

# Convocation address, 19 April 2000

## Cornell Undergraduate Research Board

This morning I had the pleasure of listening to several of your talks, and I've seen the programme of your activities today. Very impressive it is too. In my department – physics – at the University of Bristol, England, we have encouraged undergraduate research for many years, but there's not a university-wide organization like yours.

In England, we're a little shy of talking about ourselves. Here you're less burdened by such inhibitions – I know, I've seen Mr Jerry Springer. So I'll try to adapt to the local convention – but don't expect me to go that far - and tell you something about what a life in science, and research in particular, is like. I'll talk about science, knowing that many of you are doing research in the humanities rather than science, but most of what I'll say applies if you replace 'science' by 'scholarship'.

My family wasn't academic, or even educated beyond the bare minimum of literacy, and my childhood wasn't the happiest, though my mother did succeed in protecting me from most of the brutalities she had to suffer. Perhaps science was an escape into what I saw as a purer world – I don't know, and it doesn't really matter. But rather early something happened to make me know what I didn't want to do, which was to go into the kind of business some of my relatives engaged in.

I had a Saturday job in my uncle's store, selling trousers. He used to ask why I wasted my time reading books, when I could leave school and join his business. One day, a customer asked for trousers of a particular sort, which I showed him. 'What do these cost?' 'Three pounds' (That was a long time ago.) 'No', he said, 'I wanted something a bit better' At that moment my uncle walked by, took the trousers, and said: 'We do have something

better – please wait’ and then disappeared into the back of the store. About five minutes later, he came back, with the same pair of trousers, saying, ‘Look at these; but they’re more expensive: five pounds’. Of course the customer bought them. This made me feel bad. Not for me, such a life.

Then came something else. A cartoon in a magazine, that influenced me in a negative way. It showed a weedy pale little fellow lying on a beach – of course I identified with him, apart from the glasses, that I didn’t need in those days. He was surrounded by adoring girls – gorgeous in the obnoxious stereotype of those days, that is, boobs rather than brains. They were ignoring a bronzed hunk, bursting with unemployed testosterone, because he couldn’t compete with my lookalike, who was reading a textbook on nuclear physics. Nowadays I could spend an hour deconstructing the negative images and presuppositions that cartoon implied, but even then I was embarrassed by it. It didn’t fit the image of science I had then, even in my glimmering innocence.

Don’t worry: this isn’t going to be my life story. But that early idealistic belief in the honesty and decency of scientists was pretty well been borne out by my later experience. This is something people have different opinions about. There are some big guns on the other side. When Michael Faraday started working at the Royal Institution as a laboratory assistant, in the early 1800s, he told his mentor, the great chemist Humphrey Davy, that he wanted to work in science, because scientists were free of the jealousies and petty motivations that afflict other professions. Humphrey Davy replied, ‘Just you wait, young man, you’ll soon learn what the world is like, that scientists are just as mean and self-centred as anyone else.’

Maybe he was right. Maybe I’m lacking the gene for competitiveness – or perhaps it’s the meme (that is, it’s culturally constructed and propagated). We have something called *Who’s Who* – I think there’s a similar book in this country. In my entry, you can read my list of interests: just ‘anything but sport’. Not that I’m against exercise and physical activity

– indeed I approve of it - though mostly in theory, as you can probably see. But I could never understand why anyone would want to win. And I'm not blind – I see, especially in areas of science where serious money is involved, squabbles for priority, funding, etc. But my own experience has been that overall people behave pretty decently, sharing ideas, data, etc. The image is of colleagues rather than competitors. Those few who are obviously driven by a desire to beat their friends are usually regarded as having a mild personality disorder; they are not admired. If that seems old-fashioned, embarrassingly naïve, even, I'm unapologetic: that's how I've found it to be, and the way I encourage my students to keep it.

Research can get you into some quite absurd situations. Soon after I arrived in Bristol, I had a visit from a graduate student from the veterinary department. He was studying horses, and wanted me to help with a paper he was trying to understand. 'But I'm a physicist; why have you come to me?' 'Because I heard you're a mathematical type'. He was studying horses' hearts. They are like little batteries, pulsing tiny currents round the body once per heartbeat. If you can measure the electric potential at points on the surface of the horse, you can infer the polarity and strength of the little battery, and get something called the heart vector, and how this changes during each heartbeat – the heart loop – which is a powerful noninvasive way to diagnose heart diseases.

The mathematical theory underlying this inference was in the paper he was trying to understand, written by Denis Gabor (he who invented holography). The problem was that my visitor knew very little mathematics, in particular not calculus, which was a big drawback since the paper was based on integrals. His question was: Does Gabor's theory apply to a real horse, or only to an ideal cylindrical horse? The situation was desperate, because the poor fellow had spent three years making his horse a coat of several hundred potentiometers, each measuring the electric potential fifteen times during a heartbeat; he had a mass of data, and three weeks to make sense of it. An emergency requires quick action, and so it was that I found

myself helping him build a little device to measure the direction of the perpendicular at each point on the surface of the horse.

A year later, when I had forgotten all about it, the guy sent me the paper he'd written about his work. In the Acknowledgments, he thanked me for helping with the mathematics, and, for funding his research, the Horserace Betting Levy Board – that's our government agency that imposes taxes on gamblers who place bets at racetracks. I'm sure those gamblers didn't realize that their addiction supported my Monty Pythonesque activity of taking a surface integral over a horse.

Mostly, day-to-day research is pretty technical, but we should never lose sight of the perspective that what we're doing is contributing to building a patchwork of enormous scope, whose magic is that we are connecting very different areas of experience. Nowadays we are all encouraged to tell the nonspecialist public about what we do – outreach, you call it; for us, it's Public Understanding of Science (notwithstanding the unfortunate acronym). Sometimes, what we do has obvious practical application, and then it's easy to communicate.

But very often our motives are more intellectual, and then, rather than pretend applications that aren't there (it might help us find a cure for cancer, as people used to say in the 1970s), it's better to stress this aspect of unity, of connections. I find that, contrary to what media people tell us – they insist on dumbing things down - nonscientific people appreciate that: the magic of abstract ideas - even mathematical ones - that apply to widely differing situations. I realize that not all areas of research lend themselves to this style of exposition. It is very much to my own taste to discover 'the arcane in the mundane'. I'll show you an example – but again, don't worry: you'll not be getting a physics lecture today.

In the 1970s, mathematicians devised a branch of geometry called catastrophe theory, based on a remarkable theorem classifying certain shapes. These describe ways in which smooth changes in something can

generate sudden changes in something else. If the first something is weight on a bridge, and the second something is collapse of the bridge, that's a catastrophe in the everyday sense; hence the name. Some of the applications were controversial - invoking the mathematics to describe the dynamics of prison riots, or anorexia nervosa, or the switch from anger to fear - and this led to misguided attacks on the mathematics itself. A genuine application, within physics, was to give a proper understanding of the *focusing of light* in natural situations, where there isn't symmetry - that's in contrast to the perfect lenses we try to build into our cameras and binoculars. The resulting theory gets deep into the physics of light, and especially the relation between light rays and light waves - that's a case where reductionism - so controversial elsewhere - works. Here now is a piece of bathroom-window glass, wiggly on a scale of millimetres, and here is a laser, whose beam of pure light is also about a millimetre across. Shine it through the glass, whose wiggles bring the light to a focus and also give rise to interference between different rays striking the same region of the screen, and the resulting patterns exhibit the whole zoology described by the mathematicians' catastrophes. Similar patterns - with the interference detail blurred away - are generated on vast scales by the light from distant galaxies focused by the gravity of intervening stars, and more familiarly, on the bottom of swimming-pools, by sunlight focused by the water waves on the surface.

It isn't all fun, of course. Research can be frustrating in several ways. Most of the time, it doesn't work. My son did a Ph.D in mathematics, but left afterwards because he couldn't bear the uncertainty of research - sometimes weeks getting nowhere. Now he makes a pretty good living as an inspector with our income tax service - what you call the IRS - a job with security, and perfectly suited to his mean-minded intelligence. When he started, I made the usual weak joke about having to be careful about my tax return. 'Oh, don't worry, we don't care about professors - their income is insignificant'.

There is not security in research. I tell my graduate students that if they study with me they shouldn't expect to get a job afterwards. Their only reasonable motivation should be to spend several exhilarating years in total freedom, creating at the forefront of knowledge. In fact, all my students did get jobs – academic positions for those who deserved them (about half), and respectable other work for the rest. (In case you're wondering, I don't have tenure – I gave it up about ten years ago when I applied for the research professorship I hold now. Every five years, I have to reapply for my job.)

Here's a useful concept, to ponder when your research gets stuck. What is the elementary particle of sudden understanding? You can call it the *clariton*. You all know immediately what I mean by a clariton: that wonderful 'Aha!' moment, when all is revealed, and the way ahead opens up. But unfortunately there are also the unwelcome *anticlaritons*, that arrive and annihilate the insights of yesterday.

A different source of frustration is bureaucracy. In Britain there's an ignorant opinion that all bad trends in our society originate over here. And some do – for example advertisements on television (I still find them vulgar and intrusive), and commercial medicine, that our governments have allowed to threaten the kinder system we used to have. But in research we have our home-grown nonsense, in the form of endless official demands for falsely quantified information about our researches, justified in the name of public accountability. Public accountability has become a mantra that's hard to argue against, even though it leads quickly to something like Heisenberg's uncertainty principle: by asking for continual self-justification, you inhibit the very freedom to create and speculate that keeps research alive.

This is not the place for a systematic treatment of this dismal subject, but let me share a delicious example. Our National Physical Laboratory – the counterpart of your National Institute of Standards and Technology – puts out annual reports. In one, from a section called 'Performance targets' we read 'Target number three: Research Milestones'.

Now, we live in a scientific age, so everything must be defined, and indeed we have: ‘Detailed definition of measure: Research milestones are those which are agreed with the customer’. I am not joking. That year, the goal was 0.49 research milestones per scientist per year, to be increased by 3% per year over a four-year period. In the first year, an average of 0.48 research milestones were achieved. A near miss. Must do better. In the following year, though, the score was 0.79. But that’s too good! In that annual report, we read: ‘The comfortable achievement of this target, while pleasing, probably indicates the unsatisfactory nature of this measure. A revised target will be set...’ In the next few years, the number of milestones increased, until: ‘The National Physical Laboratory is making increasing use of project management techniques which encourage the breaking-down of programmes into modules, and in which the measurement of success by milestones is *even more significant* than it was at the time when the target was set.’

At about that time, I met our minister of science, and told him this ridiculous story. He didn’t say much, and looked a bit embarrassed. A week later, I understood why, when I read that he had just presented our National Physical Laboratory with an award for that year’s best annual report.

I don’t know how it is here, as far as research being contaminated by ignorant bureaucracy is concerned, but let me offer a one-word self-therapy that sometimes helps. It comes from the physicist Richard Feynman, who used it on himself whenever he was tormented by people at meetings who were forever telling him trivial things he already knew. It can work with bureaucracy too. The word is : Disregard. Try it.

Research can involve difficult issues of time management. (I’ve caught myself using this word ‘issues’, that I don’t like – a few years ago we hardly heard it, now everything is an issue – I suspect it’s a Bill Gatesism, a Microsoftheadedness.) I can’t help you with time management, because I don’t do it. Several years ago, I gave a series of lectures in Chicago, on several different subjects. Afterwards, my host paid me a compliment: ‘It

was very good for our students to encounter someone with such a well-conceived and well-implemented research plan'. I told him. 'Alas, I have to disappoint you. There's no research plan. Each day, I have no idea what I'm going to think about.' I take no responsibility for any consequences that might result if any of you follow my example (accept no liability, as I think I have to say here.)

What else? Yes. Travel. Growing up in a poor family, it never occurred to me that as a scientist I would travel beyond the dreams of everybody except the most wealthy. Recently my work has taken me to Germany, Palestine, Israel, Lebanon, Romania, New Zealand, Ukraine, France, India, here of course...I forget all the places. As well as being fun, it's also inspiring and beautiful, meeting my colleagues there and finding we communicate perfectly, and do science in the same way. This universality of the free play of the intellect is something worth pointing out, especially now when there is a different emphasis, on the separate identities of the cultures of different peoples. I have no problem with that; I see no contradiction, but rather complementarity - indeed, it could be that only when people appreciate and respect their separateness can they get truly together (on the microlevel of pairwise relationships, we know those couples who are proud to share every little thing; usually, they divorce).

One more thing. In academic life there are little turf wars, games people play with the self-image of their discipline and those of others. You know what I mean: physicists versus chemists, mathematicians versus physicists, engineers versus scientists, sociologists versus everybody...Even within disciplines there are silly little image wars. Sometimes, fashionable, often highly-technical, subjects can exert an intimidating influence on people not involved with them. Well, don't be intimidated by what other people do. Here's another story.

Back in 1985, visiting CalTech, I had just started studying some quantum physics related to some mathematics called the zeta function, itself

related to a famously untransparent mathematical speculation called the Riemann hypothesis. It doesn't matter what all that means. At the same time, CalTech was a centre of superstring theory, a speculative development that some people thought might give the 'theory of everything'. The people who did (and do) that research were (and still are) fearsomely clever. I met one of them, who asked what I was working on. When I told him, he fixed me with a pitying stare. 'Yes, we have zeta functions throughout string theory. I expect the Riemann hypothesis will be proved in a few months, as a baby example of string theory.' That certainly intimidated me, but I take some pleasure in reporting that now, fifteen years later, we're still waiting.

At the same time, the president of CalTech, a physicist, called me to apologize that he couldn't come to my colloquium, because he had to go to Palm Springs to explain string theory to Ronald Reagan. How I wish I could have been a fly on the wall...

Sometimes, the special subjects we choose to study can sound bizarre to outsiders – and it's not only science that can seem strange. Several years ago, I visited the Institute for Advanced Study attached to the University of Jerusalem. In that place, two programs run at the same time. On the first day, I went to coffee and there were all these people I didn't know, obviously from the other program. We exchanged greetings, and one of them asked what my program was. I told him: quantum mechanics. 'And what's yours?' I asked. 'The historicity of emotions'. I wondered what was the difference between historicity and history, but didn't get a clear answer. So, to lighten the conversation, I told him I always wanted to know what made the Romans laugh. Actually I know – at least a little – because I have a friend who studies Roman satire, but thought this person might give an interesting slant on it. 'Roman humour, huh! you asked the wrong person. My emotion is hate.' If you know a better conversation-stopper, please tell me.

Oh, help! It's Wednesday, ...I shouldn't be here. There's another silly little turf war – more teasing, really – between theorists, like me, and

experimentalists, who think we're lazy. One of them said: 'You'll never get a theoretical physicist to give a talk on a Wednesday, because it spoils two weekends.' So I'd better stop.

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