CHAPTER 6
THE POETS

> The equation is poetic.
>
> — Catalizador

> At the core of science, science is an art. And, you know, one of the hallmarks of art is beauty of expression. Good science writing should be completely unambiguous, but it should also be beautiful.
>
> — Senior Scientist, Nutrition and Physiology

Much has been made of the division between science and the arts. Laura Martin (2012) goes so far as to suggest, albeit implicitly, that writers and scientists are not the same people:

> Good writers and good scientists share many attributes. Both care about their representations of the natural world. Both work constantly to improve their craft. Both care about clarity and about audience.

C.P. Snow, a writer of fiction and science, writing half a century ago, deplored this "gulf of mutual incomprehension" between what he describes as the "two cultures" as damaging to society as a whole. Lawrence Krauss, writing in *Scientific American* in 2009, suggests that Snow's call to experts in both fields, to build bridges between these two cultures, has gone unheeded, that the gulf between the experts in these differing fields remains firmly in place.

The senior scientists in this study, however, do not entirely support this proposition that the arts and sciences are starkly separated. Many of the participants showed a spontaneous interest in art, music or literature. Richard's comment (Chapter 2) seemed to speak for many of the participants in this study:

> I love language, and love to read poetry and things like that. And most of my scientific colleagues who are leading scientists throughout the world are like that. Talented people are interested in stuff. How could you not be?

The majority (76%) of the senior scientists I interviewed described themselves, in some way, as regular readers of fiction. Many of the senior scientists I interviewed moved away from the questions about science writing at some stage in the interview into an enthusiastic discussion of a book they'd recently read, or a book they had long loved. Several of my interviewees' offices were strewn not just with scientific journals but with literature.

Laura Martin (2012), in her discussion of the perceived separation between science and the arts, attributes the responsibility for this division to our education systems (see Chapter 7), but the results of this study bring such a statement into question. One issue that arose in the interviews was the whole question of creativity and science. Clearly, a full discussion of the relationship between science and creativity is beyond the scope of this study, but scientists' perceptions of this relationship are not. For several participants in this study, the sheer open-endedness of creative writing at school was both puzzling and, in a way, frightening. Not until they were able to find something concrete on which to pin their imagination were they able to engage creatively:

> I never really enjoyed [writing at school]. Never. Until later. And I guess that's partially because it was creative writing, and that's quite different to the sort of writing that I do now, which I enjoy . . . I can certainly see a creative component in [scientific writing], but it's still centred around something tangible; I don't have to make it up. There's still data or theories that I can use to develop my story. (Senior Scientist, Asthma Research)

Within this context, many scientists saw themselves as engaged in a creative endeavour, which involved creativity in writing. Even Mason (Chapter 3), who was generally disparaging about the arts, saw writing papers as creative. In response to a question on the survey, "Have you engaged in writing a piece of creative writing or creative nonfiction in the last 6 months" he wrote: " I object to this question. Obviously scientific papers are creative non-fiction."

The notion of creatively constructing a story or a journey narrative was central to many of the interviews:

> A good [science] book takes the reader by the hand, and you start a journey together—even if it is a journey to formulas or topics, it is a journey. And you have to organize this journey, and this journey can be pleasant or [not], and that depends on the writing. I think this is part of the writing process, creating a story. . . . So I like writing—it's part of the creative process. (Senior Scientist, Biological Physics)

One participant, after the interview, sent me an extended discussion of this idea of story:

> A good short story is circular. The protagonist starts at point A, is confronted by a situation that raises the question of how will they resolve it, and has an outcome, B, that takes the character to a new state of being, C, which somehow reflects on the starting position or has echoes of the opening. The same may be said of scientific writing, starting with X plus Y, the outcome Z is achieved, which is compared with where we started, and what the future holds. In both situations, we (the readers) are taken on a journey—from A to C. At point C, we can see now see point A behind us but in a new context, and, excitingly, can see C and perhaps other points (D and E) marching off into the distance (implications). A good paper/article/grant application or piece of fiction, takes us beyond ourselves and opens new thought horizons. (Senior Scientist, Neurobiology)

Which is close to Randy Olson's comment in his provocative book *Don't Be Such a Scientist*:

> Science and film-making . . . are both exercises in storytelling. And thus they conform to very similar rules when it comes to doing them right.

On a more frivolous note, scientists told me about their enjoyment of creating amusing titles for their papers, or introducing slightly offensive acronyms into their writing, and dreams of introducing and referencing "a completely spurious concept invented by a completely spurious scientist" (Senior Scientist, Chemistry). For some, the creativity of writing was a central part of the fun of writing—I'm thinking of James in Chapter 2, for example, enjoying the challenge of working out what information readers need at different points in a piece of writing. Some saw a need for more scientists to engage in this kind of creativity in their scientific writing:

> I think scientists would love to write a lot more if they could be trained to be creative in the way they write, and to respect it as a creative process rather than a chore. (Senior Scientist, Nutrition and Physiology)

Yet the issue of creativity in scientific writing is complex, and needs to be managed carefully in the context of gatekeepers' expectations of genre. As Burton and Morgan observe, less creative approaches to writing (one might argue, more formulaic writing) are associated with the authors' needs for safety, suggesting that those most likely to feel safe with a more creative approach are likely to be those whose reputations are already established. This was certainly borne out in this study: senior scientists were far more likely to take risks with style, and to do so intentionally. Yet even those who stood at the pinnacle of their field, such as Catalizador in this chapter, trod warily in the face of gatekeepers (reviewers and editors).

Beyond the issue of scientific writing and creativity, the notion of a separation between science and the arts was disputed in the activities of the scientists in this study. A small number of the senior scientists had studied literature at tertiary level beyond core course requirements, or had considered majoring in the arts. While the majority of the senior scientists did not engage in creative writing, a significant minority (17%) had been engaged with creative writing in the last six months, either on a private level (the "secret writing lives" as Poe et al., 2010 describe these activities) or in the public sphere, while several others told me about creative writing or creative endeavours (such as advising a writer of fiction or an artist on some aspect of science) in which they had previously engaged. As an example of private writing, one of the interviewees had written, for family and friends, parodies of Harlan Ellison, Wittgenstein, Plato, Thomas Aquinas and Ayn Rand. Several of the senior scientists mentioned an involvement with music, including writing lyrics, while others had published poetry or science-related creative non-fiction. One had a secondary career as a writer of young adult fiction.

Interestingly, while almost the same percentage of emerging scientists as senior scientists described themselves as readers of fiction, somewhat fewer emerging scientists I interviewed (only 11%) were involved in creative endeavours, either privately or publically. One of the emerging scientists had recently finished his B.A. majoring in English, but only two were published creative writers. We may speculate about the reasons for this: it may be that the pressures of acquiring tenure, for example, work against anything but a focus on professional reading and writing; however, emerging scientists working in a context which had no tenure requirement were no more likely to be readers or creative writers than those working within a tenure-based system. Such speculation is also undermined by the fact that 37% of the doctoral students interviewed—surely the group we might expect to be most focused on establishing their scientific credentials—engaged in creative writing of some sort. However, the size of the doctoral student sample was small, and so these results bear further examination with a broader sample.

For most of the creative writers in this sample, their creative endeavours were, in some sense, separated from their work as scientists. Even when they were working with poets or artists as science advisors or writing creatively about science, they saw this activity as distinct from, and not affected by or an influence on, their professional careers. In their discussions of these activities there was little crossover between the two activities; writing creatively did not influence or cause them to reflect on their writing of science, and their professional identity as scientific writers did not lead them to reflect on the nature of creative writing or art. I include in this chapter one short extract from a physicist who exemplifies this separation. While he has worked with poets on collaborative projects, and publishes his own poetry, his primary focus is observing a fellow poet come to understand something of the language of science and mathematics rather than engaging conceptually in this process himself. About his own poetry he says almost nothing. The second narrative, by a young food technologist who writes game books as well as poetry, attempts some analysis of how, for him, the different kinds of writing have affected one another—but he too sees the two activities as quite distinct.

However, two of the creative writers in this study did engage in integrated discussion about their writing across science and the arts. One was Elizabeth from Chapter 4, in her extensive discussion of directing her writing to a range of audiences. The other was Catalizador, a poet/playwright and a research chemist, who discussed various attempts to bridge the gap between his science and his work as a poet. His narrative, which was quite different to any of the others in the entire sample, seems a fitting final narrative in a book about scientists as writers, in the way it disputes this distinction between writers and scientists.

MICHAEL

Michael is a senior physicist who also has a national reputation as a poet. He has also spent considerable time working with artists and poets, as a science advisor on national creative projects, and he's a broad and perceptive reader. His comment that scientific writing is a craft, but not one that "leaves a personal signature," suggests a certain diffidence about his writing. And while he expresses uncertainties about engaging with new audiences, he is someone who is prepared to sit in the intersection between creative and scientific writing.

Why Do I Do It? Well, I Do It Because It's Fun, and Because It's Interesting, and I Like It

I don't think I'm too bad a writer. There's no point in having a great idea if that great idea never leaves the four walls of your office, so it's got to get out there. And I think good ideas spread quite quickly in the scientific world. Getting them out into a bigger audience usually seems to be more difficult. And that's a barrier that you're always going to have, because I think as scientists you're trained to think and to communicate in certain ways, and it's certainly not the way that the general public thinks or communicates. And so bridging that is a difficult game—but not impossible. But it does make people uneasy, and there are certainly problems when there are political ramifications. If you think about what's going on in the whole climate change argument at the moment—I mean, scientists are trained to not be certain, scientists are trained to be doubters. And so, when a scientist says "we're pretty sure this is what's going on" then there's always something, there's always someone that's going to ferret around and find the 5% around the edges that we're not sure about. Which is what we're trained to do. But is it likely that that 5% of effect is going to be more important than the other 90–95% of the weight of evidence?

One of the things I've thought about is whether I should try to write some more "popular science" type articles, which I sometimes think would be a breeze—you know, write something that is aimed at a *New Scientist* audience. I've never done it—it's just a matter of time. But I think that would be an interesting challenge, as I'm not sure what the audience is there. My reading of something like *New Scientist* is that I'll read in-depth something that's close to my field, and I'll read every word about it. You know, if it's something about, say, cosmology (that's stuff I find fascinating), I'll read it all, but if it's something about evolutionary biology, which is interesting, I'll just skim it—I'll read the first few paragraphs and introduction, and look at the pictures, and see if there's something there—but I won't read it in-depth. And so I think it's a very difficult thing to try and write something that will sum up the field if you like, or talk about some interesting new results, in a way that will both engage the physical scientists that are out there, but would also be able to say something to the general readership of *New Scientist*—something that will hold their attention for a whole 500 words or whatever, I think that would be terribly difficult.

I try to write for pleasure. I read fiction all the time. And I write poetry. In 2005 I was involved with the "Are Angels Okay" project with the Royal Society, and I had a poem published in that collection. And I still just write . . . dabble from time to time. "Angels" has been a really nice project, and things that have gone on from it have been really nice. But I don't think there's any influence between the different types of writing I do. Certainly I can't see my journal articles influencing anything else I do.

Following up from the "Angels" project, I was advisor on science to a poet. So we've done at least three presentations together since that year—it's been a while since the last one. He's one of those guys who you just pick up with immediately. He thinks really hard about what he does and it looks so absolutely effortless. He's really thinking about new ways of presenting poetry, which I think is really exciting.

Being a science advisor to him was just talking about science. The "Angels" project was about getting 10 writers to write about, or come at, physics (because it was the international "Year of Physics") from their perspective. So he wanted to write some poems and we talked about themes, and it turned out that he actually liked physics and liked ideas, but always had trouble with mathematics. Mathematics is really the language of science and physics, and so getting to grips with that was actually a real stumbling block. In many ways, it's not just for this poet, it's for all our students. He wanted to look at a lot of the equations that we use and reinterpret them or translate/interpret them. And so that was the project we came up with and he wrote these 10 poems or series of poems about various equations. We would look at them and he would ask me a lot of questions about what they meant and what sort of things you did with them—why people thought that certain equations were particularly important or beautiful or whatever. That's a word that gets bandied around a bit, but there *is* a certain beauty in some of these equations. And it was a marvellous job, actually, it was a great project. You can contrast what he did with another poet in this country, who also wrote a suite of poems about science that were very, very different in character. But both those sets of poems are wonderful.

One of the poetry series included a beautiful poem about spiders' silk, about how a spider makes silk. The poet who wrote that series talked with a range of scientists about materials and things—and looking at them poetically. So a lot of his poems were perhaps a bit more prosaic in that sense, talking about everyday materials or coming at new materials. Some of it, I think, was a process of discovery as well, and he talked about that.

Why do I get involved in these creative projects? Well, I do it because it's fun, and because it's interesting and I like it . . . and that's the reason I do most of this.

EDWARD COLLINS

Edward is an emerging scientist, a food technologist—still very much engaged in responding to writing and research tasks rather than initiating his own. Much of his research is industry-based, but he has a secondary career as a writer for a board game. Like some of the senior scientists in this volume, he's interested in everything; our broader conversation weaves around living sustainably, photography, and all kinds of writing. He has a gentle, thoughtful air, pausing to think before he answers any question. He has an unusually broad interest in, and experience of, writing—and he sees each of the genres he engages with as influencing the others.

I Don't Think Scientists Should Be Afraid of Creativity

As well as the science journal type articles, and those kind of things, I do some writing totally outside of the academic area for a game company. In some ways it's not all that dissimilar to some of my academic writing in the process it goes through. We write the material, then it goes through a couple of editions of peer review, and then it gets eventually published. And it takes about two years to go through that whole process.

The game that I write for is set in the year 1220, and it's very concerned about being historically accurate. So it's researching all the things that were around in that period. For example, we wrote a book about cities of that period. So we had to research all the diseases and things that were in the cities, and also the medieval perspective of those things, because, from the point of view of the game, all the things that they thought were true, are true, in that they thought that diseases were caused by demons and bad air. So it's a lot of library type research.

I've always played those kinds of games, and then the company that does this periodically has an open call, where they just get people to submit their own 300 or 400 words about a particular topic. The better ones are then invited to write actual books, rather than snippets of small books. That's how I got into that.

And I do a little bit of creative writing. I write a wee bit of poetry. Nothing much published in the last year or two. Also short stories, which, again, I'm trying to get into a format where I can publish them somewhere. I took a writing course with a creative writer some years ago, and after that I took a freshman creative writing course, and finished my B.A. in English. I'd like to actually do more of the creative writing type material—short story, novel writing, that is what I really want to do. It's a matter of trying to fit it all in.

I think my creative writing has been affected by my technical writing in that I bring a kind of precision to it, that I wouldn't necessarily have otherwise—it's hard to know, of course. And then going the other way, for my technical writing, it's about thinking more clearly about what I'm saying. In creative writing, you're not trying to write exactly what someone else has written, you're not trying to compile a whole heap of what are almost slogans. You are deciding for yourself what you will write. Whereas, looking at some of my colleagues' writing I can see that sometimes they're repeating a few stock phrases—you know, if you're writing a scientific paper, there's a standard way of going about it. So instead, with my technical writing, I'm thinking about it, reading it, asking myself, well, is that really what I want to say? Occasionally, you think "no, I meant to say exactly the opposite to what that actually says!"

Technical and scientific writing are in some ways like creative writing—you start with a blank page, obviously, and sometimes you have to find a new way of explaining something, and that's a creative process. But there are constraints—you have to explain what it actually was that you found in your experiment, so there are limits to how creative you can be. I don't think scientists should be afraid of creativity—some of them might be of course—because science is a creative discipline. Unless you're a technician, it's not about following someone else's recipe; if you're a science researcher, then it's a creative endeavor, and you're thinking of a new question, or a new way to solve an old question, and thinking about what it all means. That is all a creative exercise. Creativity is one of the central aspects of science: it is creativity within constraints. But there are constraints in creative writing too. All creativity is confined in some way.

But the difference is that in science writing, usually you're trying to describe a physical phenomenon, and you're trying to use language to describe it, but the language is not the thing itself, it's a representation of something else. And in science you have to have more fidelity to what it is that you're describing. Whereas, if you were writing a poem, you still have an idea, you still want to describe it in a way that represents that idea, and communicates it to the audience, but you can manipulate what it is you're describing to fit your words. So you have more freedom.

Mostly, in my professional life, I write industry reports. For a lot of the projects I work on, a report tends to be more often the output, rather than a scientific paper, because they often don't want to publish what they've been up to. And other times it's more consultancy than research, so it's often not exciting or novel from a research point of view.

One project I did, which just finished a few months ago, was looking at the energy use in cool stores. The company had had a lot of trouble with the fruit not coming out of storage in the right condition, and so the work that we were doing was just looking at how they've been stored over a season, looking at the energy use and how they could go about saving energy, but not compromising the product at the same time. So the writing for that is like a summary of the findings, for both the company's technical managers and for distribution to the cool store managers, who often don't have a great deal of technical training—they might be the forklift driver who's been promoted up over the years to managing the cool store. So that's part of the problem: the cool stores have often not been run properly because they don't entirely know what's going on from a technical perspective. They've been told how to run it, but they don't understand why. So a lot of the reports are quite graphical—lots of graphs in them, but writing as well.

I don't really get to conceptualise and initiate a project myself—pretty much all the projects I've been involved in have all been something where industry has come saying "we've got this problem, how do we go about solving it?," rather than me coming up with something to do.

The way they're initiated is that a company will send a description of what they want to a more senior scientist. I think also probably they've talked to him already on the phone, and agreed on what it's going to say before they've sent it. That's something I get to read—then I usually meet with the senior scientist who'd be involved in the process, and then we write some notes about what we're going to do, and then, depending on the extent of it, we might also involve the people from the sponsor (the company commissioning the research) as well. Then we write, just by hand, brainstorming type notes, on what we're going to do there. Then we'd usually write an email document explaining about what we're going to do at various points. Then as I'm doing whatever I'm doing—maybe I'll go out to a site to look at something—then I'll write some notes up afterwards, just for my own benefit, which will then later be used for something else. Then maybe I'm writing a computer programme to simulate something, as part of the project, in which case it would be writing the computer code and trying to document that as I go, so I can explain later to them what was done and why. Perhaps there will also be instructions written for a student or technician who will perform measurements or similar. Then there would usually be one or two PowerPoint presentations that would be done. So I'd be writing those—depending on the size of the project, maybe there'd be one at the beginning about what we're going to do, and then maybe one in the middle and one at the end about what we've actually done. In a small project it would just be one at the end about what we've done. And the written report would go through several hands. Usually I would write the bulk of the report and then it would be edited by the senior scientist in the project, and then often the people at the sponsor would stick their ruler in as well and have a go at editing that.

When I'm doing those industry reports, I'm conscious of the audience. And when I'm writing for the game company, I'm also very conscious of the audience there as well, which is the players of the game. The game has a big emphasis on historical realism—it's not just played by 10- and 12-year-olds, it's played by people in their 30s, or people who have degrees in medieval history, and who, of course, know if you get something wrong. And actually I find that the peer review that goes through is a lot more rigorous than what we do for our academic writing. It is quite interesting how thorough that process often is. Each chapter of the book will get five or six pages of text of peer-review comments about it. Sometimes more if they've found a lot of holes. And then it goes through two peer reviews. There's the first draft which then the line editor reviews internally, and then there's the first proper peer review. And then you revise that, and then there's the second peer review. And then out with it. As well as real content, you're also putting in rules for the game as well, so they have to test that they make sense.

In terms of comparing the two types of writing, with the game company, I'm trying to stick in creative elements as well. You've got to make everything kind of provocative, whereas, with the scientific paper, I'm more concerned with being technically precise. For the game company it's OK to spend a few sentences getting to the point, if it makes for a more interesting read, but the technical scientific writing is usually being written to a stricter word limit, and you've got to get your main scientific points across, with no room for some ambiguous metaphor or allusions. In terms of the game, ambiguity's a good thing. Certainly. Because as well as describing the setting, you're also describing the characters and things that people might encounter, so you've got to talk about what character's motivations etc. might be, for example, but also not dictate everything, because people who get the product want to make up their own stuff. So as the author you can't fully breathe life into the character.

But if we compare technical with the scientific writing? When I'm writing the technical reports, I am thinking usually that I have to explain things in a more simple way and that's because the majority audience for them are often less technical people, so I can't assume so much knowledge (although some of the audience are technical managers who do generally have scientific training and know what we're writing about). So some simple things I would assume the reader of a scientific paper would know or at least if they wouldn't know I can at least put a reference in and say "go read that, it's there." Whereas in the technical one, if I want to make even quite a simple point, I need to explain, walk my way through it a bit more. Simply. In smaller chunks.

I think in the science writing, the blending of having graphs and equations and diagrams in with the writing—I'm not sure whether I can explain it very well—makes a bit difference. Equations and figures can be kind of a shorthand for writing. I put equations in, rather than explaining in words what's going on. Because, in that field, people would understand the equations and wouldn't need the words as well. The figures tell most of the story, even in scientific papers. I think usually the equations are a short hand, rather than a different way of thinking, 'cause you could explain in a paragraph what the equations was saying. It's just that if you understand the equations, they're clearer, shorter, and it's easier to understand some implications.

One of the things I'm never quite sure on is how big the audience for my scientific writing is. If you send an article to a journal, you're never quite sure how many people read those. There would be dozens or hundreds of people in the field, but the matter of how many of them would read every article in that field I don't know. Although even the scientific articles that I write are in an industrial kind of area (refrigeration, energy use and things like that), often quite a wide potential audience will be reading those, I think.

I think I tend to be a more intuitive writer. I don't usually consciously think what it is I'm changing. I'm just changing it to the right way! Although, having said that, when I'm editing, I do try and scan through and try and get rid of being too verbose in the science writing, which is something that I don't like about a lot of other science papers. I try to cut down on meaningless long Latin words that sneak into a lot of writing. And although you don't use too many metaphors in science writing, if I do have one, then I try to make sure that I've actually thought about what it means, that I have actually used it in the correct sense, so it won't be confusing.

There isn't a big place for metaphor in science. But in the technical reports we might have little colloquialisms (like "capturing the low hanging fruit" when we're talking about what opportunities we're looking at). So there can be little snippets like that, almost clichés, because everyone can understand them. It's important not to try to be too inventive with your metaphors in science writing. There are big commonly agreed metaphors used in science writing, of course, but they are only rarely made up by an individual scientist—they're more like clichés again, such as the "solar system model of an atom." It's no longer the latest thinking, but is still used to communicate some useful ideas.

CATALIZADOR

I drove for five hours in a snowstorm to meet with Catalizador. He is a celebrated chemist whose long career is marked by the highest awards and accolades in his field. He's also a published playwright and poet, is fluent in several languages, and has thought deeply about language and writing. He put aside an afternoon to talk to me about his writing, the connections between scientific and creative writing—and his endeavours to change both the way science is written and perceptions of scientific writing. In this narrative, unlike others, I have retained some of the questions I asked, since they deviated so far from the original question sheet.

Poetry for a Scientist Is a Well-Written Article

I read a quote of yours that said "there is metaphor aplenty in science" and yet most of the people I've interviewed have said "there is no place for metaphor in science."

Yeah, they're crazy. They're crazy, but we know where it comes from. Let's blame the current systemisation of science and the privileging of the mathematical, the natural language of science. So that anything that can be made mathematical, converted into an equation of something quantitative, and in further development processed algebraically or geometrically, it is privileged. And those aspects of the human experience which are not mathematical in nature that involve reasoning by analogy, metaphor in all its guises, narrative, telling stories—they're dealt out of science I believe. And that is crazy.

And yet metaphors are consistently used by scientists. Let me give you an example. In my field in chemistry and in physics, we deal with molecules that may have some limited stability; they may be around for a while and so the image, the metaphor that one has constructed for dealing with these involves a landscape with hills and valleys. Molecules rest, for a moment, in valleys far up, are pushed over hills to other molecules. You cannot do chemistry without drawing things, drawing structures.

But the metaphor is of a landscape. It goes something like this; that there is one valley, there's a hill and there is a lower valley on the other side. Molecules move to lower energy, unless something pushes them up. The metaphor is that this is like water facing a dam. The water wants to go downhill, molecule A wants to decompose to molecule B, so what's plotted in the other dimension is the extent of the reaction—from the beginning to an end. This is reactant, this is the product—other very chemical words. And in between there's a hill, and unless there is enough energy to get over that hill, it's going to stay there, like water behind a dam. And most molecules of this world are like that. This paper on which I'm drawing, you know what happens when you put a match to it: it burns. So the molecules in our bodies—the sugars or nucleic which make up the nucleic acids and the genetic material—they're just like sugar, in a way—they'll burn. They are metastable, that's the word to describe a molecule or a substance that is around, but high up in energy. The molecules in our bodies are metastable with respect of burning if there's oxygen around us. But, fortunately for us, there's a hill to be climbed before we start burning.

I use the word hill, but it has to be fancied up in science so what this hill is called in chemical parlance is an activation energy. The expression, fortunately, is pretty plain English: it's the energy necessary to activate those molecules to get over the hill. So how are they activated? By heat of course, or by other sources of energy. And if you make them bounce around and collide, eventually some will climb over the hill. Anyway, here is a landscape metaphor clearly before you—there is a hill to be climbed and there is an energy necessary to overcome the hill. That metaphor has served chemistry now since 1930—very, very well.

Scientists do know they use metaphor. Oh, they do. It's just part of their thinking, because what else do we have? The imagination is very geometrical; we use the metaphors of the world around us—trees are another metaphor. Cyclical things, like seasons, also. So I think scientists know that they're using a metaphor but they don't 'fess up to it.

Why? Because the metaphor is not mathematical. And they think it won't impress their colleagues. I think if they would admit to using metaphors, the world would be richer, and scientists too, for if they actually talked about using the metaphor they wouldn't be its prisoners. Because in the end the world of molecules differs in some way from that of climbing hills.

So what is a metaphor? A metaphor is a mapping of one part of the human experience onto another one by a mind—that's all it is. All the ways that one has of analogies, simile, metaphor—they're mappings of one type or another. Mappings can never be one to one completely. If you own up to metaphorical thinking, then you can realize its limitations. And look for another metaphor.

As for narrative, storytelling, let me say how I think we come to it. In seeking explanations for things, scientists are no different from other people—they fall for simplicity all the time. It seems to be how our mind is functioning—it wants the world simple. Scientists may think they are smarter than other people—of course, they aren't—and so their falling for simplicity takes various disguises.

So here are three examples of it. There are physicists who will tell you that if the equation that describes a phenomenon is a simple or beautiful equation (they equate beauty with simplicity which is interesting by itself in the context of art. How often would they like to hear Jingle Bells at this time of year—a simple melody—without any variations? They'd get sick in a minute!); then that mathematical equation must be right. And chemists like symmetrical platonic solids like cubes and tetrahedra (because those have a beeline into our soul, or to our minds at least) and have trouble with molecules like haemoglobin which look like a clump of pasta that congealed from primordial soup—there are these chains going every which way in a protein. And my third example of falling for simplicity is that we in chemistry are often looking for mechanisms of reactions. What we mean by a mechanism is enumeration of the elementary steps in a complicated process. So there is an electron knocked off the molecule A, that electron then jumps to molecule B, and B then becomes negatively charged and it reacts with C and it looks like what would be in the UK be called a Heath Robinson-type device; in the United States it's Rube Goldberg (these infernal machines which do a simple task by some complicated manner). So if you give a person a choice between a mechanism for a reaction happening that has one step or a sequence of 37 steps, even if you don't show them any proof, and you ask them which mechanism is right, 90% of chemists will vote for the one step reaction. They're just giving in to simplicity.

So when, through their own hard work, simplicity fails them and the equation is complicated, the molecule looks like haemoglobin instead of a cube, and the mechanism does have, if not 37, then three or four steps, what provides for a scientist pleasure in contemplating the complexity of the real world? I think narrative, telling a story. Even in just saying "electron is taken off molecule A, goes to molecule B, molecule B then reacts with molecule C"—that's a story, it's a narrative. It's got a beginning, it's got an end; it's got process, it's got surprises like climbing hills. You couldn't climb the hill, and then all of a sudden something (a catalyst) comes along and helps you climb that hill.

Scientists often don't realise they're telling a story. This is why actually it's much more interesting to listen to scientists give a talk about their work than to read their papers, providing you're privy to the cognitive structure of the field. And I'm talking about technical talks, chemist to chemist. When they give a talk, scientists relax and they don't have the gatekeepers—editors and reviewers, and their own perception of what a scientific article should look like (that is the worst gate-keeper overall, the one in their head which gets mixed up also with their parents and their teachers and prevents them from writing in good, simple English and narratives). But when scientists give a talk, all of a sudden telling their audience about all those byways and the obstacles, the hill that prevented them, the hero of the monologue, from seeing the solution, becomes a natural process. With one proviso, that the hero always gets over the hill.

So I listen closely to the narrative structure of the seminars; with a little work, I could tell them which Aarne-Thompson type of tale they were recounting. And of course this is so—because the speakers are human, and they're talking to other humans.

I try to fight for narrative and expression and style. In small ways—I can't fight in big ways because I couldn't get my papers published. But I do it in small little ways; I mean it's easier to do in popular journals. But here is a paper that we just submitted to a major chemical journal and I'll just read the first sentence of it.

"Near the bottom (or should it be the top?) of the periodic table, for high atomic numbers, the distinction between valence and core orbitals becomes less well defined."

Well it's that parenthetical phrase—"Or should it be the top?"

I'm talking about the radioactive elements and you could reason—it's sort of weird, I once thought about it, which is why I wrote that sentence—that you're building the periodic table by adding electrons and filling up certain quantised shells. But you're going up in energy: hydrogen is the first and then helium, and the atomic numbers increase. So why are we writing our elements so that the small atomic numbers are on top? Why don't we write it in the way that the energy goes? So that's what that little phrase alludes to. Will I get away with it? We'll see. The reviewers are in the context of finding fault.

I didn't get to chemistry and writing chemistry till graduate school. My personal history is a little unusual in that, while I did play with chemistry sets, I did not commit to being a chemist till halfway through my Ph.D. in chemistry. Before that was a sequence of other things: we came as immigrants to the United States when I was 11 and a half; English was my sixth language. It's the only one which I can write, though I speak a few others. So I'm a European from a linguistic point of view—knowing many languages. In high school the only advanced course I didn't take was in chemistry—I took others.

I started the University as a pre-medical student. My father was killed in the war, my mother remarried, and I have a sister who is 17 years younger than I am. We were in difficult straits when I was at the beginning of university. There was a lot of family pressure to go into medicine; part of it comes from being immigrants, part from the family background. In about the first year I decided I didn't want to do that—there was no particular reason, I just wasn't interested. Meanwhile the world was opening up to me in the humanities and the arts; I was exposed to a wonderful art history course. I went on to take some other art history courses and then I took a course in poetry—reading poetry, a great books course—it was wonderful! Literature and art history are what appealed to me.

I didn't think I was good enough for physics. And I think I was scared away from biology by not wanting to be a doctor. I was wrong to think I wasn't good enough for physics because now I work closely with physicists; I just didn't have enough courage. Chemistry was just the natural thing to follow; there were summer research experiences in chemistry that were good; it would satisfy at least my parents' desire that I have a profession—being a chemist counted as having a profession. So I went to graduate school and did chemistry almost because it was the next thing to do and it was easy.

Writing in chemistry, aside from writing lab reports, did not really begin for me until I wrote my first papers. And those happened after about three and a half years of graduate school, at age 25 or 26. I should say that, before that, I was a good writer. I did not try to write any poetry or anything else—I only took a course in reading poetry—but I learned quickly. I remember one instance; in my first year of Columbia I took a required writing course, given by a young English professor. He was sharp, for him I learned some Latin. I wrote a first paper in this class on some subject and it came back—I wrote it in my best secondary school English—full of red marks. It was just terrible. I'd never gotten a C in my life. But I learned.

So we write a lot and my students no doubt model themselves on papers of mine. I worked for my Ph.D. with a professor who had written several hundred papers at that point. It was a large group, there were papers coming out once a month, so there were ten papers a year from the group. That, incidentally, has been the pace at which I have published; not by design, it's just happened. So I have 580 scientific papers published over the years—over 50 years of activity.

The professor drafted the first paper, asked me to add in the computational part and the interpretation. By the third and fourth paper we wrote—and we wrote about six papers based on my Ph.D. work all in one year—I had written the first draft myself. I caught the style.

In my next three years as a junior fellow, I wrote five or six papers all by myself. But then I began to work with a great organic chemist, and we wrote five very important short papers (I was aged 26, 27). He was a master stylist in English; he wrote high English prose and he changed my prose—it wasn't high enough.

I have since gone away from that important interlude. I could not write like he did, I don't want to—I do other things, I use stylistic devices to catch the reader's attention. Of course, I will never write a paper saying "the subject of cesium floride has been investigated in the literature a number of times, references 1 through 7"—how boring to start a paper in this way—I will find other ways to start a paper. One of my stylistic devices is the density of graphic material—that has to do with writing and drawing chemistry. So maybe it's the art that's coming back in some way. Though I think the drawings of molecules are close to the heart of chemistry, because chemical structures are so much part of our articles.

A stylistic device I use is to employ as colloquial a tone as I can get away with, as close as possible to spoken language. I don't use third person passive if I can avoid it; but I sometimes have to fall into that. I will use the present tense rather than the past if I can. Part of the reason for using colloquial language is that I'm dealing with concepts that are rather complicated. So I try to use as simple language as I can. But, once in a while, I slip in a complicated word. It's more likely to be an interesting English word rather than a chemically complicated one. I love it when I can do that. I pull the reader in, then I push him a little. So, aside from telling a story, which is a natural thing to do, I try to get a variation in tempo if I can. It comes naturally, I don't plan these actions, it just comes out that way. I think my little stylistic devices make my papers more enjoyable to read for other scientists. Whether I encounter resistance depends how good I am at it. If I'm good at it they won't know it's being done.

Look at another phrase I've written "we report here, at least in theory;" I could have said "we report here a theoretical study of"—but I don't. I think what I write is more interesting because I hint at "this hasn't been yet done experimentally." And there is another message under the surface of "you can't really trust us theoreticians." Amazing what you can *imply* in a few simple words. Yet I have to do it in a way that will not antagonise the reviewers. It's a balancing act.

The other thing is I don't like hype and extravagant claims; perhaps that's something that comes with age. When you're young you go into the hype mode naturally. You always think that you're the first one to do something and it's the most important thing in the world. And when you're older you smile at that, right?

When I'm writing, I'm in a pedagogic mode. I do want to convince people that this is a good way to look at the world. I know I'm dealing with complicated things; I've got to simplify it, but I'm still talking to my colleagues. But I feel my primary audience is an intelligent graduate student, and not my fellow colleagues, and I've always viewed it that way. I do want to impress my colleagues but I really want to seduce the mind of that graduate student. Why do I want to do that? Well, because I think I have something interesting to say to them; I want them to think, and I know it's hard, it's hard to get there. So I'm trying to teach the graduate student. Sometimes graduate students have told me "your papers are easy to read" or "they're fun to read," and I've said "they're for you." If I write it for the graduate students, some of my colleagues think what I say is simplistic. Indeed, but it's a strategy—I'm trying to make theory so simple that it seems simplistic.

Another thing I've learned (which I do get in trouble with reviewers about)—I've learned a lot from teaching first-year chemistry—is to use what I would call optimal redundancy. So it's the argument of the "Hunting of the Snark"—what I tell you three times is true. You're not supposed to do that in scientific papers, but yet if you really want to convince people, you should say it at least twice—three times is probably too much. So I've got into a lot of trouble because I repeat drawings in papers; I've integrated the drawings into the context of the argument and I feel that if a drawing has appeared six figures before, then I have to bring it to the reader's attention again; he or she will lose the thread of the argument if they have to flick back, refer again to it, you know? I repeat it, but I use stylistic variation to hide repetition. I say it in a slightly different way.

I spoke to someone recently who argued that the words in a physics paper are not important; this person said that he thought in numbers and equations not in words.

I don't think he's analysed really how he's thought. I think he's probably converted the numbers and equations into some furniture of his mind, there are little blocks that he moves around in the mind. I think the intuition is inherently geometrical, drawing on a billiard ball experience. Though some mathematicians have made claims, like this physicist, that they think algebraically. His argument is the standard one and it comes from the idea of universality of science. It's a universality that we aspire to—we really do hope that the antacid I'm going to take in this little pill is going to be the same as that from the next antacid box that I buy. And we really do believe that the design of the factory for making this molecule works in Patagonia and here. There's an interesting story, by the way—the real life reproducibility of scientific findings.

But I don't agree with the person who said the words are not important; I think there is a certain universality, yet there are differences field to field. I would actually make a claim that chemistry is closer to poetry. Maybe because I do both. But I think there are 70 million new compounds that chemists have added to what was in nature, for better or for worse. They have helped to extend our life by a factor of 2. Not for everyone but for many people. And they've caused pollution to the planet as a result of doing the good thing, improving our standard of living and our health. There's a poem by Archie Ammons,

Reflective
I found a
weed
that had a
mirror in it
and that
mirror
looked in at
a mirror
in
me that
had a
weed in it

It is that particular weed, that particular drop of dew that made him write that poem. And the universality was gained from the specificity of the act—that's why you can write a million and one poems about love without exhausting the subject. It's very specific. And $E=mc^2$ is very general—it's a universal statement, for any m. That's one of the differences—one of the relatively few differences between science and poetry.

So I think the person you mentioned is talking about universality, I'm talking about specificity, and there's a lot of that in chemistry and biology, I think. But even aside from that, I think that had he been educated in a different culture, with different teachers, and done his science in a different language he might have come up with a different solution, maybe a solution phrased differently. I'd put it to him that the really interesting thing about the possibility of meeting up with another form of life (which I think eventually will happen, but not in my lifetime) is to see how that different intelligence deals symbolically with the same reality that it and we share; the reality of the universe and its laws. I have no doubt that the periodic table will look different or that the equations of physics and chemistry will be written in a different way, even though they describe the same thing.

No doubt $E=mc^2$ would have been discovered if Einstein hadn't done it—so it would have been 30 years later, somebody else would have done it; but what does it matter who did it? And yet it does matter, because the whole shape of the 20th century was shaped by that, by the consequences of quantum mechanics. And perhaps the atomic bomb would not have been thought of in time for the ending of World War II. The world would be different; we'd be worrying about other things.

One person I spoke to pointed to a symbol on their chalkboard and said "when I look at that symbol, it has a whole host of things behind it; it's not just a sentence it's a whole host of things." I didn't think numbers and equations had the same depth of connotations that words do.

Of course. And when someone else looks at that symbol or an equation they wouldn't see the same host of things, they would see a different host. Picasso drew 1,000 bulls, or maybe 10,000, in his very productive lifetime. Each one is different—slightly different. Nelson Goodman, who is a philosopher worried about aesthetics, has written of the difference between art and science. He said that the symbols of art, meaning the mark an artist makes on paper, are replete with meaning, their meaning is not exhausted by one interpretation. I'm not going along (entirely) with deconstruction, that there is no meaning. And that writing (and speech) is the message that abandons, as Derrida would say. The author's meaning matters, but it sets loose a host of other associations. The associations of words or artistic images are endless. I think also in some ways the same things, behind that formula, are let loose by the scientist you just spoke of; he is actually giving a very artistic interpretation of that formula. He should be ready for reading poems because he understands that it isn't just what the word says, it's all the words that sound like that word; it's all the words that are vaguely spelled as that word is. It's all its disparate meanings—all of those resonate in the mind. And give the poem depth and life.

And that applies to numbers and symbols as well. That's why some symbolisms of science are so rich and so persistent and so lasting. Like the periodic table—it's not just the arrangement of the elements, there's much more beyond it. So I find this scientist you quote interesting. And I disagree with you when you suggest a number has the same meaning to everyone around the world. It has the same immediate meaning in the same sense that a dog is a quadruped and not three legged. But then everyone conjures their own kind of dog based on their experience. We must attribute a richness to what's behind the concept of 2.

You wrote that the language of science is a language under stress.

I wrote this in part as one of these things that you write down and then you try to think why it is so. First of all, it's like the man you quoted earlier, our straw man physicist, who would say that the words don't matter. So here is a bunch of scientists and they're talking about things that really matter to them, but the things that matter are in equations and symbols. But equations and symbols, just as facts and measurement of data, are mute; they say nothing. And they say everything, they are very rich. But until a human being works with them they are mute. So the straw man physicist is not going to go to a seminar and just write down an equation without saying a sound; no one would give him a job if he did that. He's going to have to talk about his equation, his discovery. Amusing—there's this person talking about things that matter in the language that he or she doesn't think matters.

The reason I think the language of science is under stress is that our straw man scientist who has the idea that the language doesn't matter is still using language. And people have tried to define things very sharply, the concepts they use, like "force, energy, power, entropy." They have definitions and symbols for them. The language is under stress because those words also had common-sense meanings. In this context entropy's an interesting case, where the word was invented for scientific reasons and has drifted back into common parlance. Other interesting words are relativity and degeneracy. The latter has no moral implications but derives from a certain mathematical use, that two energy levels become of the same energy. So difference is degenerated to similarity. English is a degenerate language. Those words—relativity, degenerate—they have been appropriated by scientists. And then some of the scientific meaning has drifted back into common usage—so I think the word "relativity" cannot be used in English educated speech without some sense of the science behind it.

So the language is under stress—I digress—because there are common-sense language concepts and meanings that are being used to express ideas which people have very precisely defined. But the English words are not so precisely defined, and the language is stressed to make it fit, in some way, the equations and things. Sometimes the words are not there to describe the ideas, yet words must be used.

Let me give you an example which I've used in a poem. I went to a seminar and it was boring, I fell asleep and I woke up and it was still boring. So I defocused from what the speaker was saying and I focused on the language he used. He was solving some mathematical equations subject to some constraint, what is called a "boundary condition." And he said "let us assume free boundaries." Note, two common-sense words used scientifically. Boundary conditions are the limits or limitations on certain variables in equations, that they cannot be bigger than some number or smaller than some numbers—they delineate the conditions for the equation.

He said “let us use free boundaries.” I immediately wrote that down. Free boundaries? That’s very interesting. It’s inherently poetic because it’s an expression of opposites—to me it was. Something was free, but it was also bounded. That was a contradiction, but a very interesting contradiction. He said “free boundaries” and he didn’t even think about what he was saying. I wrote it down. And I made a poem out of it.

How did you become interested in writing something other than chemistry?

For me, everything goes back to the university, to reading literature and in particular poetry and plays—I remember a girlfriend dragging me to a play, Garcia Lorca’s *Blood Wedding*. I didn’t want to go, but then I was just captivated by it. I took a poetry course with a well-known poet. He could not teach writing poetry—that was not done at that time—he taught the reading of modern American poetry. I also took a “great books” course—over a year we read 100 books and that included a good bit of Shakespeare. But I didn’t try to write a poem in those university years.

For me the path to writing was slightly anomalous one. I started writing poetry at a certain point, at age 40, and poetry and science were separate worlds for me, though I tried to write about science. The usual progress for people, I observe, exemplified by my late colleague, Carl Sagan, was to do science, being very interested in outreach, writing essays or articles about science, and then writing a novel or a play. Stephen Jay Gould, I think, never crossed over to writing a piece of fiction or a play. Sagan did. But I first had chemistry and poetry, and they were separate parts of my existence. Then I filled in the popular science writing through essays. Then jumped back and I did plays. I have written three or four plays; I’ve written many essays, some of which have been collected into books.

I write poetry I think because I fell in love with this mode of expression. To keep up some languages that I knew, German and Russian in particular, I sat in on advanced literature courses here—a very important one for me was on the poetry of Boris Pasternak. Whom we know through *Doctor Zhivago*, but who is known in Russia primarily as a poet. And I took a course in German literature, on Goethe’s poetry. These courses brought back poetry to me. To me a poem was a wonderfully compact expression of emotions. I wanted to do that.

I thought one could also write poems about science, but that proved to be difficult.

So why is it difficult to write poetry about science?

Oh many reasons. Part would have to do with me, part would have to do with the audience, part with the subject. There is something about science that is inherently prosaic. Part of it has to do with all those footnotes, with worrying about all the exceptions and caveats, where this equation will be right or where it's wrong. I suppose one could turn even these prosaic bits into a certain kind of poetry, and I have sometimes done that—"found poems" in scientific texts. But they're not what poetry's about in general.

To really understand the science, do you have to enter its cognitive structure? There is a wall of jargon around it. I tried in a couple of poems to overcome that. There is a cadence in the language of science, even in the jargon-laden language.

In a poem, I may worry too much about getting the scientific facts right, as if my colleagues were looking over my shoulder, but they're not looking over my shoulder. So if lithium is a solid but not a gas, could I write the gas lithium? If I were a poet one might forgive it, but not really in a chemist.

But there is something else. When you read a poem or when you hear a poem read, you don't understand everything in it, every word. So a disjunction comes about. But usually you can float on the sound, if there is some metre or some rhyme. You float along until you catch meaning again, and then you're with the poet. If too many such disjunctions occur—particularly prone to them are American poems of personal experience where you have no way of making connection with them, with the poet—you lose the reader. The poem means nothing to the reader, after a while. The problem with science is if you use a scientific expression, for example, "the wall of the endoplasmic reticulum," and if the reader/listener doesn't know what that is—or worse, if someone in grade school, let's blame your teacher, gave you the idea that this is science and you must understand it, and if you don't understand it you're stupid—if that train of thought sets in, then I've lost it. So I must work so that this doesn't happen, so that such moments where a person halts and says "what is he saying?" don't occur too often, or don't interrupt the poem.

Shouldn't there be a poetry for scientists?

Most of the poetry of that type—people have tried—it's awful. So poetry for a scientist is a well-written article. That may be the equivalent of a poem. Or an equation—it captures much of reality. In what way? Well the equation is poetic, supposing you're privy to knowing what it means, the symbols and the meanings. It captures the essence of something compactly, economically. It's intense. If you can unfold the equation, it has in it a richness of its meanings. There has been some important work I did where people have told me that reading those papers was like reading a poem.

I think while I write. The longer I've germinated the process in my mind, the easier the writing becomes. It looks like an awful mess when I haven't thought it through much before. I do not write on a computer, there's still a bunch of pencils here—I write in pencil on lined paper. Then I type it up. On the poetry I go through about 10–15 drafts before I type it up; at some point I need to see how it looks on paper.

One of the joys of writing I think is that you're continually amazed that you have something to say. And this is what's made me a little more sanguine about writing things about anything under the sun—I find that if you will reflect on anything, then the chances are you'll come up with something new to say about it. Because while you may not be original (I'm saying "you," but I mean myself), you are a combination of circumstances of little pieces of knowledge that have been absorbed from teachers and experience and your parents. And the totality is perforce different from that of other people.