# Physics – My way

**I became a lecturer in astrophysics by chance. As I was completing my postdoc, looking at how one could do quantum field theory in the presence of gravity, I contacted various departments to see if there were any lectureships going. From departments of mathematics I was invariably told that the subject was too physical, and from physics departments that it was too mathematical. Astrophysics seemed a better bet, so I offered to give part of the Oxford undergraduate course on what was then the emerging subject of high energy astrophysics. I think I managed to keep a few pages ahead of the students most days. The result was a job offer from Leicester to teach astrophysics.**

Leicester was a very different place then. Many of the people who would become leaders in their fields, and some who wouldn't, were then just starting. But another key difference was the vision, at least in teaching, of the then separate departments of Physics and Astronomy, as mini replicas of Oxbridge, to the point where at least one lecturer used to lecture from his Cambridge undergraduate notes. The problem was that the students, with some notable exceptions, were not. I doubt that many of the 100 lectures a year I used to give were of that much benefit. In fact, I can only remember one. The new-fangled overhead projector was not working so I had to improvise a different lecture on the spot. The reason I know it was a success was that some of the audience brought their friends, not on the course, to the next lecture – with a working OHP (after which I regret to say I didn't see them again). More usually, as one student remarked in passing as she filed out of one of my lectures: "*you have an extraordinary way of making simple things difficult*."

It was, of course, deemed to be entirely the fault of the students that they failed to appreciate the excellent education that was passing over their heads. Student failure was evidence of high standards; although not too much failure: one of my first tasks assigned by the Head of Department was to ensure the right mix of courses on the examination papers, each of which covered a variety of core topics, so that weaker students could avoid the mathematical problems and still pass.

My official staff development was pleasingly minimal: all I can recall is being told not to write across the crack in the blackboards, the fear of so doing having stayed with me ever since. My real education in education was a consultancy with the Open University. The OU uses teams of academics to develop its courses. On the negative side this generated enormous volumes of paperwork; on the positive side it generated enormously useful discussion of what actual OU students could be expected to master in a given time. This seemed such a good idea that it was worth copying.

The first thing was to get some leverage which meant forming a Teaching Committee. It was only at this point that I learnt that people volunteer for committees not to get things done but to be in a position to block them at the earliest possible stage. Nevertheless, I found that if people can be convinced that there are real problems, then they are willing to discuss how to solve them. And the Physics Department had a real problem with the teaching of maths: put simply, two terms of epsilons and deltas followed by an exam paper that could be passed on the basis of A-level maths. The problem with a maths lecture is that after about 5 minutes students need to stop to consolidate, even assuming they are keeping up with the homework. A second problem is that, even if they know what all the words mean, abstract statements can still fail to mean anything significant, so students learn proofs off by heart without seeing why they work. So we got together a team of physics lecturers and maths lecturers and set about designing a text that delivers specific examples ahead of general statements, divided into small segments with diagnostic exercises at each stage. Originally we had audio taped lectures to go alongside the text, instead of live lectures, and we used the staff time to run exercise workshops. Later we replaced the tapes with a weekly survey lecture. We learnt several lessons from this: one was that students can't cope with typing errors; another that it takes an awfully long time to get rid of all of these, but that students wouldn't stop complaining about the course until we did. Another revelation was that, as we reduced the course content to accommodate changing entry levels of knowledge, we discovered that there is no level low enough to ensure that all students will do well: the less motivated students adjust their expectations downwards with the course content! We eventually engineered a flexible pacing through the maths programme, which allows the more motivated student to progress rapidly, while less well prepared students can go at a slower pace. This is one thing that a rigid credit assignment system does not allow. It therefore requires a relatively elaborate interface between what we do and what we say we do. My experience is that university administrators are not interested in what you are doing as long as the forms are filled out efficiently and 'correctly' and it doesn't get them into difficulties. I will not claim that one can get round *any* rules that prevent one doing something worthwhile - I failed to change the daft waste of academic staff time in writing examination papers afresh every year in favour of using carefully honed and tested confidential question banks - but there is (apparently) a lot that can be done if done quietly.

The key to the maths programme was to require the active participation of the students: ideally students get feedback only where they can explain their attempts at problems, because this allows the seats of the misconceptions to be addressed, not just the symptoms. I regret that this has been undermined in recent years by the customer culture which increasingly requires us to provide model answers as if these will enable students to magically 'see where they have gone wrong'.

The next ambition was to introduce team teaching and student-centred learning into the physics core. Here there seemed to be no need to write our own textbook, so we could just concentrate on organising the material and providing support for problem solving. It's always good to underpin initiatives with a theory, so we referred to this as 'resource-based learning' and hired an educational consultant to help us go about it. The resource is a compendium textbook to which all students have access because we give them a copy. This has needed some defending in times of austerity: one Dean claimed that it was illegal, and I had to get legal advice to demonstrate the contrary. The book frees up a lot of staff time from giving dictation (sometimes referred to as 'lecturing') which can be used for teaching (sometimes referred to as 'problem classes', or 'tutorials' at more elitist institutions).

I wish I could remember, but I don't, my first acquaintance with problem based learning (PBL). I can't recall if I found it or if it found me. But once again it grew out of the solution to a problem, here the ineffectiveness of laboratories. I think it is by now well established that students can only hold so much new information in working memory. One therefore has to decide if a practical class is supposed to teach practical skills or physics. Our problem was that, at great expense in terms of staff time and disengagement, the traditional labs were doing neither. PBL, as we do it, requires students to use their acquired practical skills to design experiments and, importantly, to evaluate their results. The design tasks are not on the face of it complex: the first one involves comparing the absorption of two liquids (differently coloured water, of course) by blotting paper. But this in fact turns out to contain several afternoons' worth of useful thought. Students find the evaluation the most demanding, because what they say depends on their results, and, most importantly, their error bars. Not that the implementation has been easy: we have changed features of the programme every year since its inception and it still is not quite right. Nor has it impacted significantly on examination performance, although informally we find that students appear to be better now at tackling problems; or perhaps those that aren't don't survive because there are now no bookwork questions. What it has changed, to some extent, is the way that students now learn to be professional physicists and not just professional students.

Here again we were lucky in securing the acquiescence of the academic staff to go along with our experiments in curriculum design even when they did not believe them. This was greatly helped by the initially modest (and later not so modest) funding we received for the development projects and for piCETL. This enabled us to hire summer students to do the development work, while the staff acted in their favourite role as consultants. My general rule for getting something done is to do it myself as best I can, usually badly, and then get colleagues to tell me how it should be done. This produces much more, much more rapidly, than a simple request.

PBL assumes a particular model of how students learn which prioritises the need to know as the motivator of doing. It doesn't tell us anything about the way that students learn *physics*. It is interesting how little interest most educators in HE have in this. In an elitists educational system it probably didn't matter: as long as enough students survived to teach the next generation the system would be self-perpetuating. In a mass system it matters a great deal if a lot of precious resource is being used to little effect. Physics education research (PER) has shown how we can build up students' understanding of basic physics by careful and detailed sequencing of activities. I have yet to be convinced that this does not suck the life out of physics or that it can produce a love of physics or promote creativity.

I believe a better approach to enthusing a wider cohort in physics is to generate an enthusiasm for science in general. Thus, instead of trying to change the students, a 40 year experiment that has barely changed recruitment to science, we try to change the curriculum. Science is not a lot of boring historical knowledge that has to be suffered before we get to the interesting things, even if this is how it is traditionally taught. Science is solving problems, intellectual ones as well as applications. Most unsolved problems within a discipline are unapproachable by undergraduates. We can invent model problems, as we do in PBL. Or we can recognise that many interesting problems can be found across the disciplines. This brings us to the Centre for Interdisciplinary Science at Leicester which runs the interdisciplinary science undergraduate programme. This embodies my vision of an undergraduate programme in natural science by guided research. The programme covers a range of learning objectives in Biology, Chemistry, Earth Sciences and Physics with opportunities to specialise, taught through interdisciplinary problems. The support for this programme through the IOP and the HEFCE STEM initiative has been crucial. The administration, pedagogy and financial model as well as the content is all innovative and has been constructed as we went along. The external support has been critical, not least in allowing the creation of the Centre by the expedient of informing the University post room that it existed (and appointing myself as its director).

Integrated Science has existed in Canada, the US, Ireland and almost certainly elsewhere as level 1 programmes for many years. It is now established at McMaster in Canada and at Leicester as a full degree programme. I see it not just as a way of embedding physics in science programmes, but as a way of retaining applied physics research within physics departments. However, it is not the only way of simulating physics. Beyond the applications of physics in interdisciplinary science problems, the techniques and concepts of physics have increasing applications in social sciences. If we embrace this it will bring a new cohort of students to physics though the interface of physics and the social sciences.

Physics is based on experiment; so too should physics education be. Physics experiments, if they fail, can be repeated. In a sense educational experiments can't be and that, as well as the effort involved in changing things, can induce a fear of failure. Educational experiments take a long time, so the funding always runs out before they can be seen to be successful. And they require energy. One of my HoD's said to me after a Departmental review, "*we've probably had enough innovation here*." We haven't. The environment is always changing so the only way to stay at the top is to change with it. This might not be a sufficient condition for a thriving physics education, but it sure is necessary.

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