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'Interdisciplinary research is not natural'

Two cultures in academic chemical engineering?

Many industrialists and academics now believe that the USA has advanced further and faster than the UK in its academic research and postgraduate engineering education. They believe that this has enabled the US to serve the needs of emerging industries more flexibly than the UK. As a by-product of this change, some in the UK argue that the USA is now less capable of serving the research needs of the more traditional industries on which such a large proportion of the economy currently depends. John Howell and Colin Axon led a team of 15 younger academic chemical engineers to the USA in 1998 to see at first hand how the systems differ and whether there are particularly useful lessons for us to learn from the USA's approach.

Introduction

In late 1998 we visited 21 of the best-ranked US chemical engineering departments and studied the attitudes and policies of various funding agencies. We interviewed overall some 250 academics and funding managers. We gained a view of their best practice and a reliable insight into why and how their system has changed over the past decade. Our full report (see 'Web sites' section) gives much greater detail and analysis than we provide here. In addition, the face-to-face interviews we conducted were followed up by a questionnaire to gather numerical data. Whilst we were only looking at chemical engineering departments, it is clear to us that many of our observations are applicable to any science or engineering discipline.

The first surprises of our visit were the extent to which the techniques of pure science are being used and the shift away from traditional industries towards the emerging ones which are likely to dominate the 21st century. These factors appear to lead to a very strong emphasis on product engineering, rather than on the older process engineering philosophy. Chemical engineers who only research the design of processes are now considered old-fashioned. Some interviewees went so far as to say that such specialised work in academia is unfundable by government and unpublishable. Whilst industry is still funding some major groups doing process design and development, the shift in emphasis has had a profound effect on the structure of academic research. This shift manifests itself in two ways: in the background of new staff being hired and in the tools being used to research areas which might be considered 'core' chemical engineering.

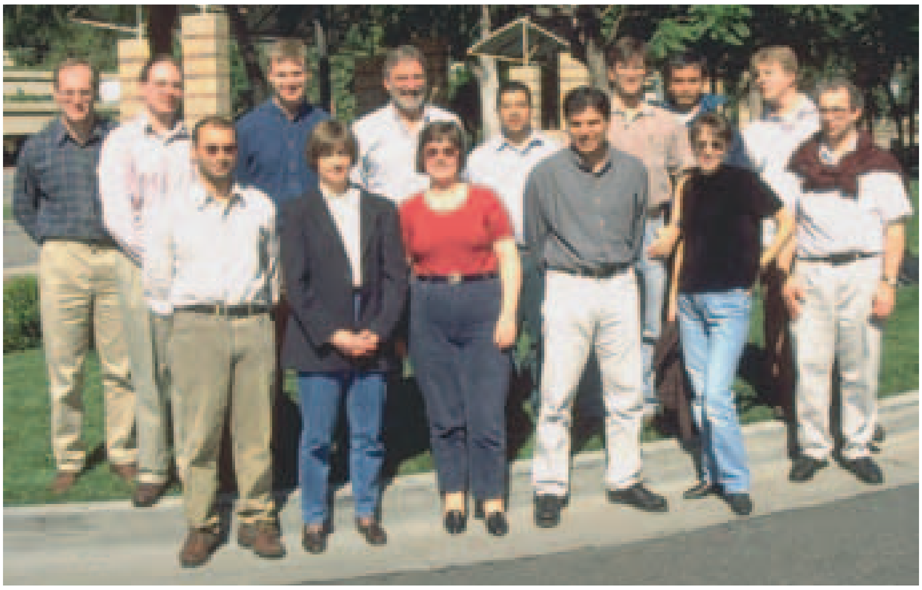
At first sight it appears that the US and the UK are conducting research into many of the same fields. However, on closer examination we find that the emphases may be extremely different: take, for example, reaction engineering – a core chemical engineering topic. Our survey shows that UK researchers are often interested in reactor design, improvement in yield, performance, and characterisation of catalysts; the US spends more time on the development of new catalyst materials and studies in surface science.

The UK is now hiring increasing numbers of lecturers with degrees other than chemical engineering, as it has become very difficult to recruit UK-trained chemical engineers into the academic profession: the result of this shift in staff profiles will aid future change here. UK academic staff are currently much less likely to have had an interdisciplinary experience in their training. We believe it is necessary for the UK to increase the diversity of experiences of researchers in training.

Engineering and science – two cultures?

It might appear that engineers who engage in basic science are being distracted and side-tracked. After all, a scientist is seeking pure knowledge and will tend to produce a hypothesis, then design a research programme to test that hypothesis. Lack of a hypothesis to be tested would imply poorly planned research. By contrast, an engineer is interested in creating new entities, designing them, making them, and solving the problems which arise in trying to manufacture and use them. New products must reach the market quickly and science, engineering, and process-research ideas are pursued together in multidisciplinary groups – no single disciplinary background is sufficient to see a project through.

The scientist often believes that the engineer is not adding to knowledge and thus his or her work is not truly



The UK chemical engineers visiting the Chemical Engineering department at UCLA. (Photograph: Dr P. Kennewell.)

innovative. By contrast, the engineer sees the scientist as increasing theoretical knowledge but not adding to wealth by exploiting that information. The widespread lack of respect for the intellectual difficulty of engineering exploitation may underlie the undervaluing of the engineering profession, and the consequential difficulties of taking knowledge to exploitation in the UK. This misunderstanding has led to difficulties in getting multidisciplinary work funded, since neither scientist nor engineer is clear about the approach to problem-solving that is being or should be used.

Referees

This situation is being tackled in the US by careful choice of referees for grant applications, even to the extent of virtually 'training' people to understand the differences in approach. The US is also finding this a difficult problem to solve and many scientists still do not sympathise with the engineering approach. As a senior professor at MIT stated, 'Collaboration is not easy, and it's not natural. Only 1 in 20 biologists will see any value in the engineers' approach.'

The reconciliation of these two sub-cultures is vital for the health of UK research – and we need to act now.

Making change happen in the UK requires that we identify the 1 in 20 scientists sympathetic to the interdisciplinary approach and use them in evaluating the interdisciplinary funding initiatives promoted by the research councils. These changes will not be driven by the majority who will tend to preserve their funding sources for their own 'clan': the US found this, and so the National Science Foundation (NSF) identifies sympathetic referees in a 'top-down' policy.

Joint appointments

The increasing overlap of research disciplines is now so great that the traditional discipline boundaries have to be swept aside. This is particularly true for research and postgraduate education, and will soon be necessary for undergraduate teaching as well. The attitude and approach we found in the US reflected this discipline 'dissolution'. For example, it is easy to make a staff appointment joint between two departments. This allows the staff member to supervise interdisciplinary postgraduate students and is unanimously backed as an important way to strike up collaborations. In the UK such joint appointments do happen, but are inhibited by the internal funding model adopted by university administrators where accountability exercises have tended to present obstacles to interdisciplinarity.

Publications

Another UK problem is that the judgement of a publication's value differs greatly between disciplines. There is no value for a biologist to have a publication in a top engineering journal when the RAE (Research Assessment Exercise) is being carried out, whereas publications in *Science* or *Nature* are highly prestigious. It is interesting that the EPSRC's (Engineering and Physical Sciences Research Council's) Chemistry and Chemical Engineering joint proposal initiative, run by the chemistry group, has awarded virtually no grants to teams headed by the chemical engineer. Referees have even asked why such proposals have been allowed. It is important that the research councils ensure that they only use referees sympathetic to interdisciplinary approaches. This is a major key to the USA's success.

The development of young researchers

The expansion of chemical engineering's horizons in the US is strongly coupled with a rapidly broadening range of backgrounds of academic staff. Consequently, their training and skills have become increasingly bi/multi-disciplinary. In the US postgraduate training system, students take a large number of courses during the average 5 (±0.5) years' PhD programme. The quality of these courses is high and students take postgraduate science courses beyond the immediate scope of their research, thus broadening their interdisciplinary skills. Recruitment remains strong, since although the students are paid a little more than UK research assistants, they anticipate good returns on graduation – US industry highly values a PhD.

Encouraging PhD coursework in the UK will require a more flexible funding approach so that students can spend at least a year doing such coursework. This is now possible because of the new studentship funding model, in which universities are given a block grant based on their research grant income. They are able to use this money flexibly to support students – even to the extent of extending the grant period.

Another possibility is to use the extra time in an MEng degree to enhance the students' science base. If students are to be attracted to taking a PhD, industry must provide an increased career earnings potential for them. However, if their training does not produce graduates with 'added value' there will be no increased earning potential. A difficulty arises with the small size of UK universities relative to those in the USA. It is not easy to provide the wide range of postgraduate courses on site that would allow for the variety in supplementary studies that is necessary to support a proper interdisciplinary-research oriented group. It is a familiar call, but it may be that web-based or other distance learning approaches can be successful here (supplemented by short Open-University-style residential periods).

These could be made available nationally to provide a sufficiently large market.

Young researchers in the US will usually undertake a further year of post-doctoral work. It is of particular note that at each stage, they will move to a different institution and/or type of department. This happens almost without exception and is considered to be very important for academic development, the spreading of ideas and the acquisition of experience of their own and related fields. This movement between disciplines is beginning to happen in the UK, but to a lesser extent, as Figures 1 and 2 show.

Once in a tenure-track academic post, substantial funds are made available to young researchers to start their research career. The best of these new appointments will obtain more than $1 million over their first five to six years (pre-tenure) in research support, funded evenly by their university and other sources, whilst even the average start-up package over *all* US departments is about $250,000. These grants promote fast development of the best young academics and attract high fliers into

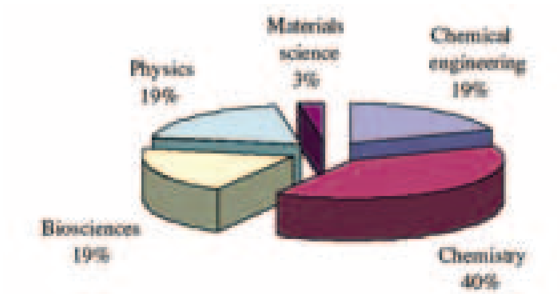


Figure 1: Postdoctoral destination departments for US academic staff.

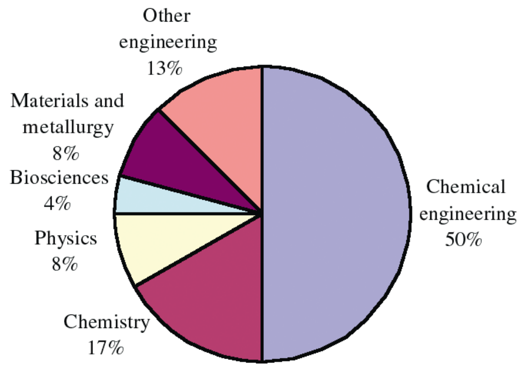


Figure 2: Postdoctoral destination departments for UK academic staff.

the profession. The downside is that after the first five years there is an immediate difficulty in meeting the high costs of US research and the hurdles to achieve tenure are high, but the best survive and prosper.

Funding

A very striking difference between the USA and the UK is that money is raised to support the work of PhD students, who are the prime research workers, rather than post-doctoral research officers. In the major private universities such as Caltech, MIT and Stanford the academics need to find a minimum of $40,000 per year just for fees and stipend for these students. Equipment is on top of that (plus the usual overheads). The top state universities such as Minnesota and Berkeley have lower fees to meet, but otherwise the situation is similar.

In the UK it is easier to fund a PhD student but the short period of the degree (especially if coursework is to be included) restricts the value of the research output. The UK relies on post-doctoral research assistants who are employed in a series of short-term contracts which do not lead into a career path for the majority – there is no perceived commitment to the individual beyond the terms of the contract. In the US, the main research workers are postgraduates; postdoctoral students are nearly always gaining experience only for a year (or two at most). Postdoctoral work is seen purely as a short-term measure, and an individual will only ever take one such post before moving to an academic position. Those going into industry are unlikely to do postdoctoral work at all.

In the US, there is a willingness to fund work over a longer period by renewing grants and anticipating that worthwhile progress in any area is likely to take longer than the nominal three-year period of a grant. In the UK it is very difficult to obtain repeat funding on a project; pressures to obtain short-term results within three years are unrealistic and disruptive to research programmes.

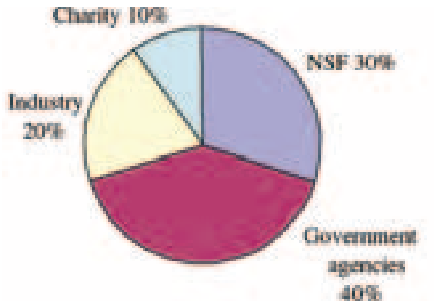


Figure 3: US research income distribution.

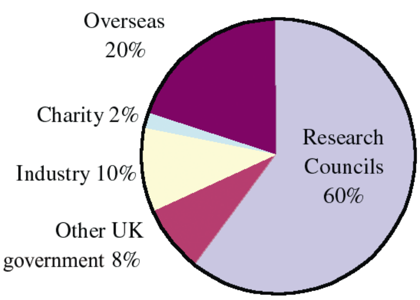


Figure 4: UK research income distribution.

Another difference is that US staff salaries are nominally for 9 months and can be legitimately supplemented from grants over the summer, leading to higher annual salaries as an incentive for the successful researchers. This allows salaries to approach industrial equivalence. It would be technically possible to adopt this policy in the UK. Basic salary scales would remain the same but academics would be allowed, and encouraged, to find additional funding in the summer by working in industry or obtaining salary support from granting agencies. This would of course require government to make allowances in the science and engineering budgets, but it could be an equitable way to make academic posts more attractive to the best graduates, and yet fullfil requirements for value-for-money schemes. The effective salaries of succesful researchers would be increased and more direct interaction with industry would be encouraged.

Funding sources

Perhaps the most important difference between the US and the UK is that there are a far greater number, and variety, of funding sources available to academics in the US. Especially important are charities and government departments such as Transport, Energy, Defence, the Environmental Protection Agency (EPA) and the National Institute for Standards and Technology (NIST). All these automatically include every discipline in their portfolios of projects. In addition, funds are available from the National Institutes of Health (NIH) and the National Science Foundation (NSF), which are the UK research council equivalents. These provide large grants and significant total funding, and are used by all the good departments. Figures 3 and 4 demonstrate these differences.

More funding of applied research in UK universities by the Departments of Transport, Energy and the Environment, the Ministry of Defence and other government departments would make a significant difference to the variety of projects funded. In the UK, the EU plays a significant role in funding university research and encourages international collaboration. However, the bureaucracy involved and the uneconomic financial overheads make such contracts unattractive except for a small proportion of university research portfolios. These EU research projects are effectively subsidised from other resources within the university.

An open-arms policy

In a sense, the US funding agencies compete to fund research and are *inclusive* rather than *exclusive* in terms of what they consider relevant and appropriate work. This inclusivity is absolutely crucial to the success of multidisciplinary research. In contrast, the UK has set up a special 'boundary commission' to decide which research can be funded by each of the research councils. In the USA if one of two agencies could fund a project (because it is relevant to both their interests), then either one would do so – and possibly both for a large programme. Agencies make their own decisions on spending their money.

As mentioned earlier, the refereeing process in the US has been consciously used to help bring about these changes, and has proved highly successful. Funding managers are careful to select and educate referees to understand the aims, challenges and success criteria for interdisciplinary work. It would be useful to adopt this policy in the UK, instead of assuming that all scientists necessarily understand and sympathise with the design-oriented approach of the engineer towards innovation. A further interesting point is that young US researchers are expected to take part in review panels – the attitude being 'how else are they supposed to gain experience?' Usually it takes many years before a UK researcher is perceived to have the experience necessary to be elected as a peer reviewer for a research council – although there are signs that progress is beginning to be made here.

Industrial funding

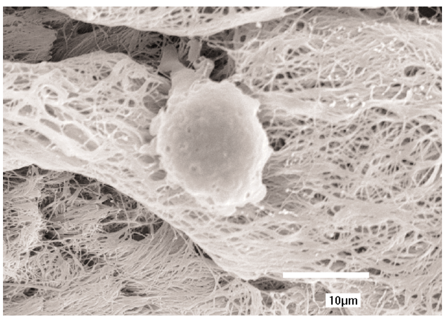
Industrial funding of US academic research is also very different. Science is considered very important to industry; industrial involvement with academic programmes is often highly beneficial for both parties. The US Congress seems to take a different view to the UK Parliament, in that Congress does not want public money being spent to support industry directly (with a small number of exceptions, mainly in the small business area and the NSF's Advanced Technology Programme). Congress only wants to fund projects with high risk factors.

When industry is involved, the government contributions are front-loaded to recognise the greater risk involved at the start of the research programme. For example, a three-phase government-wide Small Business Initiative (SBI) supports small firms in developing new products. More than 30% of the money is to be spent in universities, with $100,000 available for a one-year feasibility study. Phase two offers $300,000, and in phase three the companies are to be self-sufficient. Until phase three no matching industrial funds are sought. This differs from the UK LINK scheme or Teaching Company Scheme where industrial funding is expected to be substantial and to match government funding from day one of a project. This tends to lead to more prosaic, less risky, projects which industry is willing to invest in during the current year. The US tries to encourage participation in projects which are much riskier at the start but with the potential for high reward if they are successful.

Consortia

Industry also funds major research programmes in the universities under confidential arrangements. The US has favourable charity tax laws which encourage unrestricted donations of $5–45,000 to departments or research consortia (the latter avoid university overheads). At least half of the departments that we visited had one or more consortia, consisting of about 20 companies and a budget of about $500,000 per annum. These arrangements often support fairly fundamental work rather than short-term, industrially applicable research. However, we also noted that this was usually the only way in which research for traditional industrial areas is funded. Some held the view that the UK has gone too far towards government funding of research that is close to market.

PhD student Marcus Smith in the Department of Chemical Engineering at the University of Bath setting up his bioreactor for tissue engineering studies. (Photograph: S. Chawla-Duggan.)



Human cells adhering to a natural polymer matrix. (Photograph: M. Smith.)

Education, education, education

The common theme of all that we have discussed is about creating the right environment and training for those starting a career in science and engineering. It is vital that we address the question of student development *before* these students make decisions on career and employment. We firmly believe that the content of both undergraduate and postgraduate engineering education needs to reflect more accurately the modern concepts of the product engineering approach and the multidisciplinary nature of the future.

As in the UK, US undergraduate courses have not changed much over the years and perhaps include less chemistry and physics than in the past. Usually, US students take two years of 'general engineering' and only specialise in the final two years. UK graduates are regarded as more independent than those in the US; this has been partly ascribed to the major process design exercise that takes place in the UK towards the end of the course. As the UK moves towards MEng programmes there is potential to include more science in the curriculum.

Many US departments have recognised that their courses need updating and are now addressing this issue. NSF grants and other incentives are available for research into the teaching and learning of chemical engineering – most good departments will have academic staff with active and strong interests in education research.

The US PhD programme is rigorous, with more than a year's worth of courses spread over the term of the doctorate (front-loaded in the first year). Progression to the research stage of the PhD depends upon passing the taught courses. This approach leads to graduates with a broad and very sound understanding of chemical engineering as well as their chosen niche. In the UK, postgraduate coursework is generally undertaken only in MSc courses, specialising in advanced engineering and perhaps management. We found no tendency for UK postgraduate engineers to take science-based courses, with the exception of mathematics.

Conclusions and suggestions

The UK academic research community now has the opportunity to tackle the challenge of the new industries which require new products at an increasing frequency. Chemical engineers must engage themselves with modelling and quantification at the molecular and micro-scale. They must incorporate perceived customer needs into the *design* of potential products, as well as working on the processes that will be needed to make them. Advanced computational skills will remain core; the major change will lie in the application of our techniques to the development of new materials, for example in electronics, optronics, polymers, biomaterials, complex fluids and nanostructured composites.

The USA has changed its mode of academic research over the last ten years and moved into product engineering. This has resulted in closer collaboration with scientists and – more remarkably – a freer movement between disciplines within university departments. It seems to us that this movement has been facilitated by the structure of postgraduate degree courses. Once students are comfortable outside their immediate area, they become confident and innovative researchers who can break down boundaries and access the techniques of science to transform their research and thinking.

Postgraduate coursework should be expanded in the UK so that it is possible to include coursework from scientific disciplines. More modern science should be present in the undergraduate curriculum, with perhaps less emphasis on process design and more on product design and on research. The UK should be more flexible over the length of research training if interdisciplinary expertise is to be built up. It would also help to find ways of funding larger projects with high risk/high reward strategies where industry is involved. UK universities need to have more flexible course structures, looser disciplinary divisions, and more effective funding patterns. However, we recognise that there is a trade-off in the USA: research money is more plentiful but costs are also very high.

Chemical engineers must increasingly learn additional skills beyond those of chemistry and mathematics. This requires more postgraduate opportunities in the sciences and engineering subjects to create bi- and multi-disciplinary individuals who can carry out the new research. The UK should focus more research effort at the boundaries between engineering and science. This should be problem solving, design-based, product engineering and aimed more effectively, but not exclusively, at the interests of the new high-technology industries. This will require a more flexible and enlightened approach to funding.

In closing, it was interesting to see how the two countries reacted to our report. Whilst the UK's EPSRC has made a number of changes which are consistent with the ideas put forward, there has been little obvious change in university chemical engineering departments, with some notable exceptions where new science-based staff have been hired. This contrasts strongly with the response from the US where there has been enthusiasm over the report. They have taken to heart the report's implied criticisms of their structure. A number of departments have used the report to guide their future research strategy; others have noted that their undergraduate curriculum has remained quite traditional and has not embraced the new science thinking. There are now moves to change this in many departments to bring themselves in line with the changes that have already occurred elsewhere.

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Web sites

The full report of the 1998 visit is available at: http://www.bath.ac.uk/~cesjah/report/

The National Science Foundation web site: http://www.nsf.gov/

The Engineering and Physical Sciences Research Council web site: http://www.epsrc.ac.uk/

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