally invested decision, although some, such as Marama, fell into a public profile almost by accident. Most saw it as a challenge, but a challenge that, for the most part, they relished. All of them felt it was far easier to stay within the narrow parameters of “what I know best.” Some had difficult experiences of writing outside their comfort zone and described the need to toughen up in the face of public opposition or even hostility. There are consistent difficulties in balancing a sense of responsibility—of needing to communicate—while somehow managing the scholar’s need to attend to detail. How to find a new, perhaps more speculative or persuasive voice? Despite the difficulties of writing for new audiences, most of those who did so saw the experience as enlivening their careers and being consistent with their own values and those of science.

There was, however, some disagreement concerning the academy’s position on scientists’ active engagement with the public. James suggests that academia is changing in relation to this, that “doing a Carl Sagan” is no longer frowned on but seen as a legitimate role for a research scientist. In Richard’s view, the academy must do more to train young scientists to engage on the scientific-public interface in the interests of transforming public perceptions of science. Cameron, on the other hand, while himself seeing clear value in his outreach activities, suggests his peers sometimes implied that he was selling himself and his discipline short by being distracted by what were perceived to be tangential activities. Another participant expressed the dilemma as she tried to get to grips with why she doesn’t do something that she thinks is important:

I think that scientists, that we need to find ways and outlets to reach out to the public because—first of all, it’s become expected of the granting agencies . . . you know, within this broader impacts category, how does your work make a contribution to non-scientists, to the lay public—well that’s not all about what broader impacts are but it’s important. Why am I pausing on this? . . . If I thought this was so important why haven’t I done it myself? I don’t know. Maybe because it’s not valued by our institutions, you know. If you write a popular article, you don’t get to count it as one of your peer-reviewed publications—well, it’s not peer reviewed, right? So it doesn’t count for much. (Senior Scientist, Biochemistry)

This is the question that scientists face: even if they know that communicating to the public is important, and even encouraged by funding agencies, can they afford the time to engage with such activities when they are struggling to establish and maintain research careers? As Cameron and Marama observe, writing anything but peer-reviewed papers may be a distraction for emerging or developing scientists who have not yet established their position in their field, and there are political risks associated with taking a public position. The four scientists in this chapter, the most prolific public-facing writers in my sample, had well established research careers and, in a sense, as Marama says, nothing to lose. Yet, if senior scientists are most likely to have the freedom to engage with public discourse, as Richard observes, what impact does this have on public perceptions of science?

The figures for the overall sample in this study showed almost no distinction between the numbers of senior and emerging scientists engaging in public-facing writing (35% and 34.5% respectively). However, there is a clear distinction in terms of intent: the emerging scientists who were engaged with public-facing writing were most likely to be found in an applied discipline where writing for a specific public audience (e.g., health professionals) was expected; the senior scientists who engaged with public-facing writing were more likely to be targeting a wide general audience on their own initiative. Although several female participants suggested that there were more pressures on women to be engaged in public discourse, this was not borne out by this study.

One of the central challenges for those who engaged with public writing concerned the issue of persuasion. Many of the participants in this study were hesitant in addressing the question of whether scientific writing was persuasive—a finding that is consistent with the findings of Yore et al. (2004) who noted that while participants in their study were most likely not to see their writing as persuasive, they nevertheless used persuasive techniques in their writing. Most of the hesitance around persuasion related to participants' conception of persuasion as equating with emotive language or speculation:

In certain types of articles there [is a role for persuasion]. But they tend to be more the popular press. And some conferences—when the proceedings are published—they'll give a particular avenue for more opinionated pieces of writing to be published. But for pure science writing, no. There's no place for speculation; if one is speculating, it's poor science writing. And if one is trying to persuade, as opposed to lay out the facts as they were in an unbiased impartial way, one is not writing science. One's writing something else. But it's no longer scientific writing.

I suppose it comes back to what we mean by “persuasive.” Scientific writing should be about interpreting the facts as they present, and saying no more than that. Where persuasion tends to infer that . . . persuasion is often biased. It’s often saying more than what you can actually glean from the facts. It’s taking a position. There’s no place in science for taking a position. The facts take the position. You must simply present the facts. One doesn’t have a role in speculating, in trying to read something more into it than there actually is. It’s very, very important. That’s at the nub of science writing. (Senior Scientist, Nutrition/Physiology)

This was a recurring theme: scientific writing is not persuasive; it’s just laying down the facts. And while we might question this, and argue that scientific writing is also about interpreting the facts in the context of prior research, making meaning—“telling a story” as so many participants described this process—nevertheless the point is made that in scientific writing the researcher must stay close to their data, laying down the evidence with, as James puts it in his narrative, “my 10,000 footnotes over which I laboured lovingly.”

For those who step across the peer/public divide, though, the issue of persuasion takes on a new complexity. Separated from the familiar routines of laying down evidence, how do scientists write persuasively and compellingly, while remaining credible, for an audience whose knowledge is limited? All of the narrators in this chapter address this issue: James finds a way to write his popular articles so they “have the feel of a thought piece where one tries to build in ‘this is on my mind, I’m curious about it, this is a trend I see, let me try it out’ as opposed to ‘I will now prove this beyond the shadow of a doubt.’” Marama has been bitten by public comments and has learnt to simplify. Richard talks of sifting out the detail to tell a simple story. For Cameron, crafting a message for the public is about having really clear aims and a targeted audience.

I have chosen, for this chapter, the four participants who were most broadly engaged with a range of audiences. All four are highly successful senior researchers who have engaged in cross-disciplinary collaborations and the public discourse of science. They are domiciled in a range of locations (the US, UK, and Australasia). They are all, surprisingly enough, physicists. And they were all, it seemed to me, people with big visions, and hugely flexible writers, with a strong sense of need to engage the public with the possibilities—and the wonder—of science.

## JAMES

James is a busy man. He publishes widely in two distinct disciplines, in a wide range of genres, and as well as this holds a number of administrative roles including chair of his department. “How do you have time to sleep?” I wondered towards the end of the interview. Yet he appeared, when I spoke with him, to have all the time in the world. His office is a model of organisation and calm, the bookshelves that line every wall filled to capacity in an orderly fashion (though I’m sure I saw *A Wrinkle in Time* sitting next to a book on military history). Because he writes in such a range of genres, and in different disciplines, he has a valuable perspective on writing and disciplinary specificity—and on the value on writing for a public audience. And it’s interesting to note the number of times he describes “fun” as his key motivator.

### IT FEELS LIKE A FREENESS TO TELL BIGGER STORIES IN MUCH SHORTER SPACES

I was trained in both theoretical physics and the history of science and I teach here in both departments. As a young person I was very excited about science and was reading a lot of popular science books. Some were very old, from my father’s bookshelf—books that had been popular in the 1950s—the great, physicist popularisers of some time ago. When I got to university as an undergraduate student, I was convinced I wanted to study physics but I was also fascinated by the human story of science from these books; many of these books are very kind of heroic, you know, almost hagiographic. Luckily my first week on campus one of my physics mentors said “there’s this thing called the history of science and it’s actually more interesting than only great stories of great men—there’s actually a broader human, cultural story to be told.” And so I decided to pursue both at graduate level. That’s the short version of how I came to try to have a foot in both worlds.

It was much more recent, though, only really since I began teaching here at my current institution that I began trying my hand at other genres. I had been trying to publish fairly straightforward academic history in recognised scholarly journals, and likewise in physics journals. And then after a few years of that I had opportunities to try to write for other audiences with different scales—short popular essays and nowadays little bits like blogging. And I really enjoy it. I enjoy the challenge of the shifting genre.

It’s fun—it’s new and it’s hard. I find it difficult, and that’s a fun challenge. I’ve learned how to write the 40 page double spaced academic paper for my history colleagues and I can get better and I still enjoy doing it, but that’s a rec-

ognisable exercise. And likewise with physics research articles. But it was something quite new to me to try to write in 1,800 words or 3,000 words for an audience that will not share the same background as my usual audience.

The first feature article I wrote was for *American Scientist* and I was advised that might be a good one to try a toe in. Its readership is mostly other Ph.D.s in the sciences but across the sciences, so it's a certain kind of writing for non-specialists, writing for highly educated science-savvy non-specialists. And I was writing a 3,000-word version of the long book I'd just finished in the history of science, a 400-page monograph. That's a non-trivial task. There's a lot of technical material on quantum field theory that I was grappling with while wearing my historian hat, thinking about how art historians think, about artistic styles and representation. I had just finished the manuscript and the book was probably in press at that point, and I was immensely frightened about all the things that I imagine are familiar. I can't have footnotes? How do I show the reader that I did all this hard work and I'm speaking from some sort of authority on the topic? And that was a very brisk learning experience.

So it was not a scholarly style, not the scholarly apparatus of, "here's my 10,000 footnotes over which I laboured lovingly." This was also the first time I'd been heavily edited by a very skilled editor. What passes for editing in scholarly publishing tends to be rather hands off and minimal. In physics journals there's virtually none, and so to have a very smart editor push back and rearrange and pull this out—she was very good—was a good lesson for me. I must say I've been lucky with mostly very talented editors—at the *London Review of Books* there's one person I tend to work with whose edits will often surprise me and my writing is always the better for it. So I've developed an appreciation for the art of editing, especially these very short pieces for very broad heterogeneous audiences. That's its own separate skill it seems to me.

My most recent book was with a trade press aiming for a broader audience. Both of my books were single-author monographs of comparable length, but certainly quite different on the page and I was much more attentive, or trying to be much more attentive, to character, to the plot. I was trying to get a lightness of touch there. The title's meant to be very ironic and not to be taken at face value. The picture on the cover should prep a reader to think "this is done with some sense of irony."

It was an experiment for me, again a learning process, to see could I first of all try to explain some of the ideas in quantum theory that are very difficult, and very technical, and they sound like magic even when other physicists try to describe it. And yet they have a kind of beauty and power and have come to be enormously influential, they're really big important physics ideas that I really like, they're neat.

I'm trying to get across some very hard ideas within the history of science about knowledge being produced in very specific cultural institutional settings, that it's not free floating among great minds, and yet for all that, it's not just made up, it's not just willy-nilly. I'm trying to convey an idea of a kind of cultural embedding of scientific practice without sounding too ponderous about it.

And then frankly I also wanted to tell a good story. These people I stumbled on who I talk about in the book have led remarkably interesting colourful lives. Many of them are really out of central casting—they are just larger-than-life personalities. So I was trying to get some basic storytelling about the characters and the plot, with which I really struggled much more than with my earlier book. "I know how the story fits together, I know my argument, I know the pieces. So what do I do about the reveal?" I had to think about when to lay this out, in the sense of foreshadowing, so I could come back to it. I had not paid nearly so much attention to that in my earlier academic writing.

But I'd say the centre of gravity of my work has remained the bread and butter academic publishing: the physics articles should look like physics to the physicists; the history articles should look like history to the historians.

I decided to write for a more popular audience partly because it did seem like it would be a new fun challenge, because I knew it wasn't just the same and there were many science writers who I so much admired. Also I came to a point where I realised this stuff is just amazing to me—both the physics and the history. I mean, that's what keeps me up at night. And I thought that needn't be merely the province of a small number of other specialists. I had grown up reading popular science of a certain kind and I really enjoyed that; I know how much that inspired me, just made me interested in things I hadn't thought about before. There is this enormous smart, educated reading public. And that's when I thought it would be a worthwhile challenge for me to try to write, to engage with some of them.

I think there are some very clear differences in writing for history and writing for physics, at least in the writing process. I'm sure we could dig deeper and find commonalities. When I was finishing graduate school, I wrote two separate dissertations for two committees, precisely because the genres were so distinct; I didn't want to have the physicists throw up their hands and say "what is all this verbiage, what is all this crazy history stuff with all these footnotes?" And vice versa. Many historians on my committee would have no interest in, or the kind of training needed, to read these very specifically crafted, highly equation-filled physics ideas. And so with the history dissertation, it obviously requires years and years of running around archival sources and interviewing people and digging up all these old dusty things from many places. That was the research phase and it was at least as long if not longer in time to figure out how to write it.

But I felt almost no separation between doing the research for the physics and writing it up. I used to joke there was no trauma of finding my authorial voice around my physics dissertation—I didn't have to worry about meeting my audience halfway. With the physics, it felt very much like the writing was of a piece with the research. I mean, writing physics already felt like a default.

In the history of science, on the other side, we have to worry about historians of science who don't know anything about quantum mechanics. But when I was writing up my history dissertation, much of it went into my first book, I really struggled with a shadow of what I struggled with in my later book: "what does a reader need to know right here?" and "what do very smart historians who aren't specialists in this very specific thing need to know to get them ready for the next historical point?" That requires a level of attention to plot, almost like a detective story; the reader must know this, here, to lay the seeds for what comes later.

I didn't feel that when working on the physics dissertation. I think of that more when I'm writing my physics articles now because there are, of course, better and less well composed physics articles. One still wants to bring the reader along. So it's not oil and water, but I felt it as ends of a spectrum. It's a matter of degree and not of kind I would think. Writing my physics dissertation felt like almost an automated process. First of all I wasn't expecting many people to try to read the physics dissertation, and the physics dissertation as a genre had largely become a bunch of articles that had already been written, so it's not that one needs to plot out a many-hundred-page through-line or a narrative arc. It's not sustaining an argument, it's not sustaining even really particular themes; each chapter I think is treated much more autonomously in a dissertation. And within each chapter, I felt like there's a much clearer expected flow or outline; I could almost plug things in. Of course there's an art to that and some people do that better than others, but it didn't feel as wide open. And so it really felt like, as soon as I figured out my equations and my computer simulations for the dissertation, I more or less had written it up; I had done so much of the writing itself, it was just stringing together my derivations and my equations which I had in my notes and trying to tell the story to bring a reader along. But the expectation would be that the reader was already so hyper-specialised and following the larger story already, that I didn't feel the need to bring them in and orient them and help them on their way.

I think empirically that reading practices have changed enormously; it would be fun to do a more careful study. I think now physicists have moved not just to online reading but to one homogenised central server, then much more reading is done on the fly, online. And so what one imagines is people really just read in a continuous scroll through equations and then sometimes they will indeed



print it out and read a bit more carefully. So you can see that one aims to see in two clicks whether this other group is studying the same model as mine or not. I see “oh, here’s how they define their model” and I can see bang, bang, “OK they’re doing this, they’ve left that out, they’re putting these effects—OK, now what do I do?” There is a level of a much quicker visual scan. The words will matter but they’ll matter in a different order and people will routinely just skip the introduction.

Sometimes the introduction is written for the co-author—I say that partly as a joke—to make sure that two or three people are agreed on what the goal is. I work very hard on my introductions in physics papers. Often these things are read in many ways by many different types of people. So they’re written for the referees, they’re written for the very specific fellow specialists; partly it is a way to mark turf and say “this important work has been done here, but I’m not just doing what they’ve done.” There’s a kind of differentiation that goes on there. And that might be aimed at very specific colleagues or even competitors in the subfield. And again, you know, some journals will put a premium on purported novelty and originality and so again one broadcasts that in the introduction or the abstract even for the kind of workaday journals like the *Physics Review*. Introductions are important, but they’re not important in the same way for all readers.

History papers, on the other hand, I tend to read quite linearly. I certainly start with the introduction and pay much more attention to my own, as well as to those of my students or colleagues or a random piece in the scholarly journals. I start at the beginning. Sometimes what I’ll do is read the introduction to get the orientation: what are the main themes, what are the stakes? Then sometimes I just skim the footnotes. What are the types of sources? What are the sorts of names and dates and places that are likely to come up? And then I go back and read the body of it.

I like writing history and physics. Honestly, I enjoy the contrast because they do feel so different in construction and in reading them. That’s part of what I enjoy—it’s a constant reminder that there is a complicated world out there that we carve up and try to understand with many different tools, no one set of which has conquered the world. And likewise there are many ways to try to capture the complexities of the world in something like narratives. And so I find that fun; the contrast is enjoyable.

It’s a similar enjoyment in the newness of a style, like trying to write the short popular essays. I often find it very hard to say something big in an academic article, at least in an academic history article. Ironically, I feel like we often force ourselves to write quite narrowly to our case at hand to sustain what often are, honestly, quite narrow arguments about small bits of space and time—people and places and times—so that our fellow specialists through peer review

don't throw a fit or just because we don't want to overreach. We studied this bunch of documents with great care, but that doesn't mean that the story generalises. Whereas I think it feels like a freeness to generalise, to tell bigger stories in much shorter spaces without the footnotes, because the expectations are quite different, both of writers and of readers. I feel like I can sometimes say bigger thoughts in a *London Review of Books* piece, in 1,800 words, than in a very carefully, hyper-attentively constructed piece for a journal like *Isis* or the *Journal of American History*.

I certainly do write with some care not to dramatically overreach. On the other hand, there are trends, there are big ideas that are worth at least sitting with, and I think they can be tried out in a way that needn't come across as definitive and beyond question—saying more like “what about this?” They can have the feel of a thought piece where one tries to build in “this is on my mind, I'm curious about it, this is a trend I see, let me try it out” as opposed to “I will now prove this beyond the shadow of a doubt.” So one uses caveat words carefully, oftentimes you don't have to make every statement an absolute. I have become progressively less fearful of that, but I felt that very much with my first few pieces.

My schedule has become quite chopped up, which has been a real frustration. Particularly because I used to be the type of person who would need, say, two or three days in a row to get any quality writing done. I felt like I needed that, and that simply doesn't exist anymore. So I'm lucky if I can devote a single work day to a writing project. And once I get going then I find I can work in shorter stints; often the start of a new piece of writing requires a day, or the better part of a work day. And then I'm getting a little bit better at filling in a choppiest work schedule downstream.

I think through difficult issues by trying to talk them through, and often the talking through is as much to see if I had figured it out, whether I have cracked it or not. But it's also to try to think about the ordering. So, you know, “what does the claim really depend on, what does my interlocutor need to be on the page with me about?” Even if that's just in a conversation on Skype, it often becomes as much about “does this conclusion hinge on *this* being in mind before *that*?” It already starts getting into the process of persuasion I guess.

I tend to write with multiple word documents open at once, so I'll often start with a very scattershot outline that's sort of an outline-brainstorming that I can cut and paste around. Then I'll have a scraps piece; I'll start trying to write a particular portion of that outline in a new document and then come to realise “oh this whole part doesn't belong here, but I don't want to quite delete it” so I'll put it in a kind of receptacle file. So you would see me hunched over my desk alone much of the time, but with a few different files open at once.

I just wrote a short piece for *Nature*, 1,800 words, a historical comment piece, not a research article. And it actually felt rather freeing. But I tend to over-read; I found myself reading whole bunches of stuff that I knew would play absolutely no role whatsoever when I finally sat down to write that short piece. I felt the need, mainly because it's such a short piece and it goes back to what we were saying before about accuracy, authority, comprehensiveness, the kind of anxieties that came up about that. And so I found myself pulling things off the shelf that either I had always meant to read but hadn't yet or had read years ago. And none of that mattered; it was psychological. Maybe it was playing some orienting role for my thinking even though one would never know it from the very short piece that emerged. I guess it's a form of immersion. And I feel the same even when I'm thinking back to my recent physics research articles with some of my students, that again there's so much more that one often knows than goes on the page.

I do a lot of revision, certainly. And I tend to find—this is more true I think about historical writing—themes and anecdotes or episodes come into my first draft, and then I will work to see if there is an argument there, or what might my argument be. I'll get a story stuck in my head which is different from having arguments or theses, you know, and I start from that. It's not exactly gathering lots of historical data and then reaching my conclusions, certainly nothing like that. It's haphazard. I get intrigued by people or stories or episodes. I love to work that in somewhere: what role might that play, what would it be building up?

For example, the story at the beginning of my most recent book originally appeared in Chapter 5 in my first draft because this is the chapter where I talk about this theme, and that's where I want to introduce this main person, and so in my head that was contained in the middle of the book. And it was a lot later, in a downstream revision, when I realised I needed some hook for the readers. That little story also sets up the types of people we will encounter, and so again I began to think about foreshadowing. But I didn't think like that at first, and now maybe with that experience I might do that more intentionally. Something I have been doing in even my academic history writing for some time is trying to open with a kind of anecdote and then by paragraph 2 or 3 saying something like “the thesis of this article is”—you know, the more standard declarative approach—but trying to have even a one paragraph colourful little entrée. Doing that at the scale of a 30-or 40-page article is one thing and I hadn't really made the leap at the book length until this recent book.

Would I call myself a writer? Only recently. It's something I aspire to, something I would enjoy getting better at. And I say that because there are many writers whom I just admire so much. So that's fun; it's nice to have, you know,

goals or models to aspire to and I find that very helpful. I'm a devotee of the *New Yorker*, for example, and I have my favourite authors within that constellation. And some of them will get me every single time, whether it's to laugh or cry or just an "aha!" or to say "now that's a writer!" Or I'll pause over a paragraph or sentence. And so I don't consider anything I've done like that by a long shot, but I have enjoyed trying to figure out how they did that, trying to appreciate the craft of that more consciously. That's also why I continue to be very delighted when places like the *London Review of Books* or *Nova* have come back to me, now several times, to try to explain things for this or that group, because I perhaps have some more experience of that than other people. That's a skill that I enjoy trying to cultivate.

I do enjoy writing. Yes. And, you know, I enjoy going back to things I've written long ago. I can remember and describe at various levels of detail what my first book was really about, or even what the more recent book was about. That one has been out for two and a half years by now and there's a special pleasure in serendipitously going back and just opening up and reading at the paragraph level, not the big ideas, not the main thesis and not what archives I had to visit. But I'd say "oh that was really fun"—the joy of crafting again at the small scale. I remember now beating my head against getting that turn of phrase right, but I'd forgotten in the interim.

I know people who wrote a textbook as assistant professors or even as post-docs—though by no means is that the norm. So that's different from the end of career, legacy model; and these were often astoundingly successful textbooks and sometimes they were trying to start a new field rather than cap an old one. There were other reasons why they chose that path than the usual one. Likewise, I know many, many scientists who are actively blogging and doing some kind of writing for more than just narrowly construed technical peers. And that really wasn't true to the same extent 20 years ago.

These changes are not happening in a void; at least here the deans tend to be, in my experience, very pleased when even their very young faculty do something that now they'll call outreach—now that's a positive value, instead of saying "oh you sold out, you're doing a Carl Sagan," which was taken to be a very bad thing 30 years ago, unfairly. That is not unrelated to the shifts in national priorities and science funding, and debates over the place of science in politics and culture and so on, school boards denying evolution. I think there's less of the immediate instinctive reaction to say "stay in your ivory tower, do real science." As an example, the dean of humanities and social science a couple of years ago sponsored an event aimed at faculty and even young scholars, grad students, on how to write for a popular audience, and she brought in literary agents and editors from the significant news outlets as well as trade presses.

I began publishing physics research articles as an undergraduate—the first came out when I was still a student and then a few others based on my senior thesis, so I was trying to get habituated in the rhythms of writing for that kind of audience. That means learning how to use things like passive voice and learning to have a certain kind of standardised structure.

I learned to write by immersion; I had to be immersed in a very specific collection of articles on the same topic just to get up speed for the questions I wanted to ask and the calculations I wanted to tackle. At the same time that meant I was reading samples from a very specific kind of literature, reading them over and over and over again. These days I think we've collectively gotten better at building that stage into undergraduate coursework. Not for every course, but for several of our physics major courses here, the students will write a version of a research article. They'll learn to use LaTeX, but they will also learn the basic features that would go into a physics article and they'll often have to write a final paper that is in the recognisable format that would look like something I read in the physics journals.

I don't recall doing that as an undergraduate, not as directly, not as part of a built-in part of the curriculum; I'm glad we do more of that today. I had a bunch of independent studies as a student; I was working on a senior thesis and I had opportunities to practice more one-on-one with faculty mentors. But I remember, what became my first physics article was the second version I submitted to the journal, and there was an enormous transformation between those two drafts; the topic was the same (in my head at least), but if you could do page-by-page comparisons they would look very different.

I think the biggest shift was the notion of what's the novelty, what's the contribution as opposed to summarising what I had learned from other papers. I think a lot of the equations might be the same, I'd have to go back, I don't remember. But the first draft was, I would imagine, more like a book report—here's what I've learned, and there was some new stuff in there—but it was not pulled out or not placed the way one might try to do that. And then several months later, and with lots of help from advisors, I was able to firm up “what am I actually trying to say; what do I think is new here? Why is this relevant and interesting?” And then to place it in relation to what had come before, without making it a kind of continuous story of what has been known. I bet that's the biggest difference between those two very early, very brief papers.

In terms of who influenced me as a writer, going back to undergraduate studies there's one advisor on the history side who was a delightfully picky grammarian—she insists to this day on very clear prose. She's a very gifted writer as well as scholar. Though her own style was not exactly *Strunk and White* pared down to a stereotypical minimum, she showed me one can use interesting and

colourful concepts and theories, but the prose needn't be flowery. And to get that straight in my own head was an important distinction. She was very, very helpful with that—draft after draft after draft—she was very generous with her time. So partly it was “what are you really trying to say?” and answering the “so what” question. My colleagues and I often say with our history students, “well yes, you just dug in these archives and interviewed these 50 people or whatever it is; so what? What is the question you're trying to answer? What's the argument going to be?” And then you can worry about how do these blocks fit in to sustain that argument.

So it wasn't merely at the level of copy editing with split infinitives or commas; it really was an architectural metaphor. I think there was similar stuff going on with the physicists, that was probably articulated less explicitly.

I do think I have a role as a teacher of writing. And I take it at least as strongly or more so on the physics side than on the history side, because a lot of teaching writing is built into the process of becoming a humanities student. We have an infrastructure to help students work on rough drafts, to revise constantly, to worry about authorial voice, something like a plot. So that's on my mind when I look at my own students as well, especially my graduate students who are looking at published things. But even with our undergraduate essays, they have to worry about a thesis statement, an argument, which is the basic structure of essay writing, and that's built into what they're getting when they take a history course. I'm now publishing with a number of my undergraduate physics students and Ph.D. students as co-authors. And I try to be very attentive to helping them to guide the reader along and not letting them get away with an attitude of “you got the equations done so now you're done,” the way that, frankly, I had largely felt as a younger physics student.

And there's another thing I'm curious about: there are enthusiasts or zealots or ideologues about online-only hypertexting, saying this is the natural medium. I'm not sold on any of that; I think reading books from one page to the next actually has worked pretty well for a couple of hundred years, so I don't mind linear constructions. But I'm curious about the affordances. I'd love to write a shorter ebook on a popular physics topic with maybe some historical framework, and then to have the words, metaphors, pictures version of some important physics concept embedded in it. And there could be these layers. Let's say someone has taken high school calculus, well there's a version for them, and then maybe a third layer for someone who's a bit more advanced than that, with the technical stuff linked in. So, not to write a textbook and not to merely reproduce the physics specialised literature, but there is a way of trying to say “this idea is even cooler—have you noticed, have you thought about this very subtle thing” that's expressible in a certain medium that might not be essential to the main

point that I would hope many readers might otherwise be able to get at. So I do think this kind of non-linearity would be really interesting to play with.

I really have been interested, partly as a participant, but often as an observer of this fairly recent shift to really encourage or at least no longer overtly disdain so-called “real scientists,” with a day job in science, making increasingly creative forays into creative non-fiction, from blogging to sometimes very successful books. And I find that a wonderful transition; there’s a notion that many ideas in science are cool and they’re exciting and they’re hard and some of them are quite consequential, and why on earth wouldn’t we be trying to at least talk about the excitement of it? Not as a gateway to create legions of other specialists, but rather to say “this is an essential part of human culture and it’s a grand intellectual adventure that has a rich history.”

I wrote a short little physics article just a few weeks ago with two younger, up and coming physicists, and it was a great joy, really fun ideas. And we worked very hard, I worked very hard because I was learning a lot from them about specific things I didn’t know about and it was cool. It’s a fun and juicy topic and I was just excited about it and then we posted to this physics pre-print server. And about one or two days later we found another physicist blogger who wrote a whole blog piece about it and was so excited he mocked up his own Photoshop images about it just because he thought it was fun and then wanted to blog about it.

So there are these physicist communicators who are reading the pre-print server religiously, routinely, and are actively, in real time, communicating that “this is cool, exciting, here’s why I think this is the most fun, cool, exciting idea.” So the medium has allowed a kind of fluidity which I like.

I’m just not a blogger by nature, but it’s fun to be able to point in the hyperlinks to my colleagues’ hard physics papers that are freely available on the web, to say, “look to learn more about this, at least this guy has cool pictures in his paper, you don’t have to read a very dense technical paper but I can try to give you a paragraph of why I think it’s so neat and why it’s interesting and why in the light of the latest results from some experiment we want to rethink this older paper.” And I can at least speak to the real heart of the matter, the real article. There’s a real fluidity that many eyeballs might be hitting on any of those and following from one to the other. So it’s not that there’s a brick wall, and the real physics or the real science is over here. And I think that’s great.

## MARAMA

Marama is that rare thing: an eminent female physicist with a high media profile. She speaks here about falling into a public role by accident, by trying things out and seizing opportunities. And she talks about the risks of having a media

profile: the risks to younger scientists, the risks of alienating colleagues and institutions, and of managing hostility from a very different audience than that to which she's accustomed. But while she sees her writing sometimes as a burden, she also experiences writing in new forms as a kind of liberation, of finding a new voice inside her that was longing for expression.

## **I FINALLY FOUND THIS VOICE THAT I DIDN'T KNOW I HAD**

I never decided to take on a public role. It seems to me that I've risen up through the ranks and become a professor of physics, and over the last decade I find that I've got this other increasing public visibility, which I did not set out to achieve. So it's a question of, since I have this visibility, trying to think how to use it wisely and effectively for the things that I care about.

I think there might be three reasons why I got into public writing. One, I'm a female physicist. There aren't many of us. The choice is more limited than if they want a male scientist. Two, I think a lot of it does come down to the fact that I started blogging. And I did not start blogging to have a scientific, or a public profile, nor did I start blogging with any clear aim, if you like. I was just encouraged to do it by someone who was themselves blogging. I realised that I was reading more and more blogs and wanting to comment, and he said well go on, give it a go. I guess over the first few months I found that I had a voice. That there were things I wanted to say, and that there were people who liked what I wrote. And that encouraged me to do more. Then, the third thing was that over the next couple of years I got asked to write a few other things. It just built up from there. Of course, a lot of it is because I write not about science per se, but about the social and cultural context of science. I'm one of the few senior women who is speaking out about it. There are many early career women who are talking about these issues, but I'm coming at it from a different direction.

The thing that perhaps surprised me is that, when I started writing my blog, I felt liberated by it, because instead of having to write in the passive voice in a very formulaic way, where clarity was important but not necessarily creativity, I have found it great fun to have this other voice.

Someone said of me quite early on that it looked like I had all this stuff inside me that was just waiting to come out. And I think to some extent that's true. I felt that there had been a part of me that had been suppressed, which I wasn't aware of. While you're getting on with everything else in life you're not necessarily aware of what you're not doing. But it was as if I finally found this voice that I didn't know I had and it made me feel more complete.

I am very conscious of the fact that I write in different styles for different places. I do write sometimes for the mainstream newspapers and that has to be



very different. The first time I wrote a relatively big piece for a national newspaper, I got completely hammered by the comments. It taught me that I tried to put too many ideas in 500 words or whatever it was. It, therefore, confused people because I was mixing in different ideas. So that was very salutary. I have my own blog where I never really write about science, *per se*, but when I write for a national newspaper's science blog I will sometimes write about pure science, take a paper and analyse it. So that's different again because you're trying to take advanced physics and turn it into something that the general public can read.

When people attack you, and when people you know disagree violently with what you say, that is very hard. It doesn't mean I don't feel I shouldn't have written it. But writing things badly from experience and finding that people can pick holes in your argument is upsetting, and occasionally one makes mistakes—I have done some really daft things in my time. But there are also times where you just know that people will never agree with you. And writing about social issues in science, there have been people who just consistently attack you for the very ideas. You can despair.

Scientists don't talk about writing because it's not seen as a core competence. I'm of a generation which did get proper grammar teaching at school. I have always worried about how one writes. So my students, say drafting a paper or a Ph.D. thesis or whatever, they are surprised that I will correct their grammar and give them ideas about stylistic stuff. I've always done that. It seems to me absolutely fundamental that one communicates. And if you write bad grammar or in a rambling way or your sentences don't have a verb or whatever it is, it matters. But students think that the only thing that matters is the result and they don't understand that communication in the broadest sense is important. They feel "I did the experiment right and these are my conclusions." So I think it's part of our education. We do not value writing when we train scientists. So if you're a historian, you are instructed on how to write essays, and if you are a scientist, you are instructed on how to solve problems. I think many academic supervisors probably themselves don't get it. They play it down. I think writing matters far more than people appreciate, and I think we fail our students, our undergraduates, in not making that clear. Because they will have to write even if it's purely an internal report for their company when they do a piece of research. They have to be able to communicate.

I think creativity is an aspect of science and, therefore, of course it's going to come into an aspect of the writing. I think people often ignore that. I get really frustrated by people who say—it's the old Blake idea that science is just measurement and it destroys wonder. I think—there's no creativity; Blake was of course not a scientist. But I think there is this belief that science is non-creative. Science

is very creative in the way you tackle a problem and, therefore, that should be part of the writing process. But, and this comes back to why I feel liberated, I think it is true that if you're writing a scientific paper, that's not the primary focus. You're not being creative. I think the creativity comes elsewhere. I think one can be much more creative in other kinds of writing.

There is some narrative craft involved in writing science: that's absolutely right. Depending on the kind of results that are being written up, it may or may not be obvious how to do it, but you certainly have to think about it. I think one of the things that I know I initially had real problems with is getting beyond the chronology. It's very easy to try and write a paper in the order in which you actually did the experiments. Because that's following the thought processes you had, and sometimes you need to step back and realise that isn't the narrative that makes sense at the end of the day.

With my blogs, I will start with an idea, I will think about the points I want to make. But it's not really until I write it down that I really work out what the narrative is. It's very easy to write paragraphs and then move them around to get the flow right. In those cases, I will know what the big picture is, the subtopics, the anecdotes before I start writing. And then when I write—to be honest, when I write I typically just then do a brain dump and I rarely have to do a lot of reorganisation.

I think you have to learn the style almost by osmosis unless you're going to have a formal teaching course, which at my stage of my career I'm not. Take Twitter—again there are stylistic things and very little of it is written down and you learn by watching. It's like being immersed in a foreign language. One of the things that I find surprising is how students don't manage to do this. Like they don't realise that they need a bibliography or they don't know how to write a figure caption or something. At the end of their Ph.D. they still seem completely naïve, although they've been reading papers all the time. But then I've never instructed them, “analyse the papers you're reading for the correct structures.” Clearly it's not obvious to other people that there's this in-group way of doing things. I get draft thesis chapters where someone has completely failed to understand the point of a caption. And you say to them, “you just can't do it like this. Either you have copied great chunks of text into caption or you have just called it figure three.” I mean, come on! Eventually they get there.

Time is a difficulty. Sometimes when you're trying to write—not a scientific paper—a blog or something for a newspaper, you want to be timely. That is a real problem in an academic's life. I think there are things that I would have liked to comment on, but there's no way I could and keep it topical. But I enjoy writing. Absolutely. I worry that I spend far too much time on it now; that it's taking over my life. I have all the other things I have to do.

I think the lifecycle model is certainly how I would see myself. Other people I know who blog do it more explicitly as part of their career goals. I know plenty of people who would fit that model, but if you look at an earlier stage in their career you can't really tell if it's going to be valid. I think it is difficult if you are 25 to start pontificating about policy because you haven't had a chance to absorb all the nuances. And a lot of people who do an awful lot of writing early in their career often feel that disadvantages them because they are writing and they are not beaver away at the bench to get the results.

There are some people who are very focused and have spent their entire career working on whatever it is. And then there are other people like myself whose research has evolved and not gone in a straight line. Sometimes I think it's about confidence. Not confidence in the usual way it's defined, but a willingness to step outside the area where you have a reputation requires that you have a certain degree of confidence. I've thought a lot about this because as a young person I would never have said I was confident. I would still say in some senses I wasn't confident, but I am prepared to try new things.

So it's about risk taking. It comes back to getting negative comments about what one writes. I have written really risky things and have been explicitly told "that was brave." You have to do that. And sometimes, I have been compelled to speak up despite the fact that it was absolutely not what people would expect me to do, given my background. I feel I have to do it for personal reasons, if you like. My sense of integrity. But it is taking risks. And sometimes you don't know what you're doing before you get into it. I think when it comes to writing or when it comes to research not everyone is prepared to do that. So other people might feel "this is my niche. I am very comfortable here. And this is where I'm going to stay."

It is important not to assume that people do things consciously. I think how you act is often circumstance. And also you have to convince people there is something in it for them. If you're an early career researcher worrying about early career progression it can be a problem. A study that came out just recently about people who get involved in public engagement showed that they felt it damaged their careers and they didn't get encouragement to do it. Again, that's why it's easier for me as a senior scientist. If you are an early career researcher, you're trying to get the next position. You're trying to get tenure. So I think that however much you might want to take risks, you may not feel that you can, particularly if no one encourages you. If someone says, and I've heard this of people, that they might be more likely to get a job because they were perceived as having these other interests, then fine.

But I think you can believe something very passionately yet not feel it's your responsibility to talk about it. Not talk about it publicly. You do have to worry about the ramifications of taking a position. There are people who are writing

about areas of research which become very controversial. Do you want to keep your head down and write a scientific paper or do you want to write for a broadsheet? I think integrity can come in many shapes and forms and just because you're prepared to speak up publicly doesn't mean you've got more integrity than someone else.

Learning to write as a scientist just evolves, doesn't it? We weren't given much opportunity to write as undergraduates, or at high school. One of my professors when I was postdoc-ing was very picky about style and taught me to think more about it. He's the one I remember. He maybe just critiqued, but explained his critique. So I just evolved as a writer. I wasn't rationally thinking it all through.

But there are things we could do better about writing. I think really what we need to teach students is that it matters. They can find their own voice. They can find their own style. But they should be thinking about it. It isn't something that necessarily just happens or isn't important. It's the whole thing of valuing communication and we don't do that enough.

I enjoy writing. What surprises me is the fact that people read my writing. It started off as maybe even self-indulgent, but now I feel that people value it, all kinds of different people. I'm very conscious of the fact that I have very different people who read what I write. It's wonderful—incredibly good for the ego! But that also becomes a burden. People's expectations—just because you once wrote a nice piece, people expect them all to be that sort of way. It can become quite heavy.

## **RICHARD ROSE**

Richard has an unusual place within his country's psyche: he is a nationally celebrated scientist. Throughout his career as an internationally significant physicist, he has developed an influential national public profile including a regular slot on a national radio programme, as well as writing a recent popular book exploring the potential of science for promoting economic development. During our afternoon together, he took complete control of the interview, waving aside my questions, and engaging in his own way on questions that truly mattered to him: why we must teach our science students to communicate, the public misconception of science (and why it matters), the centrality of the story. After a brief tussle to regain control, I relaxed, sat back, and enjoyed listening to his voice and his forceful views, occasionally throwing in one of my questions when an opportunity arose.

## **WE ARE TELLING A STORY THAT MEANS SOMETHING**

I wouldn't want to think that only older scientists are the voice of science, that they—we—are the only ones communicating science to the public. In fact, I

think my passion around science education is to change that completely. I would like graduate students, now, to see science communication as an essential part of their youthful role as scientist. Einstein's best work was done when he was a boy—not when he was an old man with crazy hair. You see this beautiful picture of this young man, in his twenties, and that was the Albert Einstein who did the work that we remember, that changed everything. So, the face of science is often, I think, perverted by the fact that you see these older people out there who are the famous scientists, and people have this vision of the scientist that way. And in fact science is a youthful game.

So, what we need to do is to change that dynamic, so that science communication becomes an essential part of the training of a scientist. And with our institution we've taken the view that we see our role primarily as educational. So, for example, every year our students get together and we get them to give talks, and their talks can consist of, for example, "what are the ethical dimensions of your work?" or "How would you explain this to your grandmother?" They have a choice, they can do one or the other, or "How would you commercialise that work?"

And the reason why communication is so vital is that science has to project its value to the society at large, it has to be of value. It has to engage with the public, who have legitimate concerns about the use of science, and legitimate anxieties about ethical issues. I mean, this thing about these eight babies, it's a disaster for science! I mean, it's terrible! These people are complete hoons. Cowboys! [The Suleman octuplets were conceived in 2009 by IVE.]

So, you know, we do have these problems. And it's no longer good enough just to be smart at what you do, and to publish papers. That is gone as far as I'm concerned. You look at the smart organisations around the world, the best universities, and the on-the-ball organisations, they know this. So I think the model of the young ones learning only to write and speak to their discipline, and the almost-retired scientists speaking to a broader audience, is an old model that might have been true once. I don't think that the new approach to the way we're looking at graduate education is like that. We try to make sure that all the students in the institute get practice at talking about this, we encourage them to be science communicators.

And yet there are undergraduates who think that they shouldn't have to write. They've spent their high school years avoiding writing courses—well they're stupid! And they'll be failures. Look, the fundamental discriminator between those who are successful in science and professionally is their ability to write. That is the fundamental difference. I have students who are very good scientists who can't write prose; they will never become leaders in science. They can't do it. Why is that? Because first and foremost, science is about communicating clearly.

And the most difficult audience to communicate to is your own fellow scientists because the ideas in physics (or whatever field it is) are quite complex ideas, and it's difficult even to explain them to our colleagues. I go to conferences and a lot of the guys I can't understand! Those that I do understand, I remember. And I look to those scientists, and those are the scientists who are successful.

So, whether it's oral communication or the ability to write a beautiful paper that's really crystal clear, the ability to engage in the craft of the science itself quite apart from the public aspect of it—it's absolutely vital.

The other thing is you have to write a lot. You hear scientists complain "oh, I have to spend all my time writing research grants." What I say to such people is "write faster! What's wrong? Why does it take you a month to write a grant?" It takes me a day, or two. Because I write fast. And if you write fast, you're efficient.

I think it's probably true in most professions. In business you have to write clearly, reports and so forth. Convince other people that this is the idea we want to go with. So I think these skills of communication, and in writing particularly, are absolutely crucial. And the writing is the most powerful expression of this because this is where the formality of the ideas can be presented. I mean, you can sway people with an oral presentation, but the evidence base—the argument—is presented in writing and the more crystal clear the prose, the more effective the communication and the more effective you are in any profession. I can pick out the students who are going to be successes. They're the ones who can do a draft of a paper no problem. And they tend more to be female than male, and that's one of the reasons why women are really changing the scene of science tremendously too. As these communication skills become more important in science, become more recognised, you're seeing women pick up a bigger role.

But I say to students "it's not enough just to be good at what you're doing. Why, why are you doing this? How many hip replacements does it cost to do your science?" And I actually talked about this yesterday at this conference. I said "this is how much money I've had in research grants over the years. That's 600 hip replacements, or 120 septum treatments for one year for breast cancer. That's what my scientific research has cost the tax payer. How do I justify that?" Now this has made some of my colleagues uncomfortable, but we must start asking these questions and thinking in that context of science. I often say "Who pays for what we do?" It's people who clean buildings at three o'clock in the morning, for minimum wage. Their taxes pay for what we do. How could we go to that person and say "this is the lifestyle I have as a scientist, I travel to conferences, I do this work, I do this erudite stuff that gets published in journals." How do we say to that person that their money was well spent?

Now, people didn't talk that way a couple of generations ago. There was this kind of a sense of privilege, of priesthood, a kind of a sense of almost entitle-

ment. It's all gone. We don't live in a world like that. We question our medical practitioners, and that's right. So, if scientists don't do that they will not be supported by the public. And, so, it is vital that these young people are able to think about these questions, think about context, think not just about the economic value but about the human consequences, the ethical issues that sometimes arise in science. Also to communicate the beauty and the passion around the subject and get people excited. So they see that science is . . . it's a wonderful thing.

You understand evolution and suddenly the world is just an extraordinary place—you have insights that make you feel more, I don't know, connected with the world . . . that science is actually a beautiful way of looking at things. So, there are many dimensions to this communication thing. But any person, any undergraduate who says “I don't want to learn about communication in science” well they're just fundamentally stupid! I mean, you might as well say “part of the job of the university is to ensure that people like you never get a near a profession!” Of course, you can't say that, but it's the truth! Bright students won't say that, a smart student won't say that.

I've always enjoyed writing. I loved writing at school, and it's always been part of what I do. I even did English literature at university. I did two courses in my first year. I was toying with the idea I might do an arts degree and English was my top subject at school. I loved it! But I had some battles with my poetry tutor in first year. I didn't quite like first-year English and I got into physics. But I've always loved reading, and I read novels and all sorts of weird stuff, and I enjoy that. And I love language and love to read poetry. And most of my scientific colleagues who are leading scientists throughout the world are like that: they are broad-minded people, just like they would be if they were musicians or lawyers. Talented people are interested in stuff. How could you not be? And so, that's not a remarkable thing, it's not peculiar to science, even though it's contrary to the image of science.

People know about the value of technology and science in their lives—antibiotics and so forth—but, there are these other images, and there are these worries that are there as well. Mary Shelley wrote about the fear of technology, the Dark Satanic Mills, which were the result of the industrialisation, way back in the 19th century, so I guess it's not a modern thing. People fear the inhumanity of some of these things, that science doesn't necessarily make our lives better. And there lingers the image of “the scientist alone in the lab,” the autistic, dysfunctional person who has no personal relationships and just loves their test tubes, and says “let me get on with it and do my mad thing.” Now, that is a falsehood because science is, of all the creative areas, the most social.

You take a writer—they're a very solitary person. A composer, an artist is solitary too. But as a scientist, it is very hard to be solitary. I mean, even if you're

a theorist doing your own work you have to be looking at what other people are doing and talking to experimentalists. So science is by and large done in teams, by collaboration. It is very social. If you do a Ph.D. in the humanities, for example, or if you write a book, you are sole author. Whereas with the sciences you more often would have collaborated with your advisors, you'd be co-authors. But this image of the solitary scientist persists, and whose fault is that? Surely it's science's; we're not explaining for people the way it is. So we have a lot of issues there, we haven't put enough effort into that, we haven't been professional enough as a profession to actually explain to people what we do.

I learned to write science when I was doing my Ph.D. I remember the first paper I wrote when I was at Oxford, it just seemed like a natural thing to write a scientific paper that was just like writing anything else. It was just another form of writing. Now I did have a wonderful Ph.D. supervisor who really knew his craft very well; he wrote beautiful scientific prose himself, and I guess I probably learnt a bit from him. But is it different from writing other things—I mean, writing is writing, you know? I don't think there is anything unique about the way you write science, except that you say what you're going to say, you say it, and say what you said. You have to almost exaggerate the clarity that's required. So there is a structure to a paper. But, you are telling a story. I tell my students when they've got to write a paper, "what is the story we are going to tell? Can we tell the storyline?" And I ask them to think, "tell us about it! What is the beginning of the story? How does it develop? And how does it end? Because that is the story we're going to tell in this paper." If we don't know what the story is, you can't write a paper.

You don't sit down and say the experimenter did this, and then this. We had this awful thing at school, you know, "Observation, Results, Experiment." I mean, whoa! Oh my god! You know, the things we do to kids, we teach them this garbage! No, no, you are telling a story and in truth, you've done all these experiments and this didn't work and that didn't work and that didn't work but this did. And we've got to somehow sift out of all this complexity, what we've learned, and throw the extraneous stuff away, and tell a story. If we don't do that, no one's going to read it and it won't make an impact. It's not that we're being dishonest, and if we were it wouldn't be accepted in any case. But we are telling a story that means something.

In the top journals, like *Science* or *Nature* or *Physical Review Letters*, they have a process where, at an editorial level before they even send it out to experts reviewers they'll look at the first paragraph of the thing, and they'll say "Is that of interest to a wide audience?" Right, so you've got to know how you write that first paragraph that grabs someone by the throat! That says "my god, I've got to read on here!" If you don't do that, it's not even going to get through first base in



those particular journals. Now that's something you have to teach the graduate students. It's not something that is natural, because it is peculiar to the situation. A bit like the journalist, they'll start with something that is right at the top, that's the most vital thing, and it gets less important as you go down. In science, there are ways of writing papers for certain journals, and ways of dealing with a referee's criticisms, and those are some of the peculiar things about writing in science. It's a craft that experienced people like me know, we know the game and can teach to our students.

I think the other thing is to pick out what's important and what are details that don't matter. So in some ways a short paper is a letter. What are the key elements of this, what is it you want to say? And for me, I always say "What are the pictures we are going to show?" Start with "what's the story" and "what are the pictures we're going to put in there?" Because, when most people read papers the first thing they see are the figures or the pictures. And, it's like—well, I grew up on cartoons, comics, and now kids watch TV. As human beings, we are visual beings. The very first thing we notice are the figures or their captions underneath. So I say, "Really, in reading a scientific paper, you should be able to look at the figures and the captions and you should just about get it from that." And furthermore, the figures will guide the process of telling the story. They will be the reader's anchor points for the meaning of the story. So I say "Ok, we're going to write a paper, it's going to be for *Physical Review Letters*, it's four pages long, so there will be four or five figures, little things that fit into a column. What are those figures going to be? What is our story going to be?" And once we've settled that, then all these other things seem to follow.

Figures are very information rich. And of course they are the presentation of the scientific results, the proof. You had a theory, you've got some data . . . now, does it agree with the data? That's the killer bee thing. The words are just guiding the storyline. But the killer bee punch line? In physics anyway it is the pictures. The role for visualisation of graphics is very important and it's always been that way in physics. You know, Leonardo Da Vinci's beautiful drawings—so important.

The mathematics of physics is very important too. What's the mathematic story that we've got here? How can we get this at its most sparing but clear way to write down this without too much detail? Where might we take some mathematical detail and put it in an appendix, so as not to distract from the story? So there are some peculiar things to writing a scientific paper in physics which are different from, obviously, writing a review.

Is scientific writing persuasive? You have to be very careful with this. Something can be persuasive because the evidence so compels you. That has to be the case in science. In one sense, the data, the evidence have to be persuasive in

themselves. In that sense, even a person who is a poor communicator, who writes badly, should be able to shake science at the foundations because of the profundity of their discoveries. So the medium is not the message and it must not be so.

So there are people who are very successful in science who are not, frankly, good communicators, not even good writers but their work is so good it shines through anyway. And that's as it should be. They might need a bit of help sometimes from colleagues or editors or whatever. And I defend those people: science needs them, everyone needs them. They have to be exceptionally brilliant in order to succeed; it's harder for them if they're not communicating well. I mean, I say that all scientists who are successful are good communicators. That has to be tempered by the fact that some people are just so exceptional they manage even though they are not. But it is much harder.

I'd say the science itself has to be persuasive, not the writing. However, it does help if the writing is clear. I don't think persuasion, in the sense of an emotion that might come from reading the prose, should have a role in science. One shouldn't be swept along by the beauty of the prose; it's got to be right.

I am a pretty mediocre scientist. I think, to be honest, a lot of my success and my recognition in science, is simply because I do know how to go to an international audience, I can speak English in a way they can understand me, and I can present in a way, thinking about my audience, that they actually come away and say, "you know, I understood that talk! And, I didn't understand those other ones." And so they remember what I did. And honestly, I've had a lot of generosity towards me which is undue, simply because I've made an effort to try to explain.

I think learning to be persuasive is part of the life of being at a university teacher; I often say that university scientists should have a big advantage over those are pure research scientists, because they have to teach undergraduate classes. And there is nothing more humbling than standing in front of a bunch of kids who are saying "frankly I've got to pass this exam, are you able to get me interested in this subject? Can you motivate me?"

I've taught freshman physics all my life. I teach freshman physics here, and the great thing about teaching undergraduates is that they are fearless, in that they're not afraid to ask a dumb question because they want to pass, and they've got to know. So if you stand in front of an audience of your peers, they're not going to ask a dumb question, because they're afraid to look stupid. They'll ask something to show how clever they are. But students ask, "Can you explain what you said?" And so you learn, when you're teaching, particularly freshmen, some of whom are not very motivated, to make it clear. And then when you're teaching students who have chosen to study physics, they're struggling with the concepts and so will very quickly sense if you don't have a deep understanding

of the subject yourself. So the clarity and the understanding is kind of a part of what you have to do as a university teacher. My observation is that people who come from universities tend to be better at this than people who don't, though it's not universal of course.

Much of my writing now is first drafted by or with someone else. All of the team will create the story. Someone has to start with a draft. What I will do, particularly with my graduate students, say a first-year Ph.D. student, is we have our first paper, but they have never written a paper before. So we start and we say "now, look, what is the story? What are the pictures and so on?" The most difficult part to write is the introduction of a paper, because the introduction is kind of "what are we going to say? What is the context? Why are we doing this?" They find that the hardest. They're very good when it comes to "what did I do for my experiment" and to be brutally frank, I say to them "why don't I write an introduction? Because I'll give you an idea, you'll get the sense of the way this works." So, the way I'll work in a team is I'll say . . . "we agree on the story" (that's a discussion, right . . .) but when the writing actually starts I'll say "look, here's an introduction. I want you now to go away and write the rest of the paper." So, they will start, and the next thing will tend to be what was the experimental method, what were the results, and so forth. Then we'll start getting the more difficult stuff about the interpretation of that story, and how we would end it off. In the process, it will go backwards and forwards. We don't sit down and write together. I write something, they add something on, I will correct that or make suggestions, sit and talk with them, they'll have another go. We'll go backwards and forwards.

Someone's got to start it off. And you just iterate the draft around. I do have exceptional students who sometimes say "look, I'd like to write the draft" and I've had some who have written a draft and I say "Perfect. Just perfect. Just do it like that." But they're rare.

I've had many students who are almost illiterate (they're illiterate in the sense that they don't write good prose). But the remarkable thing I have discovered is that, in the process of writing a Ph.D. thesis, with all the pain that surrounds that, and me tearing into their prose and rewriting it, by the time they're at the later chapters, it's not too bad. It's amazing! Clearly they just haven't had the practice until that point. And the very practice of writing the Ph.D. is in itself a major learning exercise for many. You have to wonder what they have ever done in the past.

I've had students to whom I say "go and read some novels" and they say "what?" and I say "Go and read some novels!" Don't get them reading science books, go and just read—I don't care what it is, just read something. And, you know, if they're not readers, it's going to be hard, isn't it? I mean, fundamentally

the ability to write comes from the fact we've read. There's a resonance to the language. We're not thinking in terms of grammar in a conscious way (even though we might have learned grammar), we write almost instinctively because there's a register of voice that we're used to and we've picked it up from our reading. Things unconsciously become part of the means in our brain and they end up on the page. So if people are not readers, it's hard for them to do that.

The cannon of science, everything that we have, which is standing on the shoulders of those who have gone before, is recorded in writing. If I want to get to know Albert Einstein, I go and read that paper, *Brownian Motion*. He wrote that paper in 1905. And it is absolutely magical. I can only read it in the English translation. And I can see right inside the mind of that man, it's like I know him as a friend from that record that's left. It's nothing to do with the pictures that have been in *Time* magazine or any movie of Albert Einstein riding a bicycle that tells me anything about the man. It's what written, that's the record that remains. And that is all we have in the long run, in science, is the written record of what we do. We all die. I'm not going to be standing up in front of an audience in twenty years' time, but I would like to think that someone might read one of my papers and think "that's really interesting."

There is the sense in which the recording of, the visual through digital recording medium, means there is another mechanism for people's science impact living on, and you can see Richard Feynman in these wonderful lectures he gave in the early 2000s. And it's fantastic to watch but, nonetheless, you're really not quite in the mind of the man at the deepest sense unless you go and have a look at his scientific writings. Because that was where he was writing for that audience, his scientific peers. It really mattered for him. So that's the ultimate record that we have. I think that's surely the most important thing. That's what we leave behind.

## CAMERON

Cameron, a close colleague and co-author of Richard's, is also committed to changing the public perception of science and encouraging government to recognise the potential of science in relation to economic development. In mid-career, he made a choice to engage in outreach through a significant blog, and thus has an interesting perspective on the role of social media in science, as well as a perspective on writing in different genres. He has a warm, self-effacing manner, and his style of speaking entirely lacks Richard's forcefulness. But this in no way diminishes his influence and perceptive vision for how writing and communication will influence not just the future of science, but also the future of government and humanity.

## IT COMES WITH A KIND OF MATURITY, KNOWING WHAT WAY YOU CAN PUSH THE BOUNDARIES

My blog evolved out of my role as Deputy Director of this institute. I took on that role in 2008, and one of the things that the institute has always done is that it's had a big emphasis on outreach. When I came on as Deputy Director, our Director was less into the outreach and so I decided outreach was one of the things I should take up as part of that leadership team. I thought about what I could do, and I'd had a little bit to do with the science media centre, and I was aware that they were planning to start a blogging site, and so I just decided one day that that would be a really good way to start getting into the outreach. And it was something that was a comfortable way to get into outreach, although I still remember I was fairly nervous when the blog went live, but still it was an easier way into outreach than some of the other things I could have done, like going on the radio or trying to do more active things. It was something I could do in my spare time and just work on and practice. So that was my entry way in. I guess I've been at it for about four years.

Actually I have to say my blogging's dropped off—I'm only putting out probably at the most a post every two months at the moment—because I've now written a book and I have a column, so my writing's spread out and my blogging has dropped off a bit. I guess at the peak of the blogging, when I was putting out things regularly, I was probably getting a readership of about 2–3,000 people per month, something like that.

I was blogging about innovation at a time when there weren't many people writing about that area, particularly from a scientist's point of view. I've had several people point out that I fortuitously filled a market, a niche. And then also I guess there are a few topical things that happened that enhanced my readership. So, during the Fukushima earthquake with the nuclear disaster, I wrote some pieces which got picked up by a national newspaper and that generated a lot more traffic to the blog.

Right at the outset I had a goal. Richard and I talked about some of the things I might do, and he said one of the things that he'd been able to do, and that he wanted the institute to continue to do, was to offer thought leadership for the country. So that's what I've tried to do. I've tried to be analytical and think quite deeply about some of the challenges facing science in the country, and also—from my blog at least, in quite a few of my articles—to aim it at policy people. So I was trying to push topics that I thought would be of interest to them, and I knew I was reaching chief executives in ministries and politicians, so I knew that was successful. I had a clear strategy; I had a whole lot of stuff that I wanted to cover and it was a matter of just putting some thought into particular topics.

The other thing that happened is that—and this was interesting—having signalled my willingness to engage through blogging, I then started getting a whole lot of other things happening. So I would get requests to talk and I also got a slot on radio, and so then if I was going to do a particular interview on a topic I would try to write a blog post—I had to prepare material anyway. So I had this big, overarching theme to my writing, and then, if I saw something topical I could write about, I would jump in and do that as well.

My overarching theme is about how science contributes to the economy, and also what is it that makes a successful science system, or what makes some parts of the world more innovative than others. And I actually turned this into a bit of a research area, and so sometimes I was writing about original research that I'd done on this topic and other times I was drawing on work done by other people.

As well as this, I have a monthly column in a business magazine, and I've also had op-eds reasonably regularly. So there has been a shift in my writing—this does tend to happen in a physics career. I mean not the other side of writing, popular writing, but as you move up in physics you tend to become the leader and, because you're working with students, part of your job is to train them to write so they become the primary author on their papers. That's generally true. I guess the other part is that traditionally you end up writing grants; the group leader writes the grants and the students and post-docs write the papers is how it's traditionally done. I still have to do that, but then I also do a lot of this other writing now.

I enjoy writing. I mean, I have to say having a deadline on the column, that's hard work. It's not that writing is not work, but I do enjoy it and I particularly enjoy the popular writing—it's been a bit of an experiment for me as well and I do like doing new things. I really enjoyed writing the book—that was a really good experience. It was really hard work but good.

I was writing the book with Richard, and it was probably not a typical experience because he passed away halfway through. So that was a challenge. But then again, you know, we had quite a bit of momentum, so even though we still had about half the material to write, I felt like there was enough momentum. What I did find hard was . . . the bits that I knew he was going to write, I found it hard to write in his voice, if that makes sense? No one's yet been able to guess which bits Richard wrote and which bits I wrote, so the style's kind of consistent. But I found it uncomfortable and awkward—trying to put words into Richard's mouth, I guess, is how I would put it. That was a strange experience.

I think I'm probably a drier writer than Richard, less flowery. And I think maybe it's blogging that has changed my writing; I've had a lot of practice and I've made a deliberate effort to simplify my sentence structure when I blog. Richard's writing in a much more complex way than I am. It's very clear when

Richard writes, but it is more complicated. I do find myself to be a very functional writer—that's how I'd describe my writing. You know, I'm not sure I'd read me.

Richard has certainly influenced my interest in writing. When we planned out the book, we planned out the narrative and then we both went away and wrote. For the first couple of chapters, he was in Cambridge, and I was travelling as well, and we both came back and compared notes. And actually we'd both written stuff that went at the same pace and I wonder if, having read lots of Richard's stuff, I was anticipating how he was going to approach it, and then I think I probably tried to match the tone I was expecting. Obviously we've done a lot of editing since then, but those first three chapters really did feel like they went at the same pace in the way we skipped over the ideas.

Perhaps the difference with my popular writing and my writing for a scientific audience is that, when I'm writing for a scientific audience, it's typically a collaboration. So, even when I'm writing a grant, I might be the lead person but I won't necessarily have the expertise to write enough detail on a particular topic. So I think one of the things that's different is that you know it's a collaborative process, writing a grant, and so you do have to have a discussion to start with. But often you need to start, so I will need to start by putting some text down just to get other people thinking along the same lines. So I might have to write something that's very structural, that has the structure of what I think the grant should look like, and then I've got to put it to my collaborators.

Then I really start thinking about how I want to explain the ideas; and so we might get some structure to it; we're going to give the general introduction to the idea, get into some specifics, say why we're the people right, etc. Then you really actually need to put some meat on those bones and think about what you need; you might need to think about some examples, or some metaphors. You need to consider how to spark people's interest in the grant. So you've got to have a punchy interesting introduction. You'd perhaps go through that process where you're trying to write everything, make it interesting, and then often you start losing accuracy and, of course, you've got space constraints with the grant proposal. Then it's an iterative process as you try to keep the interest in the proposal while making sure it's accurate, but also keeping to space constraints.

The grant goes to a physics panel—well it's broader than just physics, so it might be physics and chemistry. It's a relatively general audience; it can be very challenging for someone in chemistry to understand a proposal in theoretical physics. It's reasonably high level. So you're kind of negotiating between wanting to make it readable for a more general audience but keeping it specific enough for somebody who is on the panel who wanted to make sure you could get the detail right.

I do edit as I go, and so I might get halfway through and then go back and re-edit because I'm not happy with how things are going. And then I like to put it out to my collaborators to have a look at, get their comments back, maybe get some edits from them. So having gone through some editing and writing, I then like to have a little bit of space; I often like to have a couple of days just to come back and look at it fresh and then I'll almost inevitably be quite dissatisfied with it.

For a paper, thinking about the journal we're targeting is almost the first conversation. You need to know at the outset what type of journal you're aiming for. And so for the more prestigious journals you're going to go for a quite short succinct paper or for the less prestigious but more technically specialised journals you'd go for a longer format that's more in depth. So you need to make a decision right away. It doesn't mean you'll necessarily get into those journals, of course.

I definitely am thinking of my audience. I don't always. I don't always feel a difference between, you know, when I'm writing different things. I mean I do think about it, but it's often the structure that will change rather than my style of writing specifically. It's difficult to describe. I guess it ought to feel different when I'm writing for different audiences but it doesn't always. So it is something that puzzles me a little bit. I suppose I might be more playful with the broader, more public audience—but I can also be quite playful in grant applications too, to try and capture people.

When I started blogging I was very uncomfortable because, as a scientist, you try and write without opinion—do you know what I mean? You know you're writing based on things you're very, very certain about and there might be a little bit of speculation at the end of your paper but it's clear you're speculating. But when I started blogging, I had to put opinion in because I could see from the stats on my blog that the more opinionated my blog the more readers I got. And I think, for a scientist, when I started out doing that, I was quite uncomfortable and I was particularly worried about criticism from my peers. The other thing that happens, of course, with science is, if there's a stupid mistake in your paper that will get picked up through closed peer review, you won't be humiliated in front of all your colleagues. But when you're blogging or when you're writing popularly there's not that private checking necessarily going on, and I think I was quite nervous about that when I started, but it's something I've gotten used to.

When I'm writing, I do think I'm being persuasive. I think so. Although I said I am putting opinions out there, I'm trying to make them evidenced-based opinions and so probably one of the things in my writing is I do draw on evidence a lot and try and explain where that evidence comes from. And in scientific writing, that's even more evidence-based.



Scientific writing is probably easiest for me. Probably just because I'm much more practiced at it and it's much more based on my own work. It's the stuff I know best; the further I go from where I'm grounded in my own work probably the harder it gets. But, I'm a theoretical physicist, so compared to solving difficult equations in physics, writing for the blog is not something I think of as difficult. I guess it's time-consuming, it does take work, and I do need to put effort in, and I need to motivate myself to do it, but I wouldn't say I find it difficult.

Finding the time to write is actually really difficult, that's the tricky thing. And especially what I've found with writing the book is I needed to take out big chunks of time to do it; you know with the blogging I was able to write something on a Sunday night or on the plane or something like that. When it came to the book, I needed to clear a week, and once I'd spent a couple of days preparing my material and thinking through a bit about the structure and stuff, then I would actually write quite fluidly. So by the end of the week I was writing a lot faster and a lot more fluidly than I would at the start—so actually finding that time is critical and, of course, when you're trying to sandwich it in with your academic job and teaching and things, that's quite hard.

I'm a bit of an idealist I suppose, and I do think that it's important that scientists do communicate with the public. You get all sorts of positive feedback for doing it as well, so that's always good. When you see that you're having an impact and having an effect and changing people's opinions—that's really positive. And I want to make a difference I guess. You also get direct rewards for doing it—I learn a lot as I write, and by reaching out to new audiences I meet new people and I learn from those people. In my research group we've picked up funding because someone's read a piece I've written—actually understood what it is we do, and come to us to say “well, could you do this for us as well?” Or “I've got this idea.” But fundamentally it comes down to wanting to change the way the country does things and the way we think about science. The writing is a way to achieve that. I've found it's really effective.

There might be times when you just go away and do the science and then finally report the results. But these days communicating with your team is very much part of that, part of the scientific process, because science is so much a team effort these days. And if I've got a student or a post-doc in my group, one of the things I'll get them to do is write as they go because (a) it helps keep their thoughts organised, but also (b) it's a good way of communicating to the rest of the team as to what's going on and what they're thinking about. So I do think writing is now embedded as part of the scientific process.

When you read equations, they should read like a good sentence and I don't think everybody gets that, but that's certainly how I feel. Equations are part of the language and they should fit into good writing. I think there are still corners

of science where you can beaver away just writing equations perhaps, some areas of mathematics—but most of science (and this includes almost all of physics) you've got to be able to communicate, and writing would be part of that. For me, equations are like writing. Or you could look at it the other way—sentences are equations. That may explain why my writing is so functional! I don't know.

To me sentences and equations are not very different. And I think again perhaps, if you work in pure mathematics—that might be the case that those equations don't correspond in sentences. But in physics, these equations describe part of the world, so they're descriptive. I do have the ability to read equations that don't necessarily have a physical meaning. But generally I'm not comfortable with an equation until I can put a sentence structure to it or a physical interpretation. That's a very wordy way of explaining what I mean!

I think people are communicating much more broadly at all stages of their careers now. There are far more outlets now for scientific writing than perhaps there were 10–20 years ago. And I know we have Ph.D. students here who blog and who tweet and who do all sorts of things—which wouldn't have been possible in the past, when I was a Ph.D. student. Writing's become much more democratized in the sense that we can self-publish through our blogs. I think people have embraced that and we're maybe not following the traditional model any more.

You know, having said there's a whole lot more outlets for writing these days, it can also be very distracting. Where should you put your efforts? You do have to mentor people, and so you have to talk about their priorities and that they do need to put time into things. There are people who think that I've probably hived off and starting doing this stuff too early as well. There have certainly been colleagues who think that in your early 40s is when you're at your peak of your scientific productivity, and by diluting that I've probably hurt my academic career. There's no doubt that the popular writing I do takes away from my scientific productivity; but on the other hand I think I'm doing different work because I'm doing this writing as well, and I think I'm probably doing more interesting work because of the wider exposure I've got with a wider variety of people.

I see the other point of view, but it also worries me. What are you missing out on when you're one of only eight people in your field? If there's a circle of you all talking to each other, there are opportunities you might be missing for taking your work in new interesting directions. There's a risk, a risk that people's work just disappears down rabbit holes—and this is one of the things that comes out when you look at how innovation and creativity work. The social network that you're operating under is crucial for creativity and innovation. So talking to people about your work is important and not just those people that are in your own field.

There are conventions for writing in my discipline, but some of the most pleasant scientific articles break that mould. Certainly those types of conventions are a good rule for people starting out, and of course a lot of physics is written by people for whom English is a second language and so if they're going to write effectively they'd need some tight constraints. So there do tend to be constraints, passive voice and so forth, but they're not always followed these days. I wouldn't always follow them. It comes with a kind of maturity, knowing what way you can push the boundaries.