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The Lambert Review

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contents

Population growth: slow, slow or quick?

Two recent headlines based on the same source are informative, "UN warns of population surge", said *BBC News Online*. "UN predicts much slower growth in population", said the *Washington Post*. Both are respected news sources and both are right, as the report that they were writing about has plenty of material for such divergent sounding stories.

The report, *World Population in 2300*, produced for the Department of Economic and Social Affairs (DESA) of the United Nations, was published on 9 December. The UN produces these long-reaching projections as a resource for environmental scientists, policymakers and others who need to assess the long-term implications of demographic trends.

The latest results extend the time horizon to 2300 (previous long-range projections were to 2150) and they now include country forecasts (previously, long-range projections were available by continent only).

According to the medium scenario of these projections (in which world fertility levels will eventually stabilise at around two children per woman), world population will rise from the current 6.3 billion to around 9 billion persons in 2300. But even small variations in fertility levels will have enormous impacts in the long term. As little as one-quarter of a child (sic) under the two-child norm, or one-quarter of a child above the norm, results in the world population ranging from a possible low variant of 2.3 billion to a possible high of 36.4 billion in 2300.

The report included another scenario undertaken for the sake of illustration. On the "constant scenario" if fertility levels remain unchanged at today's levels, world population would rise to 244 billion persons in 2150 and 134 trillion in 2300, clearly indicating that current levels of high fertility cannot continue indefinitely.

The report is available on the web site DESA's Population Division: www.un.org./esa/population/publications/longrange2/Long_range_report.pdf ❐

UN fails to reach agreement on human cloning

On Tuesday 9 December the UN General Assembly postponed a decision on the increasingly acrimonious debate about human cloning for a year. All 191 members of United Nations agree on a treaty to prohibit cloning human beings, but they are divided over whether to extend the ban to stem-cell research.

The decision follows a battle between two competing UN resolutions. One backed by more than 60 countries including the United States, proposed a blanket ban on both reproductive cloning and therapeutic cloning of human embryos for medical research. The other, supported by more than 20 countries, called for a ban on only reproductive cloning, leaving the door open to therapeutic cloning.

The UN legal committee instead narrowly passed a compromise resolution proposed by Iran to defer the decision — 80 countries voted in favour, 79 voted against and 15 abstained. In the absence of UN guidelines, countries can continue to regulate human cloning as they choose. The United Kingdom, for example, already bans reproductive cloning but allows therapeutic cloning. In the United States, there are no laws against either practice.

Following the vote on the compromise, the United States delegation revived its continued lobby for a total ban, working with Costa Rica, but no vote was taken on the resolution. The matter has been rescheduled for next year. A spokesman for the United States UN ambassador said that they will continue to work for a total ban.

Britain's deputy ambassador, Adam Thomson, told the UN Assembly, "It is clear there is no consensus in respect to therapeutic cloning research, but by ignoring this fact and pressing for action to ban all cloning, supporters of the Costa Rican resolution have effectively destroyed the possibility of action on the important area on which we are all agreed — a ban on reproductive cloning." ❐

Badgers' reprieve

Ben Bradshaw, Britain's minister for nature, conservation and fisheries, announced on 4 November that the "reactive culling" of badgers will no longer be used in the trials comparing the effects of reactive culling with no culling and "proactive culling". This follows from the results of a study[1] that raises doubts of the benefit of reactive culling of badgers, thought to be carriers of bovine tuberculosis (TB), on British farms.

With proactive culling, badger numbers are reduced over an entire area regardless of the incidence of TB. The initial results show that the number of infected herds in reactive-culling areas is 27 per cent higher than in regions without culls. More than 20,000 badgers have been killed since the mid 1970s in areas where there are infected herds in an attempt to control bovine TB. This policy was put on hold in 1998 so that a study could assess the effectiveness of the method. It is still not known why reactive culling has done more harm than good in the fight against bovine TB. ❐

1. Donnelly, C. A. et al. Nature doi:10.1038/nature02192 (2003).

Bureaucratic maize

Earlier this month British representatives voted in Brussels to back the Europe-wide sale of a variety of GM sweetcorn produced by the Anglo-Swiss firm Syngenta. The vote reflects British anxiety for the EU to avert a trade war with the United States over the issue. The product, known as Bt11 maize, would have been the first GM foodstuff to have been approved since 1998, when an EU-wide moratorium was imposed because of public unease about the technology.

Spain, Ireland, the Netherlands, Sweden and Finland voted to support Britain but France, Denmark, Greece, Luxembourg, Austria and Portugal objected, while Germany, Italy and Belgium abstained. Another vote on the issue — at ministerial rather than expert level — will be held early in 2004. The UK will continue to vote in the same way. "We go for a science-based approach and we agree with the European Commission that this food is as safe as normal food," said a spokesperson.

Syngenta wants to import the sweetcorn and sell it frozen, in cans, or as corn on the cob; it is already on sale in the US, Canada, Australia and Switzerland. EU scientists concluded it is "as safe for human food use as its conventional counterpart". ❐

Japanese thaw Russia's frozen Kyoto shoulder?

As we go to press, we hear that Japan is still hopeful that Russia will ratify the Kyoto Protocol to curb global warming. The Russian prime minister Mikhail Kasyanov is due to visit Tokyo from 15 December where it is expected that he will meet with his Japanese counterpart Junichiro Koizumi. An official at the ministry's global environment bureau, Hiroshi Sagawa, said Russia had not informed Japan through diplomatic channels of any decision not to ratify the protocol. "The protocol won't come into effect unless Russia ratifies it. We will continue to urge Russia to do so", he said. Japan may use the opportunity of Kasyanov's visit to press Russia to ratify the protocol.

For the treaty to come into effect it must be signed by countries whose emissions together total 55 per cent of the global total. To date, the 113 countries that have ratified the treaty comprise 44 per cent of the global total; Russia's 17 per cent would tip the balance towards ratification. Meanwhile, the United States remains defiant, defending its 37 per cent of world emissions by refusing to sign. ❐

On 2 December 2003, FST arranged a discussion meeting on university–business relationships in research, specifically to discuss reports by Richard Lambert (on technology transfer) and David Hughes (on innovation).

Academic research and business

The Lambert Review on the relationship between British university research and British industry and commerce, published on 4 December 2003, is a backhanded compliment to British universities, which are throughout represented as an untapped resource of intelligence, expertise and skill for British industry and commerce.

The report is also a minor victory for the universities of Oxford and Cambridge, whose management arrangements are not as severely criticised as in an interim report last summer. It probably also marks the consolidation of the influence of the British Treasury (which commissioned the study) over academic research.

The report is named after its author, Richard Lambert, editor of *The Financial Times* until 2002. His study was meant to suggest ways of promoting closer collaboration on research between universities and business. The formal terms of reference are even-handed between "universities" and "business", except that Mr Lambert was asked to seek the views of business on the "governance, management and leadership arrangements" of universities, but not academic opinions of company governance and management.

Changed environment

Lambert says this is a good time for an assessment of collaboration between academic institutions and business. British universities, which are said already to collaborate more widely than their European counterparts, regard the deepening of these activities as a potential source of extra funding.

Companies, on the other hand, are cutting back on in-house R&D, not only to reduce overheads but, more importantly, to have access to a wider range of ideas than in-house laboratories can sustain. The report is replete with real-life illustrations of how both partners have benefited from collaboration.

Nevertheless, it seems that the industrial sector has been largely responsible for the recent relative decline of the percentage of GDP spent on R&D. In 1981, Britain is said to have spent a larger proportion of GDP on R&D than any other member of the G7 group of countries (except Germany); now the proportion has fallen behind that in Germany, the United States, France and Japan and is just level with that in Canada. (The seventh country is Italy.)

Between 1987 and 1999, British business spending on R&D declined from 1.5 per cent to 1.18 per cent of GDP (but has picked up since 1999). In other words, in just over a decade, business R&D reduced its proportional contribution to GDP by more than 21 per cent.

Lambert accepts that business R&D influences national economic performance. "There is a well-established link between R&D, innovations and productivity, and … ample evidence that the weakness of the United Kingdom's R&D spending over the past 20 years has played a measurable part in the country's productivity performance."

Indeed, British R&D seems to be concentrated in pharmaceuticals (including biotechnology) and defence, with comparatively little attention paid to electronics, electrical and chemical engineering, software and IT services. The report notes that the pattern is much less skewed in countries such as France and Germany. Britain also continues to skimp on R&D in the services sector, in contrast with Scandinavian countries, Spain and France.

One fear expressed in the report is that industrial research already located in Britain may migrate elsewhere. Lambert says that there is a tendency for multinational companies based in Britain to relocate their research in their principal markets, especially those with a strong research tradition (as does the United States). The tendency for British companies to grow by acquisitions rather than organically may further erode the British research effort.

R&D benefits

Lambert nevertheless offered some hope. Economic stability should encourage managers to invest in research, public spending on research has been increased, greater proportions of business managers have been to university and so may know what university researchers have to offer and, above all, "there has been a marked change of culture … in many universities".

Many faces of innovation

David Hughes emphasised that innovation was more than invention, but the successful exploitation of new ideas in new business practices, personnel policies, products or services.

Innovation was crucial for economic success. Britain could no longer compete on a low-cost basis; technological and scientific understanding was increasing quickly; global communications meant that consumers knew about, and wanted, the latest and best; and the product lifecycle had dropped from 3–5 years to one. UK business must therefore compete by adding greater value than competitors.

Government spending in support of innovation was already considerable — DTI programmes, tax credits, technology transfer programmes, Department for Education and Skills (DfES) spending, the Regional Development Agencies (RDAs), the science budget and, perhaps most important, government procurement. But strategy and priorities needed better definition.

Collaboration and networking by businesses and universities was crucial. New technologies needed to be applied to a variety of products and services. A successful innovation strategy would build on: existing and new skills; cooperation within regions; informed public procurement; wise regulation and exploitation of national assets.

David Hughes FREng, is director general of the Innovation Group at the Department of Trade and Industry (DTI) and is an engineer by background.

Background

The accompanying text breaks with the recent pattern of articles in *FST Journal.* Because Robert Lambert's Review was published two days after the FST discussion meeting, readers' interests may be served by this extended account of his report. The contributions of other speakers are taken from a summary by Sir Geoffrey Chipperfield. The full publication can be found at www.lambertreview.org.uk. The Hughes Report on innovation may be found at www.dti.gov.uk/innovationreport/

The benefits to business of collaboration are varied, ranging from the use of academics as listening posts for developments in science internationally; access to a wider range of disciplines than could possibly be accommodated in-house (Procter and Gamble aims to increase its out-sourcing of product innovations from 10 to 50 per cent within five years); "leveraging the research dollar", meaning either that costs are shared or that academic research is cheaper; talent-spotting (especially of the young); and access to specialised consultancy.

The report includes data purporting to show that companies with existing university collaborations are more successful than others in the market-place, but Lambert would probably agree that these do not unambiguously identify cause and effect.

Boosting R&D

Starkly, Lambert says that "most UK companies" have no experience of working with universities and of the benefits that could follow. He asks that:

- British business set up "a high-level forum" to promote increased collaboration and, implicitly, more effective lobbying of government;
- the Government should direct more of its support for industrial R&D towards smaller companies (which already have a creditable record on research spending);
- the Regional Development Agencies (RDAs) should become prime movers in setting up collaborations (even to the extent of telling companies that they should find an academic partner). Some readers of the report may nevertheless say that not all RDAs are equipped for this task;
- Knowledge Transfer Partnerships, previously "Teaching Company Schemes", under which graduate-students are assigned to industrial research partnerships largely financed by business, should be better marketed.

Lambert is on safe ground so far. Few will complain that his proposed re-arrangement of the deck-chairs is unreasonable. On the other hand, while the report frequently refers to the need that business should have better information, it is surprising that it does not suggest a "one-stop shop" for business seeking academic help — and the relatively small sums of public money on offer. It does, however, commend an organisation called Knowledge House, which since 1995 has provided such a service in the northeast of England.

What universities must do

Consultancy by academics for industrial partners appears to be growing: the report estimates that its total value is about £100 million a year. Lambert asks that British universities should regularise academics' work as consultants by means of explicit policies on the time individuals may spend each year.

Since 1999, the British Government has been providing relatively small sums of money (now about £90 million a year) to university schemes meant to foster "knowledge transfer". The report notes academic complaints that the award of grants under the scheme is cumbersome, slow and uncertain, but Lambert asks that what is known as "third stream" funding (a supplement to "dual support") should be made permanent and increased to £150 million a year for England alone.

Some of these funds are used for investigating the feasibility of bright ideas (called "proof of concept" in the technology-transfer trade) as well as for initial funding of spin-out companies. Lambert argues that the former use is a better investment of public funds than the latter.

Among the impediments to collaboration, the most difficult is the need for universities to agree in advance with potential business partners on the value of the intellectual property contributed from the academic side. Lambert acknowledges that academics tend to overestimate the value of their inventions, even to the extent that some potential collaboration has been abandoned as a consequence.

The remedies suggested are that the research and higher-education funding councils, together with appropriate business organisations (for example, the Confederation of British Industry) should draw up a protocol to guide negotiations. A practicable suggestion is that the third-

The passion of research

Colin Lucas acknowledged that innovation was the driver of economic success. Universities, as the creators and transmitters of knowledge, must be at the heart of it. It was commonplace that universities must seek to transfer knowledge to the wider economy and have structures suitable for doing so. Collaboration between business and universities was essential.

But the difficulties should not be underestimated. Both parties found it difficult to find partners. When found, partners were discovered to have divergent cultures. Finding appropriate research projects was complicated by differences in needs, aims and skills and by universities' need to align research with resources and to balance it against their other objectives — producing the trained and skilled people that all sectors of the economy needed.

Richard Lambert had been right to emphasise both the importance of teaching and the primary function of knowledge transfer being "the public good". But it would be mistaken to try to prescribe innovative outputs. People do best at what they want to do; the best results come from letting people get on with their passions, not in attempting to manufacture specific outcomes.

Effective supporting structures in universities were vital for technical transfer: there must be staff with expertise to collaborate with business (not academics); investment in realistic valuation of intellectual property; adequate sources of seed corn finance. Ever present was the danger that commercial pressures could affect research programmes by requiring short-term results, or diverting research from fundamental work. Oxford was well run; it had had suitable structures and resources.

Sir Colin Lucas is vice chancellor of the University of Oxford.

Juggling priorities

Robert May said that the knowledge economy had three legs: research, researchers and cashing in on the results. The first two were the job of universities, the third that of industry and business. There were two sets of costs in basic research: the direct cost of projects and the indirect cost of creating the necessary infrastructure.

The Research Assessment Exercises did not adequately recognise cross-institutional or crossdisciplinary work, while the 5–10-year gap between creating infrastructure and the completion of projects could not be financed by smaller institutions. Moreover, the system did not recognise collaboration with industry, and tended to devalue teaching.

But Britain's achievements should not be undervalued — we did well in international comparisons of high-technology exports while university/business collaborations and patent filings were increasing. The research gap between the United States and Europe lay in the private sector, not universities. It was business that had the problem, not universities.

By all means, change the risk-averse culture of universities, encourage researchers to go into business, but do not erode the fundamental academic values of the search for knowledge. Governments must not think that they can achieve their economic aims by persuading researchers to do work which is not the centre of their passionate involvement (or, more colloquially, which they find fun).

Lord May of Oxford has been president of the Royal Society since 2000, was previously chief scientific adviser to the British Government and before that was an academic researcher at the University of Oxford and Princeton University.

discussion

Attracting talent. In the discussion, there was concern that the problems and opportunities afforded by the intense international competition for high-quality researchers had not been fully understood. Britain had great advantage in being able to attract and retain good researchers who wished to exploit innovation, because of the English language and the sound legal and commercial systems. But rewards were low compared with the United States and facilities were nowhere near as well funded so that a drain westwards must be expected.

Why should the British taxpayer fund the education of researchers who left the country? Was it right to seek to attract able researchers from less developed economies? The answer must lie in the motivation of researchers. If it were right that their primary motivation was passion for their research, then they would go where there were the best opportunities.

So Britain must maintain universities of the highest quality, with outstanding facilities, if it is to keep attracting and retaining research leaders. European opportunities should not be neglected and there was room for collaboration on transnational research.

If such people were to be kept in Britain, the need for collaboration between businesses and universities would need to be strengthened. Networks would have to come into being where they could meet and discover each other's potentials.

stream funding should be to support regional offices managing the intellectual property rights of universities in their areas.

University governance

Lambert acknowledges that it is natural that there should be differences of management style between older universities and those created in 1992 and afterwards. The heads of the latter (many of them former polytechnics) function as if they were chief executives, whereas the former retain traces of the origin of universities as "communities of scholars", requiring consensus on many issues.

Oxford and Cambridge are extra-special in that the separate colleges can impede decisions on matters of benefit to the university as a whole and that some issues can be decided by the votes of all members of the university (Convocation at Oxford, Regent House at Cambridge).

The report records several examples of how individual universities have recently been moving in the right direction, vesting powers of decision in individuals, academics or administrators. But it complains that the governing bodies of the older universities are still too large (and that the supposed benefits to the universities of being able to tap a wide range of experience are illusory — attendance records are poor).

Lambert argues that British universities should produce a model code of practice for academic institutions and has even produced a draft of this which, among other things, specifies that the head of a university should function as a chief executive with responsibilities reviewed annually, together with the attainment of performance targets. Vacancies on the governing council should be advertised publicly and a majority of its members should be independent (as should be the chairman). The council should formally review its own performance every three years or so.

The case of Oxbridge is dealt with by the recommendation that the two vice-chancellors should, three years from now, review the "progress of reform" and agree with "the Government" what further steps need to be taken. The only threat in the document (which is meant as an objective comment) is that, in the absence of reform, the two universities will not be able to pay their academics competitive salaries.

To sweeten the pill for universities, Lambert asks that the funding councils should not be required to administer earmarked funds (often taken from their general budgets) on behalf of government and that government departments should be less zealous in micro-managing what universities spend.

On balance, the Lambert Report is a continuation by other means of the Dearing Report of 1995. But its distinctive feature is that the text is supplemented by a wealth of illuminating case studies of good practice (printed in blue boxes). They splendidly fulfil Lambert's aim of putting new and interesting ideas into circulation. ❒

discussion

Adding value. Was the concept of "adding greater value" simply a cry to create more advanced products, or had it a wider meaning? Could it be seen as promoting linkage between design, social issues, such as ecology or CO_2 reduction, and purely technological advance? But perhaps the largest area where "greater value" could be found was in development, rather than in research.

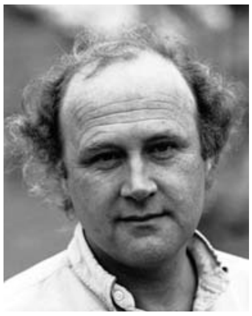
Businesses did not appreciate that universities could help all the way through the innovation process, while universities did not realise what the opportunities were. Because universities had not organised themselves to be effective in assisting development, one major company suggested that development work could not be effectively placed in British universities.

It was agreed that technology transfer should be for the public good, not to increase university revenues. But the better doctrine was that the public purse paid for the creation of knowledge, not its commercial exploitation: "public good" was a motivation for universities, not another means of taxing the public.

But there were tensions between public support and commercial interests. Some government organisations compete directly with businesses and, in particular, where government procurement programmes demand publicly-funded research, it should be clear that such research does not benefit only the eventual supplier.

Trust, it was agreed, was crucial. Trust meant long-term stable arrangements, which could inhibit flexibility; it also meant secure funding programmes and business arrangements which would give people the confidence that they could take risks, without sudden shocks from changes in government policy. Changing cultures was not without risk. It was the task of government, in implementing the two reports, to find the right path.

Re-creating the Garden of Eden



From the moment it opened in May 2000, the Eden Project has attracted both tourist and professional like bees to a honey pot. Tim Smit CBE, chief executive of the Eden Project in Cornwall, explained how the project came about in the Foundation's 2003 Lord Lloyd of Kilgerran Award Lecture, given at the Royal Society on 7 October 2003.

The Eden Project is not the first Cornish tourist attraction that I have been involved with. Some years ago I was interested in breeding rare pigs and met someone who had just inherited a Cornish estate. I saw a field on the estate that would have been a great place for rare pigs. The owner said that I could not have that field but to take a look at some derelict land next door, which had been a garden. I walked into the garden, which was 15 feet high in brambles, and fell in love with it. Within in an hour I decided I was going to give up music (I was a producer of rock music) and restore the garden.

Now known as "The Lost Gardens of Heligan", these Victorian gardens overlooking the fishing village of Mevagissey taught me a lot about the English, the media and how to interest the public in scientific matters.

The first lesson was the power of the media. Gardening expert Dr Stefan Buczacki made a documentary for the BBC. It was a very good documentary except that, at the end of it, he forgot to mention that we were not open to the public. The next day people began to turn up and insisted on being shown round. The day after three or four coaches turned up. We had become a tourist attraction overnight and in our first year of opening we had 40,000 visitors.

The public enjoyed seeing a place that was being developed and worked on. They also liked the fact that we did not put Latin plant names on our labels and posters. We told anecdotal stories and many people who arrived thinking they disliked gardens left with a feeling of real enjoyment.

The second lesson I learnt, and there were many, was that adults are not as amusing to children as they think they are. The numerous school groups that visited were not amused by my attempts at entertainment. Fortunately, I had been reading to my children various books by the author Roald Dahl and one day I decided to get my own back.

I began by telling a group of kids about the poisons that burnt through the stomach lining and then went on to the poisons that make your tongue go big, black and furry, choking you to death slowly. At that point the teachers were getting alarmed but the children were fascinated. I went on to make it more academic by talking about the poisons that the Aztecs used to stop people screaming when they were having their still-pumping hearts removed from their chest cavities. This is the Datura, which you may grow in your own garden and is extremely potent, possessing the capacity to paralyse the central nervous system without affecting the respiratory system.

After stories like that, even the humble potato takes on a new and previously unsuspected lure; then we go on to stories of the plants that have changed the world.

My third lesson from the Heligan experience strikes a cautionary note. As an outsider perhaps I can comment on the incredible faith the British have in the past and in our "heritage". That we tend to want to conserve and preserve everything can be a terrible cancer; we want to preserve anything more than 60 years old forever.

Now the story of Eden. I had this idea to build a greenhouse in one of the conservatories at Heligan that would tell the story of plants that changed the world and the productive plants of the world. I talked with Philip Macmillan Brown, my horticultural director, about the plants that we would have. After about half an hour we had come up with a list of plants that would have taken up the whole of Heligan, never mind one greenhouse, so the idea was put on the back burner.

Then heritage secretary Peter Brooke announced the launch of the Millennium Lottery Fund. But the only project that anyone was talking about was the ferris wheel on the Thames. The London Eye is great, but it seemed to be rather disappointing as a statement as to where we in Britain might be at the dawn of the new Millennium. Thinking about this while driving into Cornwall on the A30, I looked at Goon Barrow and suddenly thought of Arthur Conan Doyle and the Lost World. Lost civilisations, engineering projects and then, suddenly, there it was in my mind, the Eden Project.

One of the lessons I learnt at Heligan was that many of the brick walls against the future are to do with your own fear of it, the barriers are to do with the fact that you do not want to be disappointed or to leave yourself open to ridicule. I decided to "go for it" with Eden in exactly the same way that we had done with Heligan.

I made my first presentation on the subject to the Economic Development Committee of Restormel Borough Council. I kept it simple. I said "I have this great idea; we are going to take a clay pit and build these fantastic conservatories and it is going to be a new scientific foundation. I haven't any drawings, I haven't got a business plan but I want you to give me loads of dosh to do it". A stunned silence followed but Restormel gave me £25,000 and the Eden Project was underway.

With local support we were able to build up a fighting fund. I went to the Millennium Commission to tell them: "We have this great idea to build a lost civilisation in a clay pit." The civil servants looked at me and said, "It's a terrific idea, but you don't seriously expect us to believe that anybody in Cornwall is capable of building it, do you?"

We needed someone of international stature. We went to Nicholas Grimshaw, who built Waterloo International rail terminal, and said, "the good news is that we would like you to build the eighth wonder of the world; the bad news is that we can't pay you". The following day we got a call from Nick saying that he had talked to his team and they wanted to do it. Not only that, but they had persuaded all the people who had worked on Waterloo International to work on it as well.

For the next 18 months this world-class team worked for absolutely nothing. Then we had to find people to build it. We eventually ended up with the two McAlpines, Alfred and Sir Robert. Having chosen them, I was very nervous. I asked them and the design team an unusual question: "if you were me, talking to you, what question would you ask to make you build it on time and on budget?"

About five hours later we came up with a revolutionary construction contract. They said "We have to get one thing straight: are we allowed to make a profit?" and I said "Of course" and they said "that's fine".

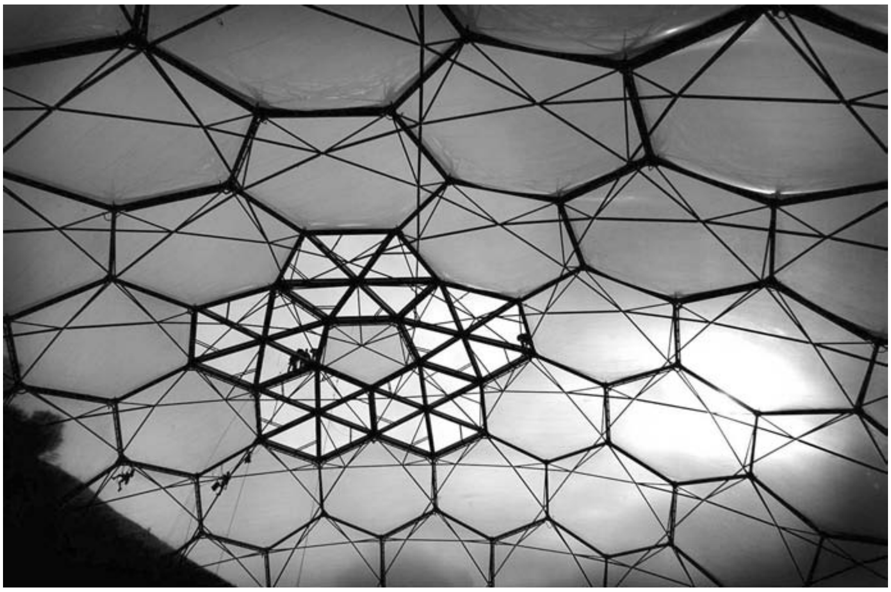
We did everything on an open book basis, on a no-blame culture, and we built it on time, on budget, without one single major argument of any kind, no litigation between us. When we started to develop the next phase of the project the same team all volunteered to work again for nothing. The lessons we learnt were very humbling as well as incredibly exciting. When you work hard in the narrow confines of your business, you very rarely get the opportunity to celebrate and enjoy the sheer talent of your fellow human beings. Most of us do not take the time to relax and think "wow, that is fantastic".

On 15 May 1997, we were awarded half of the total £75 million, but we could only have each pound when we laid down the matching pound. The civil servants that I dealt with at the Millennium Commission were fabulous, bending their own rules to make things possible. For example, when our pit was going to be bought by a landfill company and we still had not raised the matching money they worked out a way to buy the pit. I applaud them wholeheartedly for that.

On 17 October 1998 we bought the pit and by dusk that day we had a giant hole full of dumper trucks and bulldozers. The following morning, we started to scrape away where the foundations were going to be and it started to rain. It rained for 134 days. Forty-five million gallons of water fell in the first 10 days of January 1999 and we had to stop work completely. But our construction team was marvelous, taking it in their stride.

We opened the doors on 15 May 2000 and had 1.8 million visitors that year and the next. Inspired by Buckminster Fuller's geodesic designs, the conservatories are broadly geodesic on hexagons with a couple of pentagons thrown in for good measure. We have two major conservatories, the humid tropics biome and the warm temperate biome. The humid tropics is rainforest and Oceania. Warm temperate is Mediterranean climates.

The brief we gave Nick Grimshaw was a tough one; we wanted a conservatory that was fit for functions, great for plants, could compete in terms of performance with an ordinary commercial greenhouse and was on a big scale. You cannot use plate glass because that is thick and heavy and needs big steel. If you have big steel you have big shade. Also plate glass cuts out a lot of the light spectrum. We ended up choosing a foil called ETFE (ethylene tetrafluoroethylene) foil. This is bascially cling film with attitude.



A biome nearing completion as the last of the foils are put into place. The biomes were constructed around the biggest free-standing scaffold structures ever built.
Picture: Apex www.apexnewspix.com

The Eden Project web site is www.edenproject.com

The structure was built using very thin steel and the weight of the superstructure above the foundations is almost the same as the weight of the air contained inside it. It is so tough you can have a rugby team dance on top of it without going through.

Even if we had not opened to the public, the money we spent on Eden would have been worth every penny because we had to pioneer earth technology. We made 90,000 tons of our own soil, using china clay wastes, domestic compost, mushroom compost, bark compost; no-one has ever done it to that scale before and it is a technology that can be adapted to any derelict land in the world. We are hoping to work with other people to help them with their derelict land. My horticultural team not only had to create this place, but also grow the plants in a medium that no-one had ever grown in before.

We are going for the next phase of Eden because the first design can only cope with 750,000 visitors. With nearly two million visitors a year there is a lot of pressure. The next phase includes one more biome, the dry tropics, to tell the story of water. When we have done that we will not want to build any more; we are not a typical botanical garden, we do not want to collect multitudes of plants.

Part of the pleasure of the experience at Heligan was the discovery of how to get people interested. We are unashamed about embracing popular language. Many people in the scientific profession are more afraid of offending, or appearing to be "dumbing down" in front of their peer group than they are excited by enthusing the general public with what they are doing, in a way that can be understood.

There are at least three million people in this country interested in the environment, so they will want to come to see Eden anyway. How do we get the other 54 million excited, because none of us is going to get a constituency of support for massive change, the sorts of changes that we are all going to face within our lifetime, if people do not understand the issues? Addressing issues of public awareness of science is a very tricky thing; I think that you have to catch people unawares.

To understand the Eden Project you have to visit it. It is not about plants. The reason we have plants, and our mission statement is about human dependence on plants, is because plants are what I call a canvas against which you can tell human stories. Eden is about ideas, about how you bring fantastic people together, about how you dare not to be so vain that you want to own those ideas yourself and it is about sharing.

We now have about 600 staff at Eden. We have put £160 million into the Cornish economy. We are what is called a "social enterprise". Eden is a fantastic model for governments to look at in terms of understanding how the returns on state investment should be measured, as opposed to the straight return from the money invested. Look at the wider community and the results that come from that. ❐

The British government regards horizon scanning, or foresight, as an essential tool of policy-making, as made clear at an FST meeting on 20 June 2003 at the Royal Society, preceded by a workshop on the subject at the Irish Embassy led by Dr William C. Harris, who argued that Ireland's success in computer science and biotechnology stems from its government's commitment to education.

Horizon scanning rooted in science

David King

Sir David King KB ScD FRS is chief scientific adviser to the UK Government and head of the Office of Science and Technology. Professor King was a lecturer in chemical physics at the University of East Anglia and at Liverpool. In 1993 he became head of the Department of Chemistry at Cambridge.

Two key elements of the Government's horizon scanning activity take place in the Office of Science and Technology (OST) and the Strategy Unit in the Cabinet Office. In OST, we use the Foresight programme to look at the many possible futures and try to determine whether actions now, or in the short term, can influence what will actually happen. For OST, the key element is science; in the Strategy Unit the viewpoint is somewhat different, although the objectives are similar — to help the UK to be as proactive as possible in our planning and policymaking.

I speak with feeling on the subject, having personal experience of an example of the OST acting in a reactive fashion without the advantage of foresight, the 2001 epidemic of foot and mouth disease (FMD). It is worth asking whether it might have been possible to predict that an FMD epidemic of that magnitude might hit the United Kingdom and what made the 1967 outbreak so much smaller.

It is certainly possible to argue that we might have predicted the outbreak using foresight. Farming practices changed qualitatively between the two outbreaks. There was a relatively small amount of animal movement in 1967 but a vast amount in 2001. From that knowledge, we might have predicted that an epidemic occurring in 2001 would have massive repercussions. So it is better to be proactive. This is what foresight is about.

Virtually all the subject matter for horizon scanning lies in the scientific arena, but if the process is to be effective it must cover natural and social sciences and include political and economic considerations. So the Government's Foresight programme, launched in 1994, aimed to create a "national capacity to think ahead" beginning from the current state of science and technology and considering how this might change and influence society in the future.

Until 2002, Foresight was a broad, panel-based process covering all research sectors, linked to research agendas. Since 2002, it has been project-based, with 25 staff in OST and wide expert external support. The starting point for a project area is either a key issue where science holds the promise of solutions or an area of cutting-edge science where the potential applications and technologies have yet to be considered and articulated.

No more than four projects run at any time in a rolling programme, with each project taking around 12-18 months to reach completion. Each project is tightly defined and a key feature of the new-style projects is that each has a stakeholder government department, or departments, closely involved in the process. This means that, once OST has finished its report, we hand it over to that department for action.

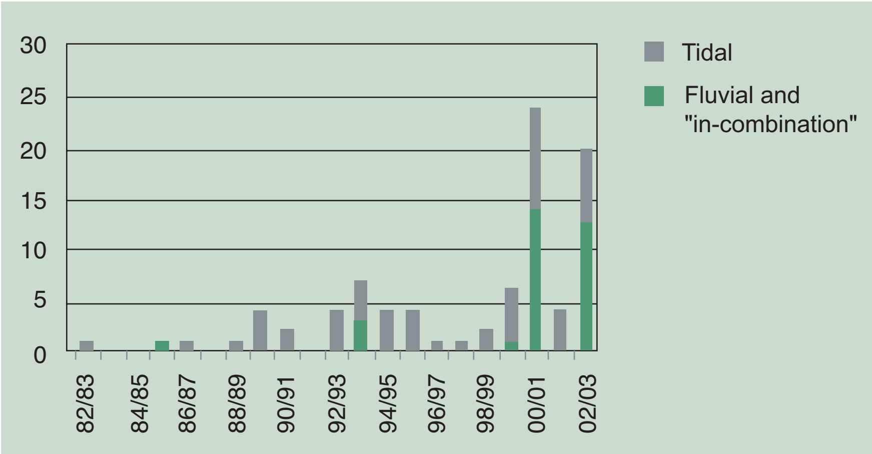
The four projects in this first period of the new Foresight are:

- flood and coastal defence, concentrating on the long-term impacts of and responses to climate change;
- cognitive systems, linking brain science and computing, looking for opportunities in possible wealth creation spinouts;
- cyber trust and crime prevention, focusing on the risks and rewards of the next generation of information technology;
- exploiting the electromagnetic spectrum will take a novel, broad view of the spectrum and its potential future exploitation.

I would like to expand on the work that has taken place in the flood and coastal defence project. In Britain today, more than £200 billion worth of assets are at risk from flooding and there are 1.7 million homes in flood plains. The project team has taken the broadest approach to the problem and involved many of the UK's leading experts.

The stakeholder department is the Department of Environment, Food and Rural Affairs (Defra) and the project also involves other key stakeholders both in government and outside, which reflects the wide range of important issues to be covered in this project.

Initially, we thought that climate and sea-level change would have the biggest impact, however the analysis indicates that the socio-economic changes ahead are equally important. It is anticipated that storm surges will be of increased ferocity, posing increased threat to the coast as well as river flooding and sewer flooding inland.



Thames Barrier closures – tidal, fluvial and "in-combination"

One of my favourite examples of good foresight happens to be in this area. The Thames Barrier was built in 1980 at a cost, in today's money, of £1.4 billion. It was first used in 1982-3 and, in its first five years, was not much used. But between January and May this year (see right), the barrier was operated 20 times. It is estimated that, had one of those 20 potential floods occurred, the flood damage would have cost about £20 billion.

In other words, an expensive construction has actually saved a lot of money. Indeed, the usage of the barrier is a vivid measure of the change of flooding and storm surges over more than two decades. The question naturally arises of whether this is directly related to climate change. I personally believe that there is sufficient evidence to indicate that this is a continuing trend and that climate change is the big driver of that trend.

Another example of current Foresight work is the cognitive systems project. Here the stakeholder government department is the Department of Trade and Industry (DTI). An interesting aspect of the process is that, when we first brought together the two groups of scientists, life scientists studying the brain with modern physical techniques and the IT community, there was very little communication between them.

To overcome this, we produced state-of-the-art reviews of the science relevant to the topics defined. These reviews then had to be translated by a science writer into a language that both of the scientific communities involved *and* non-scientists could understand. We then brought the groups together again to review their work and explore its promise for the future.

What we are trying to do is to understand what the scientists actively engaged in these problems are doing, so as to see what future themes may emerge. There is great excitement around the project. Some of the very interesting themes emerging from the initial phases of this project include "a theory of forgetting", "reasoning with uncertainty", "planning processes" and "building an artificial animal".

Briefly, the third and fourth projects of the Foresight programme are cyber-trust and crime prevention. A Home Office minister chairs the Stakeholder Group for this project which will study the potential opportunities and threats from the next generation of information technology as far as issues of trust and crime are concerned

Exploiting the electromagnetic spectrum. Here, the DTI, Innovation Group, is the key stakeholder. Our aim is to identify opportunities across the spectrum from recent developments in basic science, ranging from the use of synthetic metamaterials with unusual properties to the direct imaging of objects on a molecular scale

In conclusion, I offer some reassurance for those who may be concerned about the demise of the old Foresight programme. In effect, we are using the Foresight "brand" in a different context. Horizon scanning is an ongoing process in all departments. It is essential that knowledge of horizon scanning is shared between departments, not least because it is so difficult to test the results of horizon-scanning programmes.

The current Foresight programmes and previous Foresight rounds can be found at www.foresight.gov.uk. ❐

The techniques of horizon scanning

Geoff Mulgan

Dr Geoff Mulgan is head of policy in the Prime Minister's office and director of the Strategy Unit in the Cabinet Office. He was previously the Prime Minister's adviser on social policy and was the founder and director of the "think-tank" Demos. His most recent book is *Connexity*.

The work of the Strategy Unit involves a mix of fairly detailed day-to-day policy design and attempts to map a broader picture of the likely future in certain fields, ranging from local government to fish and from prisons to drugs. Here is a brief account of some of the methods we use to get a picture of the future.

There are very few reliable methods for predicting the future, particularly where human beings are involved. There are simply too many variables. Moreover, as any knowledge of the future can also influence the future, the challenge of mapping likely futures is inherently more complex in social systems than in relation to physical systems. So there is a valid point of view that says it is pointless doing any futures work. The best articulation of that view comes from Pandolfo Petrucci, Lord of Sienna, in a letter to Machiavelli, when he wrote, "wishing to make as few mistakes as possible, I conduct my government day-by-day and arrange my affairs hour-by-hour because the times are more powerful than our brains". That is not far from the view taken by many of today's leading politicians and business executives, who believe that the best that can be hoped for is speed of reaction to unpredictable events and that all else is doomed to failure.

There are reasons why some governments might take this view. Governments are not naturally long-termist: if you have a very small parliamentary majority or very high inflation, it is difficult to plan ahead. Many ministers have relatively short tenures in their jobs and do not see huge advantages in make making life easier for their successors; there are also the day-to-day pressures of the media and Parliament. Generally, governments are more at home with processes — making announcements, publishing white papers, passing laws — than with outcomes, which again engenders a bias against looking at the future.

However, we are now in an unusually propitious position for more serious long-term planning. Compared to the recent past, the United Kingdom now has higher public capital spending, longer-term spending allocations, relatively higher spending on prevention in health and crime, real rises in science spending and pays serious attention to very long-term environmental considerations, above all climate change. Crucially, too, we have a series of arrangements to insulate some key decisions from excessively short-term considerations, such as the Monetary Policy Committee for interest rates and the Food Standards Agency for food. These developments have helped to shift the focus of government towards the longer-term questions.

Nevertheless, when we look around the world, it is clear that Britain, like most other big countries, is worse at this than many small countries. The best practice in foresight tends to be found in smaller countries such as Singapore, the Netherlands, Finland and Switzerland. Not wholly coincidentally, these countries also rate highly in rankings of competitiveness and technological intensity, and they seem to be better at getting a wide community of decision makers across science, business and government, thinking in a much more sophisticated way about future challenges and opportunities.

In the United Kingdom, we have put in place new machinery to make us more like the best small countries. The Civil Contingencies Secretariat, along with a domestic horizon-scanning group, exists to ensure that, when we face the prospect of something like the SARS crisis, government has rigorously assessed, anticipated and, where possible prevented or mitigated the potential problems.

The secretariat also makes resilience assessments to see how communications and information technology systems would cope if there were, for example, a shock such as a terrorist attack. We have further strategy development capacity in units across Whitehall and in the Foresight team in the DTI. There are also long-term processes for allocating resources, setting targets and so on, through spending reviews which have helped to embed a more rigorous approach to preparation, the use of evidence and planning.

Some of the analytical methods we use to get a richer understanding of the future also contribute to a more sophisticated understanding of how present systems work. Some of these methods are quite simple — trends analysis, for example. Thus in our work on ethnic minorities, we have found, that, based on ethnic education patterns, pay rates and so on, the pay rates of Indians have now caught up with those of whites and that on the basis of school and university results, they are almost certain to overtake whites; other groups, such as Pakistanis and Bangladeshis, on the other hand, are falling behind. Information like this can be used to inform decisions in education and social policy.

We use a lot of benchmarking methods to see which countries we can learn from and which might be indicators of our future. Comparisons cover indicators on things such as GDP, life satisfaction and economic growth. More specific benchmarking can focus on performance in specific areas, for example police detection.

It is often very easy to be deceived by facts looked at in isolation. For instance 20 to 25 years ago, many thought that inflation in Britain was an insoluble aspect of late industrial society. Again, 15 years ago many thought the same of long-term unemployment. Both have turned out to be tractable and if, at the time, we had looked at other countries using benchmarking methods, we could have learned that sooner.

Other analytic methods include the assessment of market dynamics in different fields, systematic reviews of evidence and formal modelling.

These can at the very least stimulate thought. The US Department of Energy, for example, has issued a forecast of population and GDP for individual countries as a share of the world's totals, starting from 2003 and looking forward to 2050 (see Table 1). The US population is predicted to rise sharply in the next 50 years, while the European Union population falls slightly and the Chinese population rises sharply. But more striking are the data on share of world GDP: for the United States, this falls slightly, the EU's share virtually halves, while in China it goes up fivefold. Those are, of course, forecasts based on demographic and economic trends so they may not be all that accurate, but they give us a lot to think about when considering strategic options.

Foresight exercises, which go well beyond forecasting to map a range of possible futures, are also becoming more widely used. A recent Foresight exercise in the health field looked at the likely impact of patient expectations, medical advances, demography, epidemiology and so on. Perhaps the most striking finding was that we are probably still 15 years away from the full impact on the public of widespread genetic screening, gene therapy and products of stem-cell technology.

Another set of tools is simulations to assess the dynamics of systems: obvious examples include contingency exercises for chemical, biological, radiological and nuclear weapon attacks. An interesting study was concerned with the National Health Service (NHS) at the time the internal market was being introduced in the early 1990s. A big three-day simulation exercise was carried out, with many participants acting out the likely behaviours that would happen in the internal market. After the second day, the whole system crashed. Ministers did not want to hear that lesson and so it was ignored, though

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Scientist shortage. On the shortages of people choosing to study science, it was pointed out that the market normally solves scarcity problems by increasing price (in this case the remuneration of scientists). The choice of the right individual to head research organisations was vital. Private universities in the United States do pay to get star performers. But perhaps the huge influx of "cheap" scientists into the US had distorted the system. The OST were planning to examine this issue.

Table 1 Forecasting as stimulus

	USA	EU	China
Population (millions)			
2003	278	389	1275
2050	411	370	1700
GDP (world percentage)			
2003	29.1	29.3	3.7
2050	27.8	16.5	15.9

much that subsequently happened to the NHS internal market was pre-figured in that simulation exercise.

Foresight and scenario exercises can have a big impact on decisions. The Wanless Report, *Securing our future health: taking a long-term view* (2002), was billed by the Department of Health as the first ever evidence-based assessment of the long-term resource requirements of the NHS. Derek Wanless concluded that, to meet people's expectations over the next 20 years, Britain would need to devote more resources to healthcare and that this would have to be matched by reform to ensure that these resources were used effectively. The report was a key factor in convincing government to commit large sums of money to a steadily rising health budget.

An important lesson for those involved in systematic horizon scanning is that it is vital to challenge conventional opinion. What people expect to happen in the future is likely to be systematically wrong. Even the best-informed people would not have expected ex-communists now to be leading most East European countries, for example. In 1990 nobody expected a European civil war with 200,000 dead; genome mapping was expected to take a lot longer than it did; most people then thought that the US economy was stagnant, not about to embark on a long boom and that Japan was a model economy, not starting a 12 year slump. The word 'internet' was unknown.

Partly to counter the influence of conventional opinion it is important in horizon scanning to keep an eye on the margins: everyday phenomena such as complementary medicine, the internet, gun culture, text messaging or Big Brother were not well understood by mainstream institutions. Changes of this kind are not usually detected by the radar of establishment institutions, which is why some governments and companies try hard to go beyond their normal sources, to look at open source methods, at leading indicators rather than just backward-looking statistics and gossip.

Horizon scanning and futures methods should be part of the mainstream toolkit of any large institution, be it a firm, a government or a university. These techniques are not foolproof; but they do bring to the fore implicit assumptions, they attune decision makers to uncertain processes of change and they help to clarify choices.

However, on their own these methods can only take you so far. As in Pandolfo Petrucci's day, often speed of response is the most important key to survival, because you will never be able to map or track the near infinity of possible events. For organisations it will be just as important to have a capacity which can respond very quickly to events of low probability and high impact, as it is to attempt to plan for every contingency.

There are no easy ways of doing horizon scanning, no shortcuts and no guaranteed results. Instead what Charles Darwin remarked of his achievements in science is apposite here too: "whatever I have done has solely been by long pondering, patience and industry". ❒

discussion

Priorities. University research should be informed by industrial priorities but not be aimed at solving short-term problems. Its first product should be "stars of science", and only then should spinouts and industrially useful products be used to gauge success.

Foresight predicates commitment

William C Harris

Dr William C Harris is director general of Science Foundation Ireland (www.sfi.ie). Previously he was vice president for research at the University of South Carolina and was founding president and executive director of Columbia University's Biosphere 2 Centre in Arizona. Dr Harris served at the US National Science Foundation from 1977 to 1996, including as the director of the mathematical and physical sciences division (1991-1996), responsible for a federal grants appropriation of $750 million per year.

Over the past 30 or 40 years, Ireland has been transformed from primarily an agricultural economy to a country with a major manufacturing presence in many areas, particularly in information and communications technology and biotechnology. Ireland now exports more software than any other country[1]; 9 of the top 10 biopharmaceutical companies operate in Ireland[2]. This has been achieved largely through major investment and commitment to education. It is doubtful, however, that horizon scanning of the Irish economic prospects in 1985 would have predicted that this would be the case in 2003.

The moral is that foresight exercises are important, but you also have to be able to respond to opportunity. The thesis that I am going to present here is that the best way to prepare for the future, absolutely the best way, is through education. If you want to build an economy or industry, you do it through individuals and ideas, and the source of these is the educational system.

In many ways, though, the educational system is at risk. True, there are many high-quality universities, but there are weaknesses in the primary and secondary education systems throughout Western democracies. Finland, where there has been continued emphasis on these sectors, is one of the few exceptions. Our children choose not to study science, engineering and mathematics and we should be asking why, but instead we are sitting back passively accepting the situation, hoping the problem will go away.

The problem has been solved in the United States, largely by importing incredible talent for the past 25 or 30 years, but that cannot go on. Systemic issues such as this education problem have become an important aspect of the role of government. In studying the agenda for the future and defining the Government's role in the future of society in terms of helping to manage and guide the economy, horizon scanning provides a framework, a template, as it provides the roadmap for the economy.

A complication here is the tendency for governments to be composed of people richly talented in finance and the law but lacking that level of expertise in science. In the United Kingdom there is an attempt underway to put the science adviser concept into every department. It is obvious that scientific expertise is an advantage in dealing with health systems and agriculture, but it is also important to apply science in many other areas. Ireland does not yet have a science adviser and does not have the talent in science that the UK Government is putting in place, but I think it is important. In the US, science throughout the government is considered essential; almost every agency has talented scientists.

It is also important to recognise that, as you think about predicting the future, the structure of government departments needs to be capable of responding to the challenge and ministers need to be committed to the project.

There is some urgency. Speed is important if the nations of Western Europe are to compete effectively with countries such as China and India. Right now, each of these two economies has about 300 million middle-class, well-educated people; a huge base to compete with. This development is a good thing for the world as a whole and this type of competition and cooperation is generally good for economies.

During Ireland's transition from an agricultural economy in the late 1980s to a manufacturing economy, governments realised that there had to be major transformations throughout its society. These transformations occurred rapidly and Ireland's population adapted. The population rose from almost 2 million in 1960 to almost 4 million today. Instead of losing young well-educated people, who often went abroad to find opportunities, many are now staying and incomers are moving to Ireland.

Let me summarise what is happening in Ireland. First, there was the Foresight Technology process, borrowed basically from the early work in the United Kingdom. In Ireland we put this process together in 1998 and by the year 2000 it was clear that we needed to invest in its future. The decision was made to invest primarily in two areas, the information and communications sector along with the science and engineering underpinning both that and the biotechnology sector. We had the advantage of having a strong industrial base in both areas. The question was whether they could either go beyond that or sustain that for the future.

Importantly, there was political commitment to the project and, to make this all happen, the government has committed to invest €646 million in starting the Science Foundation Ireland (SFI). Before the SFI, much Irish funding came from European Union research programmes, while our universities competed against each other for funding and for links with European universities. We are trying now to find a better balance where the universities are working together.

In Ireland most of our universities are small and, rather than picking one or two and saying, "You are going to be the next Cambridge or Harvard", we are trying to build a system where the talent in the university system can serve all the people of Ireland.

We have committed over €200 million to approximately 80 projects and we have started three new centres for science, engineering and technology: the National Centre for Human Proteomics (based at Royal College of Surgeons in Ireland), the Alimentary Pharmabiotic Centre (at University College, Cork) and the Digital Enterprise Research Centre (at the National University of Ireland, Galway). These are clusters of industrial and academic researchers, interdisciplinary, internationally competitive and working on large-scale problems. It is never easy to get the universities and industries to work together, but that is our aim.

For these centres to thrive we have to create mechanisms that will enable the Irish universities to recruit and retain international stars of science, and to ensure predictable and sustained investment in university research. It is costly to bring in a significant senior investigator and it takes between €300,000 and €600,000 to set up a laboratory.

Being a small country makes it easier for us to experiment in this field. We have a quality control mechanism, we control the review and aim to identify the people we need and negotiate with them.

My message is to encourage the investments that are being made and to recognise that speed is important. We are in a competitive world economy, there are a lot of scientists out there and the successful economies will be those that make the correct decisions about which areas of science to invest in and identify and recruit the right people to do the work.

Finally, you have to make choices. No nation, certainly no small nation, can be good at everything. But if you make the investment in university research and have talented people going back and forth between universities and industry, it is possible to catch up very quickly in any given field. ❐

1. OECD Information Technology Outlook Survey 2000.
2. Standard and Poor' Healthcare: Pharmaceuticals Survey, 23 June 2003.

discussion

Civil foresight. The early UK Foresight exercise had been more important for the interaction of the people than for its product. There was now a problem in convincing people in big companies that they were not already all-knowing about issues likely to affect their businesses, while smaller companies often did not have the scientific capacity or manpower to take the process on board. It was important that the English regions became more involved in Foresight. Devolution had led to progress in Scotland and Wales. Traditionally, horizon scanning had been more used for defence and overseas policy purposes than by civil departments, but it was now recognised that there were equivalent challenges on the civil side of government. One was the demographic changes facing many Western countries. New Foresight projects could be selected by panels, within government, or by allowing groups of visionaries to brainstorm.

discussion

Scepticism. There was scepticism about forecasting, because of people's inability to foresee disruptive technologies. For example, no scientist would forecast that his discipline would disappear. People would miss spotting future trends that were against their interests and might emphasise possibilities that led to more research funds (global warming might fall into this category). One way of dealing with these problems was to use scenarios, which could at least help identify what gaps needed addressing. Evaluating the success of Foresight exercises was difficult, but could sometimes be achieved, as with the Thames Barrier.

Creativity, science, engineering and technology. How do science, technology and the arts interact in our modern world, and should this interaction be more creative? This was the topic of an FST discussion meeting at the Royal Society on 14 May 2003.

An amalgam of two cultures?

David Puttnam

The Lord Puttnam CBE is chairman of the National Endowment for Science, Technology and the Arts. He has produced many films, including *Bugsy Malone, Midnight Express, Chariots of Fire and The Killing Fields*, for which he has won many prizes. He is chair of Enigma Productions and has been a director of Anglia Television, Columbia Pictures and many other film companies and charitable bodies. He has served as a vice president of the Royal Geographical Society.

The relationship between science and the arts has often been, as C.P. Snow observed, one of two cultures, "and never the twain shall meet". Keats, you will remember, accused Newton of "unweaving the rainbow". In contrast, Nobel-prize-winning physicist Paul Dirac once said that: "in science you want to say something nobody knew before, in words which everyone can understand. In poetry you are bound to say something that everybody knows already in words that nobody can understand."

I am a passionate believer in the importance of cross-fertilisation between science and the arts. The development of just about every art form, from new forms of oil-based paint in the 19th century to new media art in the past few years, has at some time or another been liberated, even enabled, by scientific innovation.

There are several issues on which I would like to focus: first, the degree to which science and engineering are a "creative" process; second, the ability of science to learn from the arts; and third, the National Endowment for Science, Technology and the Arts (NESTA).

Cinema is a perfect example of how science changes the way we see and imagine the world: it is an art form that is a unique blend of commerce and culture. Throughout the history of cinema, technological and creative innovations have gone hand in hand: "talking pictures", the emergence of colour, the creation of special effects and the use of digital technology are just a few of these developments.

Equally, many of the most significant scientific "breakthroughs" have come about as a result of some creative vision or insight, which has overturned prevailing beliefs and assumptions, or found solutions in areas where nobody had previously thought to even look.

Architecture is a fine example of where the arts directly influence engineering. Leading practitioners, such as Frank Gehry, Norman Foster, Daniel Libeskind and Richard Rogers repeatedly challenge engineers to realise imaginative concepts which they have only sketched out in their heads.

How should the arts and sciences be meeting and combining, and why is this so important?

Today's increasingly "knowledge-based" economy — the exploitation of research, commercialising ideas, the transfer of learning — has its own needs and makes its own new demands. This was explicitly recognised by the chancellor, Gordon Brown, when he said in his spending review last July (2002) that, "invention and innovation are the key to long-term national competitiveness".

If you visit the Science Museum in London, you will see that about half of the world's "firsts" in invention since the industrial revolution were created in the United Kingdom. Yet we have been incredibly complacent about taking original ideas and turning them into products that are marketable. Time and again, other competitors have enjoyed the success generated by our inventiveness.

The way in which we should overcome this barrier is clear. We need to invest much more in people and teams, we need to stimulate and promote our extraordinary pool of creative talent. We have to generate productive activity by pursuing creativity and innovation through to production and into the global marketplace.

We need scientists and engineers who can be adaptable, apply their knowledge and skills in different and challenging contexts and bring genuinely creative approaches to problem solving. To achieve this, we need cross-cutting government policies which put real meat on the bones of the chancellor's commitment.

We need:

- A policy framework across all government departments, with adequately funded programmes and a streamlined regulatory structure;
- An education system that nurtures creativity and interdisciplinary thinking;
- Increased investment in R&D; we currently trail well behind countries such as Japan, the United States, Germany and France;
- Funders and investors from both public and private sectors;
- An improved system of intellectual property rights that stimulates innovation and investment by protecting the commercial interests of the rights-holders while not preventing others from accessing and using information and carrying out research.

A little of all of this is coming together at

NESTA. Established in 1998, NESTA was the first "national endowment". That endowment now stands at £250 million, built on two subventions from Lottery funds. NESTA's remit is to support the development of talented individuals and to promote creativity and innovation across science, technology and the arts.

We have three principal programmes. Our Fellowship Programme helps creative individuals who have demonstrated outstanding talent and originality, but who have not had the opportunity to develop their talent or to explore new creative territory. The Dream Time awards are designed to enable remarkable individuals to take time out and pursue hunches, things they could not do in the context of their current work. Our Invention and Innovation Programme helps turn ground-breaking ideas into innovative products, services or techniques, with commercial or social potential. Through this, early-stage investments are made to assist projects to get off the ground, and to prepare those making good progress to find further investment from elsewhere.

Our Education Programme helps to pilot innovative methods of creative learning and ways of fostering individual talent to improve people's understanding of, and engagement in, science, technology and the arts. Often working in collaboration with the private sector, this programme aims to develop and test approaches that have the capacity for wider application that may go on to inform and even transform mainstream educational practice.

We also ran Science Year (now Planet Science) for the Department for Education and Skills (DfES), which helped to raise interest and participation in science, particularly among children. Again in partnership with the DfES, NESTA Futurelab researches and develops innovative ways of encouraging learning through the use of emerging information and communication technologies.

NESTA is also working as a catalyst for creative and innovative work across science and the arts, with the intention of creating intellectual property that can be of real and sustainable value to the economy.

These approaches have enabled us to support projects such as Steve Grand's robot child, complete with a mind of its own. His current development, Lucy II, will have a more powerful brain, better eyesight and hearing and stronger muscles than his earlier experiments.

Brian McClave and George Millward are working on Aurora 2, a three-dimensional video of the *aurora borealis*, or Northern Lights, creating a large-scale projected art installation in which the viewer is immersed within this awe-inspiring phenomenon.

NESTA is developing new approaches to creative risk-taking by supporting projects which others have balked at. Over the next few years we will improve our support, in particular enabling some of the best art and design graduates to set up businesses. We also intend to promote a whole new world of best practice.

If the United Kingdom is to be a world leader in creativity, it must identify, reward and nurture those who are going to get us there. NESTA intends to play a significant part in this, by seeking out excellence and potential, empowering creators and innovators and taking informed risks on the unknown.

Unless we develop our capacity to innovate and take risks, our competitive advantages, our wealth of creativity, our imagination and inventiveness, all of these will come to nothing. ❐

discussion

Education. A principal theme of the discussion was the role of education in promoting creativity and innovation. The problems started in schools themselves, where too great an emphasis on fact-finding inhibited the development of problem-solving skills. But you had to build on children's competitive desires and create incentives using techniques which enable them to see results (which, of course, should be better than those of their competitors) quickly. Lego had some ideas.

Innovation in musical composition

Julian Anderson

Julian Anderson is composer in residence at the City of Birmingham Symphony Orchestra and head of composition, Royal College of Music. He started composing when he was eleven and studied at the Royal College of Music. His compositions include *Tiramisù. Khorovod and Imagin'd.* He is also active as a broadcaster and writer.

My title is intended to illustrate the relationship between tradition and new technology in music. Composers today wish to create something new, but we do not wish to alienate the audience. How do we achieve that?

It is great to discover new forms of music and to discover new forms of beauty that can be socially useful and, I hope, stimulating. There are three main areas we consider: acoustic situations and facts, the world around us and the sound of the world around us. The latter could include the sound that musicians make, the sounds of the natural world or machines or whatever, as well as the actual sounds. By analysing these sounds using electronic technology, we can discover what they are made of and re-create them through music.

When I write a piece, I am writing for people. For example, I have been asked to compose for a symphony orchestra, at the moment the City of Birmingham Symphony Orchestra. That means I have to write a piece of music that can function with 88 or, sometimes, up to 100 different musicians, playing music together. I cannot talk to those musicians so they have to understand from the way I create and notate what it is I am trying to do and to make the sounds that I hear in my head in such a way that the audience can sense what I am trying to convey.

Note that the composer must take account of the social situations in which the music will be performed. There are group activities, of which an orchestra is one, and individual situations, such as a soloist, or chamber music — smaller scale work.

My understanding of the creative process is that there is an initial conception that must be constrained by three different sets of considerations: extra-musical factors, traditions and habits within music and the means available to produce the sound — the technology, the instruments and the players. All of that is put together to create the work you hear.

Now, the work that you hear has one visual form, a score — if it is notated in the Western tradition — consisting of musical notes on paper. That score is a set of instructions for performers and at the end of the chain is the public reaction. All these aspects feed off each other. That is to say, when I am writing my next work, I ask myself whether the sound the piece made was the sound I had imagined, what was the public reaction to that it, how that related to what I had imagined, and so on. I cannot communicate with myself; I need to have a public to respond to.

Imagine the sound of some sea. This can be analysed by means of technology to produce what we call a sonogram. You can take fragments of the sound, selecting the most prominent ones or slowing down the sound. I can take a tuning fork and discover exactly what the frequencies are. We can sculpt the sound and use it to create harmonies and melodies.

I have used frequency analysis software to analyse not a neutral, natural sound but a real social situation from a ritual service of Ethiopian Jews, the Falasha community, which was recorded in the mid 1980s in Jerusalem. A leader sings a simple tune and the congregation of about 20 people all sing the same tune after him, but each slightly differently, resulting in a chaotic wave around the original melody. It is a very complicated sound produced by a real social celebration. It is not possible to analyse it entirely by ear so I had to use technology to pull it apart to see what it was made of.

I was writing a large orchestral piece for the London Promenade Concerts, a piece about the change of the seasons and collective celebration. I chose to take this extract and use the information about what frequencies were where, where things swirled, where they were less thick, where they were more thick and so on. I applied that information, sculpted it as it were, onto my own harmony and melody. This music is not meant deliberately to imitate the wonderful ceremonial, rather it is music that is inspired by it. Technology has been used to see inside the structure to convey to the audience the feeling that I got from that original ritual.

In conclusion, I should emphasise that the feedback of the audience is very important to the end-product. I cannot write music without believing that there is somebody out there who will react to it; and that is also important in influencing what I do next. The result is a constant and flexible feedback process between the technology, my instinct, the social situation I find myself in and am inspired by and the audience itself.

I should say that none of this marvellous technology is British. The sonogram program was developed in Paris, the sound program is American. These technologies have already proved very useful for commercial purposes, both for recording and, in the case of the sonogram, also for film music. There are many applications for this technology beyond the realm of art music. This technology is the product of collaboration between composers and scientists. That meeting point is crucial to the future of music in this country. The objective is not to dehumanise music but, on the contrary, to make it more human. ❒

discussion

Music. Music came up frequently in the discussion; many members being fascinated by Julian Anderson's analysis of sounds. But, alas, no member had suggestions for developing musical creativity. The importance of understanding sound as a component of design and marketing was noted and the effect of music in helping people understand emotional and mental states was observed.

Through innovation to productivity

David Hughes

David Hughes FREng is director general, Innovation Group at the Department of Trade and Industry (DTI). Previously he worked as special project director at BAE Systems. He has also worked for Ford, Lucas and GEC-Marconi. He serves on the CBI technology and innovation committee and the EPSRC Council.

The DTI is reviewing innovation and is, in particular, investigating what drives innovation and what effect innovation can have on productivity as measured by the rate of change of GDP. Although our review is only half complete, I will give you some clues to what is emerging from the findings of the many exercises and consultations we have been conducting.

Our starting point, or hypothesis perhaps, is that businesses in the United Kingdom will find it increasingly difficult to compete in low-cost labour-intensive goods and services against competition from Eastern Europe and the Far East. Therefore, businesses will have to look to increase the value-add of their products and services.

We have published *The Value Added Scoreboard*, based on the value added that companies are achieving. Very simply, "value added", is employee cost + operating profit + depreciation + amortisation. We have tabulated this for 800 British and 600 continental European companies and have reached some interesting conclusions.

Value added is a measure of wealth creation and does not differentiate between manufacturing businesses and those providing services. While we have a high employment level, the UK currently has more low value-added businesses than our major European competitors. In other words, in terms of value added, we need seriously to think about how we can improve our game. Businesses need to gather knowledge, to think creatively about the applications, to develop and to discussion

Academia and business. Doubts were expressed about the view that relations between academia and business were as difficult as had been suggested. The CBI statistics, on which such a view was based, were open to challenge and the position had got much better in recent years. But it was clear that better liaison was needed, particularly with SMEs. The Lambert Review (see page 3) should give some helpful ideas. Certainly, one problem was whether the universities' position on IPRs was beneficial to innovation. A major difficulty was that universities sometimes put a much higher value on their product than did the commercial world. The academic tended to see the world-beating potential of his discovery, while the company looked at what would be the sales in the short term. The Government's attitudes did not help. On the one hand they said all the right things about academia making a priority of knowledge transfer, on the other hand Margaret Hewitt was praising universities for being hard about keeping IPR.

commercialise their enterprise and to take it to market.

Innovation can occur at any point in that value chain. Innovation is not just about science and technology and not just about products, but can involve processes, new business models, clever ways of going to market and so on. There are many ways we can improve our value added.

Once we have decided where we want to get to, we have to determine whether our workforce has the right skills and capabilities. What many small companies find is that to bring their wonderful idea to the marketplace they may need skills other than they have and they need to establish how they can collaborate.

In our work, we have also discovered that Intellectual Property Rights (IPR) are important to innovation in the business environment. In a fast-moving business such as games software, patents may be less relevant; you will be on the third generation before you have the patent, so a trademark or branding is important. IPR covers patents, trademarks, copyright — there are areas here where we could probably communicate more helpful information to businesses.

Regulation is critical. At present, there is a lot of prescriptive European legislation. We want to make that outcome-based, encouraging creative innovation.

Public procurement is a very large part of GDP and government procurement, in turn, is a large part of that. Can we take the same kind of idea forward? Can we make our specifications output-driven, encouraging industry to find novel ways to achieve specified outcomes?

The whole delivery system to businesses is central to success. We need to coordinate and focus all the regional agencies, between departments, the Department for Education and Skills (DfES), DTI and so on so they can help businesses find the best way to develop and grow. There are numerous areas we could discuss, but I am going to concentrate on three: technology, finance and design.

Generating and sourcing new knowledge underpins modern economic systems. The British science base is very strong, but there is ample evidence that this strength is not being pulled through into applications. Although government investment is increasing, industrial R&D as a proportion of our GDP is well below that of the Organisation for Economic Cooperation and Development (OECD) average. When it comes to university/ business collaboration, we are often told that business people and academics do not speak the same language. My colleague Richard Lambert is conducting a study of small to medium employers (SME)/university links, which are known to be patchy and difficult to forge.

There is also concern about IPR. University inventors have a high opinion of what this IPR is worth and I can think of several examples where significant industrial companies have walked away from collaboration with universities simply because their perception of the value of IPR is not as great as that of the inventors. We certainly have to act in that respect. We place a lot of emphasis on spinouts, but what about working to encourage the licensing of the IPR in universities to established companies? What can we do to forge links with established companies?

Importantly, we have found that, although we have all sorts of schemes (particularly in the DTI) to support various programmes of R&D, we lack technology strategy. Our competitors, who are ahead of us, have very clear top-down technology strategies that appear to drive the exploitation of their science base.

In the United States in the early 1990s investment was heavily focused on communications, telecoms, computers and IT. That investment paid off dramatically. America is continuing to focus on advanced technology, including, interestingly, technologies for service industries. They are encouraging collaboration between industry and universities in selected perceived critical technologies. Much the same is happening in other developed countries.

If we can foster collaboration between universities and industry, we shall be able to work more closely with the research councils, but first we must decide what technologies to work with; we shall also need a body of scientific industrialists who can interpret and work with the science base.

We have already put together such a programme in one field — nanotechnology. We have created a programme of collaboration between much of the academic base around the country, Regional Development Agencies (RDAs), regional groupings and a number of large industrial companies. This network is largely funded by the RDAs, while industry has put in its IPR and some money. This is a good start and may be a model for future projects. Increasing value add will often require development of new products and services, but often companies (as well as people) find financing difficult. Venture capitalists, concerned by the

discussion

Finance. The difficulties companies found in financing innovative developments were acknowledged by a number of speakers. Venture capitalists were not interested in taking risks; the NESTA schemes might help. But there was strong criticism of the numerous small DTI schemes: they were too complex, too small and of little use to SMEs. The 1970 scheme was better: fewer, bigger, simpler schemes were needed if they were to be of any use. It was important that EU funds from Framework 6 went more to industry (as with our competitors) than to universities. The DTI must take care, if a national technology strategy were developed, to tread the narrow path between choosing priorities and attempting to pick winners.

discussion

Specialisation. The problem of the narrowing study for A levels was discussed. Was there a need for a foundation year at university where budding engineers and scientists could study with, say, architects to widen their horizon? It was pointed out that such a year would be equally valuable — indeed possibly more so — for arts and humanity students. Alternatively, such a year could come between graduation and starting professional work These suggestions met with the serious objection that the whole of education, and government policy towards it, was determined by utilitarian objectives: gaining core skills which would enable the student to make a focused contribution to the economy through employment as a lawyer, accountant, scientist or engineer.

bursting of the dotcom bubble in the late 1990s, are moving to later stage investments. We have seen a gap emerging at the £0.5–2 million funding level.

I shall concentrate on finance affecting small companies which (particularly if they are start-ups) face market failure in raising capital. We need to find incentives for both individuals and companies to invest more widely and actively in R&D at this level. An interesting source of funding could be small business investment companies for which the chancellor, Gordon Brown, announced a consultation in the Budget earlier this year. The Government could help in a number of ways: R&D tax credits are already providing powerful incentives for SMEs by actually providing cash back for R&D activity. We have some more ideas for enhancing the R&D tax credits.

Lastly, design is tremendously important. A new product does not necessarily incorporate novel technology. Each time Sony put a new Walkman on the market, there is not necessarily new technology, but there is creative design that makes it a fashion icon. Design delivers innovation, it connects the technology to the market place and it adds value. For example, Aqualisa, well known in the shower business, created a clever and elegant shower, specifically designed to be installed quickly and easily. The product exceeded all sales targets. We need to persuade people and companies of the benefits of good design.

DTI is now running courses such as “Living Innovation” which has three themes: inspire your workforce, help them to create designs and “connect them to the market place”. A very simple concept: inspire, create, connect.

Government can assist in all these areas, but we also have to address management skills. Do we have the capability to lift our game to a new level and to continue lifting it, because this is not a one-off change? We expect to report more fully later this year with recommendations for Government action. ❒

Creativity in teamwork

Robert Hawley

Dr Robert Hawley CBE DSc FRSE FREng is an advisory director of HSBC Bank plc. Beginning as an apprentice for BICC he rose to become managing director, in 1976, of NEI and in 1992 chief executive of the Rolls-Royce Industrial Power Group. Dr Hawley was chief executive of Nuclear Electric until 1995 and of British Energy until 1997. He is past president of the IEE and past chairman of the Engineering Council and the Particle Physics and Astronomy Research Council.

Some 45 per cent of the United Kingdom’s growth is derived from applications of technology, and engineers play a pivotal part. As David Puttnam has said, the Government’s role in creativity is to ensure an effective science base and the right environment to enable well-run companies to innovate.

Today’s engineers are either leaders or members of a team and their work is often not overtly evident. It is often impossible to tell the difference between engineers and scientists. So where do innovation and creativity come into such a combined team approach?

I begin with some simple definitions: creative, having the quality of creating; innovative, to change into something new; design, the preliminary concept of an idea that is to be carried into effect by action. The transformation of basic science into a wealth-creating product is a process carried out by teams whose members cover many disciplines. Creativity drives the whole process. Designers have to work within costs and have to keep manufacturing processes in mind.

That is not to say that the design of a bridge is not creative but that creativity needs to be redefined in the team sense. James Dyson is quoted as being bothered that a recent list of creative professions failed to put engineers alongside film makers, publishers, fashion designers and the like. That is outrageous; engineers create real things. To quote Geoffrey Crossick, chief executive of the Arts and Humanities Research Board: “the issue now is not so much building bridges between the creative arts and technology as it is recognising that much of the creative arts are rooted in technology which makes possible new concepts of the creative process.”

Designs arise from a creative response to a need and that requires the ability to think laterally, to anticipate and to appreciate the aesthetics of problem solving as well as material aspects. In today’s high technology world, engineers need to be creative.

My own experience in the world of heavy engineering, in the power and the construction industries, includes projects such as the building of Sizewell B power station in England, the Rihand power station in India and the Greenwich Millennium Village project adjacent to the dome.

These are good examples of everyday engineering that are hidden from the PR view. Creativity is needed via teamwork within the project team itself but also between that team, its suppliers and its

discussion

Culture. Creativity was a matter of culture; a belief that it was worth taking risks and that one could learn from other people in apparently unrelated works of life. The Bloomberg offices, which encouraged open communication, networking, sharing and "fun" were described as being conducive to creativity. But would the UK personnel like working in such conditions? If we were serious about creativity, efforts would have to be made to encourage a culture of much more open and interactive working.

contractors. This creativity constantly needs to be applied by engineers in developing and managing a major project.

As a group, engineers are taciturn, hardheaded and uncompromising about standards. They are at ease only with tangibles. Contentment comes with that which can be measured, quantified, objectively evaluated and monitored. Even so, creativity and innovation are needed at all stages of a major project.

Sizewell B nuclear power station is an outstanding example of the professional, creative project management that requires total obedience to design and safety codes. First conceived in 1980, it necessitated one of Britain's longest public inquiries which lasted 340 days before consent was given. Construction started in 1988 and the station began supplying electricity to the national grid in 1995.

One of the biggest civil projects in Britain, it was completed on time and on budget. It involved a multidisciplinary team of thousands of men and women, working for Nuclear Electric, 32 main contractors on site, 21 sub-contractors and over 3,000 suppliers of equipment and materials.

The building of the Rihand power station in the state of Uttar Pradesh in India, 750 kilometres southeast of New Delhi, threw up completely different challenges. At the start of the project, there were no infrastructures, services or facilities of any kind. Problems relating to the remoteness of the site were compounded by the climate. The weather pattern is of two extremes: for most of the year it is very hot and dry but, between July and September, the torrential rains and resulting floods frequently cut off road and rail links and turned the construction site into a sea of mud. The surface temperature of the lake supplying the cooling water to the station varies from 16°C to 40°C. There was no telephone connection for the first five years of construction. Any messages had to be carried by car to the local office for onward transmission and the journey could take between 5 and 12 hours.

The shortage of modern construction equipment meant the use of traditional labour-intensive methods and the employment of 9,000 labourers; mainly female migrants from district regions, who lived in the most primitive conditions on site. Throughout the entire construction period, only one tower crane was used (compared to12 at Sizewell). Creativity was much needed as a problem-solving tool.

The project also involved coordinating the work of 38 main sub-contractors who, in turn, dealt with over 2,600 individual suppliers. The overall project necessitated the supply of over 1 million engineering drawings, 4,000 design submissions, 3,500 manufacturing field quality plans and over 75 tons of correspondence. More than 2 million shipping movements were monitored; over 1 million tons of concrete were poured on site.

Three examples of creativity, two by engineers on the site and one by the local Indians. One day, work stopped because of a shortage of steel scaffolding; in response, the site manager took a truck, cut down lengths of bamboo locally and work continued. When the first shipment of distribution transformers arrived on site, it was found that they had been drained of insulating oil during the train journey — the Indians used it as cooking oil. For the next shipment, the problem was overcome in a creative way by putting labels on the transformers that read "contents radioactive".

Large diameter pipework was shipped to India with the inside protected from corrosion by sealing the ends with wooden discs approximately a metre in diameter. One day, I was alerted to the fact that these pipes had arrived at the site with rust inside; on examination, I found that the wooden end covers were missing. Backtracking down the road, I found at the rail yard there were a number of wooden houses built from round 1-metre wooden discs!

Greenwich Millennium Village is an excellent example of creative teamwork, involving engineers and architects in partnership with suppliers. To implement the futuristic design of this village, advanced solutions in the use of materials, energy-saving methods and construction methods were developed by the project team. Central to the sustainable plan was the bringing together of economic, social and environmental innovation. These innovations are typified by an increasing emphasis on energy and water saving, prefabricated construction to reduce waste and the use of information technology, both during construction and occupation.

Combined heat and power, improved building insulation and better heating methods achieved a 65 per cent reduction in primary energy consumption. A 20 per cent reduction in water consumption was achieved by using better devices in the homes and also grey-water recycling, that is, taking bathwater and recycling it for use in toilets and so on.

Science is the search for understanding, engineering the search for compromise, the arts and humanities the search for expression. The common thread between engineering and creative arts is thinking and making. Engineering courses are too overloaded to allow scientists and engineers time to study arts and humanitarian subjects. Whilst being creative, engineers must obey design rules and have the experience to interpret them. We need to change our education system to ensure that young engineers rapidly gain the experience they need so they can apply themselves to the creative aspects of engineering design. ❐

discussion

Foundation year. Was there a need for a foundation year at university where budding engineers and scientists could study with, say, architects to widen their horizons? It was pointed out that such a year would be equally valuable for arts and humanity students. Another suggestion was that such a year should come between graduation and starting professional work. But all such suggestions met with the serious objection that the whole of education, and government policy towards it, was determined by utilitarian objectives — gaining core skills which would enable the student to make a focused contribution to the economy through employment as a lawyer, accountant, scientist or engineer.

Can the science curriculum in secondary schools prepare young people both to be citizens in a technical world and technical specialists? In a discussion on 20 May 2003 at the Royal Society, organised jointly by the Foundation and the Association for Science Education (ASE), most attention was given to a curriculum being designed for 14-16 year-olds at the University of York.

Bridging the vocational divide

Ken Boston

Dr Ken Boston AO is chief executive of the Qualifications and Curriculum Authority (QCA). He was previously managing director of Technical and Further Education, and director-general of Education and Training, in New South Wales, Australia. His previous positions include director-general of education in South Australia. In 2001 Dr Boston was made an Officer in the Order of Australia. He is a Fellow of the Royal Geographical Society.

Life, the Universe and Everything is the title of a book by the late Douglas Adams, who was described as thinking like a scientist, but being much funnier. The title epitomises what those of us in the curriculum and qualifications business feel when faced with the several conflicting challenges of science and technology. But the title is also a reminder that we need to convey to young people that science and technology can be fun.

My subject, however, is serious. Our goal at the Qualifications and Curriculum Authority (QCA) is to ensure that society gets the curriculum and qualifications it needs. The sheer success of science and technology has sharpened the challenges we face, which are:

- How can scientists and technologists, aided or hindered by journalists, communicate effectively to non-technical people, as well as to journalists and broadcasters, information about complex issues on which democratic societies require decisions?
- Are there pathways within the curriculum that cater for potential specialists in their fields of study, for those entering occupations drawing on the same body of scientific knowledge and for the rest of us, who need basic scientific literacy to be able to understand the ethical and political issues thrown up by scientific advances?
- How can we ensure that there are sufficient scientists and technologists to meet growing demands for their services?

On the last point, we have a long way to go. Sir Gareth Roberts' report last year, *SET for success*, made that clear. But we have also come a long way, with the national curriculum and with the qualifications framework, which help to meet some of these challenges. The national curriculum gives an entitlement to all learners in schools. It enables them to follow a balanced science course up to age 16, which has removed the pre-existing gender bias when girls chose to study biology and boys the physical sciences.

In the national tests in science for 11-year-olds, 87 per cent reached the level expected in both the past two years, which is better than in English (75 per cent) and in mathematics (73 per cent). International comparisons show that students in England at age 15 are near the top of the league in scientific literacy.

On qualifications, 90 per cent of 16+ students take two or more GCSE (General Certificate of Secondary Education) examinations in science and most attain good grades. We are also broadening the range of subjects students can study and win a qualification. Last September, for example, teaching began of a new GCSE in applied science. There have also been encouraging reports from schools' inspectors of the impact of innovative teaching. The experience of vocational A levels, introduced in 2000, has been positive; we will be making changes to their structure so that standards can be more easily related to other A-level qualifications.

In both these developments, there is evidence that teachers recognise the value of applied approaches to the subject for the more as well as the less able students. The QCA, similarly, is encouraging the updating of science AS and A2 qualifications. Some recent arrivals include an up-to-date physics course from the Institute of Physics and Salters-Nuffield advanced biology from the Nuffield Foundation, while we are expecting proposals from the Institute of Materials that we shall consider for accreditation.

So I return to the central problem. Despite the achievements of recent years, the problem remains of enthusing and inspiring sufficient numbers of young people to continue studying science and technology. It is a major challenge not only for the QCA but for all who teach, write, publish and broadcast support materials. There is no easy solution. What I have to say is more speculative than definitive.

Young people themselves are put off science for several reasons, weighted according to ability, age, gender and so on. Some students may find that what is taught is not relevant to them, but relevance is a highly subjective notion. Not everything that is exciting in science is immediately applicable, but just tacking onto the curriculum things that might be useful or relevant does not guarantee that a young person's interest will thereby be captured.

The difficulty stems in part from the nature of science. The truth is that the results of scientific research and technological innovation are hard won; nature does not yield its secrets easily. A further complication, as Lewis Wolpert has reminded us, is that much of science is far from being common sense. Indubitably, becoming a scientist or a technologist requires a long and demanding apprenticeship in the broadest sense. Teachers must, therefore, bring the excitement and fun of science to the fore in their teaching.

Another difficulty is dealt with in the Roberts Report, which argued the need for more subject-specific support for science teachers, many of whom are required to teach outside their subject-specialism. There is, for example, an acute shortage of physicists in schools. At Key Stage 4 (14-16), two-thirds of those teaching physics do not have a degree in a related subject and nearly half of them do not have a physics A level. At Key Stage 3 (11-14), the situation is worse, contributing to limited progress reported by Ofsted.

What are we doing about it? We are working with the Government and with others on several fronts.

Thus, with the Department for Education and Skills (DfES), we have a strategy to improve teachers' subject and pedagogical knowledge in science: the programme was launched last year. It requires science departments to carry out an audit of their strengths and training needs, for schools to decide their priorities for training. Training is then offered across all Local Education Authorities by consultants. Evaluation of the first year suggests that teachers have been invigorated and science laboratories have become more interesting places in which to learn.

On the curriculum, three years ago the QCA launched the project 21st Century Science by commissioning research from curriculum developers and assessment agencies on how the science curriculum can involve all students. The objective has been to devise a common core of science for all while offering ways of engaging the interests and future needs of different groups of students. The main outcome of that work is a suite of three GCSE science qualifications that will be piloted in 80 centres from this September. Work on this was commissioned by the QCA from the University of York; Professor Holman will have more to say about it.

The proposed common requirement for all students aged 14-16 is expressed in broad terms. Central to it is the understanding of what it means to be scientific, which includes practical skills, knowing how scientific data are interpreted and studying the impact of science on the world in which we live. Thus the curriculum includes the requirement that, "all students should be taught, for example, that radiations, including ionising radiations, can transfer energy". Such statements are, of course, amplified to show the standard of learning expected in the core.

Students can complement the common core with extra science. Such flexibility should provide alternative progression routes beyond 16. Our proposals are out for consultation; the course can be found on our website[1].

One of our objectives has been to end the division between academic and vocational qualifications.We have produced a common framework for all qualifications so that standards can be compared. I conclude with the observation that the expectations of science place considerable burdens on science education. The system must educate potential scientists to a high standard, provide a range of technical education and give everyone basic scientific literacy. The QCA is but one of many partners in this endeavour. We recognise that an enormous amount remains to be done, but we relish the prospect of working with our partners to add to the stock of Britain's human capital. ❐

1. www.qca.org.uk

A science curriculum for everyone

John Holman

Professor John Holman is professor of Chemical Education at the University of York. After studying natural sciences he became a teacher of chemistry before working as a writer and science education specialist. In 1994 he became Head of Watford Grammar School for Boys, where he continued to teach chemistry. In September 2000 he moved to York, where he is also director of the Science Curriculum Centre.

I begin with a warning and a reflection. The warning is that we have had a national curriculum in this country only since 1988. Britain is not alone in having a national curriculum but we have a particularly vigorous form of it: not only does it define the curriculum, but the accompanying assessment arrangements. When you combine that with league tables of school performance and school inspections that hang on assessment results, it becomes a very powerful — one might even say a virulent — form of national curriculum. There are, of course, advantages: things can be made to happen. But the circumstances prompt questions about the use of these levers of power, and by whom.

My reflection is that the universal science education that we have is very new. It is not like mathematics or English, which have been taught as part of compulsory schooling for many years. So naturally we are still asking "What should be in the curriculum?" and, "Who should decide?" The result is that the curriculum has been based on what went before which, for science, was designed for future subject-specialists. So the interests of those who would study science for A level and at university have been the dominant influence on the curriculum.

Who should decide what goes into the science curriculum? It should not just be scientists, science education specialists or teachers alone. Not even the general public nor even the students themselves should be the deciders; none of these groups on its own should call the shots. That should fall to all of them in concert, for are we not all now consumers of science education?

In my project, we have consulted widely among all the constituencies listed and many others. They will be represented on the advisory committee for 21st Century Science, which Sir John Krebs will chair, together with science communicators, professional science writers, specialists in the public awareness of science, representatives of NGOs and of the National Federation of Women's Institutes. (The last has a tremendous interest in science education for the general public and is an excellent source of informative views.)

The reason we must consult so widely is that science education has to perform different functions for different kinds of youngsters. The problem is acute at Key Stage 4, when 14-16-year -olds preparing for GCSE begin to decide on careers. A differentiated science curriculum is then essential.

Until I left three years ago, I taught science at the Watford Grammar School for Boys which, despite its name, is an all-ability school. The students were, indeed, all different, especially in their career aspirations. But they, like 80 per cent of youngsters in this country, were all following the double GCSE-award combined science course, spread across physics, chemistry and biology. They were all looking for different things from their science, but they were all studying the same course.

That is one of the things that 21st Century Science seeks to remedy. The science curriculum now has a dual mandate: to provide basic scientific literacy for everyone and to give youngsters a preliminary training in science, whether specialist or vocational. And we must remember that the first group is a minority.

21st Century Science has its origins in a widely acclaimed report called *Beyond 2000,* commissioned by the Nuffield Foundation[1], which proved to be an influential definition of what the science curriculum could and should be doing. In October 2000, the QCA asked us at the University of York to suggest possible models for Key Stage 4. The outcome is the course that is being piloted in 82 schools from September 2003.

The dual mandate explains how 21st Century Science is constructed. The element common for all students, core science (the equivalent of a single GCSE certificate), is a course in scientific literacy that everyone will take. But we expect most youngsters to take an additional science, perhaps because they want to go on to do A levels or because they want to prepare for a specific vocation. We are providing the options that the youngsters from my school needed but did not have.

The flavour of the core science course needs further description. One of its aims is to lay the foundations of scientific knowledge and an awareness of the way science works, so that people become critical citizens. Here is an illustration. When you walk into a supermarket these days, you see a lot of information about organic foods, and then you see a newspaper headline proclaiming that organic food is a waste of money because measurements do not show detectable differences between pesticide residues in organic and non-organic food. The contrast spells confusion, but also raises fascinating questions about how the measurements were carried out, whether the samples examined were sufficiently representative, whether the absence of pesticide residues in food is the acid test of organic farming's benefits and so on. I would like my students to be reading newspapers critically, picking out the kind of comments that I have been making.

By science explanations, we mean the big ideas of science. We have singled out 16 of them: the idea of a chemical reaction, the gene model of inheritance and so on. Equally important in core science is the way scientists work: how they use data (and whether and when they can rely on them), correlation and cause, the role of theories, the way the scientific community works, the way society makes decisions using science. Those are the foundations of our core science.

For the trials in 2003, there are nine modules in core science that the youngsters will study. Through them, they will learn about the 16 science explanations and the ideas about science. They span some of the major areas of science and technology that impact on people's lives.

Young people interested in continuing with science would follow the Additional Science General topic, again made up of nine modules, which are spread across chemistry, physics and biology. Indeed, this topic includes more chemistry and physics than biology, while core science is weighted towards biology. That reflects the kinds of topics people encounter as citizens.

If youngsters want to prepare for something more work related, they can choose three modules from the applied group which include lifecare, which is about first aid and elementary medical procedures, plant products, scientific detections, the chemical industry, communications and materials and performance.

All this work is underway. We are preparing books and computer materials, QCA is working closely with the awarding body, Oxford Cambridge and RSA Examinations, so that schools can be confident their work will lead to a properly accredited qualification. This work is funded by the Nuffield Foundation, the Salters Institute and the Wellcome Trust.

Finally, I am very glad that QCA has decided that this must be carefully piloted and evaluated before we impose it on the world at large. And when Science for the 21st Century is available, I want to be quite sure that schools can take it or leave it. Curriculum development is, after all, a continuing process. ❐

discussion

Practicalities. The broad approach of the York curriculum was generally welcomed, but there were many concerns about its implementation. Could the factual content of the courses be so reduced that there would be time for the discussion and problem solving rightly advocated? Could testing capture these aspects of students' learning? Schools were skilled at helping their students get good marks in tests, but could testing be adapted to the new kinds of learning that will be required?

More broadly, might there be a danger that teachers would study the tests and ignore the new curriculum's aim of cultivating a wider interest in science and technology? Could a general parity of esteem between those following academic and applied courses ever be achieved? How would ethical considerations, central to many adolescents' interests, be brought into the teaching? Where was creativity?

These doubts and fears were vigorously challenged by others in the audience. Assessment was indeed crucial to the new agenda, but there was no reason to fear that tests could not be devised to assess students' thinking about wider issues other than knowledge of the facts. GM foods, for example, could not be discussed without raising questions of civil disobedience and the needs of the developing countries. *In vivo* biology inevitably brought up the issue of animal experiments.

The problem for the teacher was to direct discussion objectively, for the examiner to assess the way students related facts to values without regurgitating strongly-held (and possibly mistaken) opinions.

In reply to a question about the place of psychology in the new curriculum, a platform speaker said it would feature in modules on the brain and mind, but also in curriculum material on the scientific method — how to use data and not deceive oneself. In the same vein, the emphasis on problem-solving would be the fulcrum of creativity.

1. Osborne, J. & Millar, R. (eds) Beyond 2000 — *science and education for the future* Kings College, London (1998).

The view from the classroom

Sue Flanagan

Sue Flanagan, deputy head-teacher, Forest Gate Community School, Newham and chair of the Association of Science Education (ASE), has taught science in East London comprehensive schools since 1982. She has been a teacher, Head of Science, a Science Advisory Teacher and Key Stage 3 manager in various schools and LEAs. At Forest Gate she teaches GCSE science and astronomy.

To fulfil my brief to provide a perspective from the classroom, I have consulted my students and colleagues at school, in the Association of Science Education (ASE) and elsewhere. We all agree that science education in a changing world needs a curriculum that connects. Science is important because our society requires sophisticated choices. School science is crucial for success.

Can there be one answer? We have a wide variety of students with individual interests, needs, backgrounds and aspirations. We seek to provide a relevant curriculum for all, which calls for flexibility. The curriculum should help to shape attitudes and values and we want these to be positive and useful.

I reiterate Professor Holman's point that we have a lot to celebrate. We have science for all to 16; we are now looking at children engaged in science in primary schools and even in reception classes. I do not believe there is another country in the world where that is done. But we must be careful that we do not lose what we have won. Before the national curriculum, there were commonly restraints requiring young people to drop important subjects that they later would have found useful.

One of the comments I most often get from people is that science needs to be more fun, more exciting. Part of the trouble is that we do not have the time to fit everything in. Instead of charging through the curriculum towards the test, most of us would like to cut back on content to allow time to present science in a more engaging way, spending more time on the exciting bits, developing themes and encouraging a better understanding of the issues, with more discussion and dialogue. We do not always have the scope, time or money to do what we want to do.

The content of what is written in the curriculum may be plain, but there are lots of things that can be taught through science, which is a gateway to engagement and further learning. We can reinforce positive attitudes to science and technology and develop a good understanding of the issues. Science education has also, for a long time, been looking at ethical and moral issues, which crop up across the science curriculum. In that spirit, it is good to see the value of education for public understanding of science being recognised at Key Stage 4.

What we really need are manageable schemes appropriate for our students. It is a shame that many engaging practically-based courses have been displaced by the national curriculum. Not every child is aiming for an A* grade, but virtually every child can have his or her interest developed when given interesting material, time for discussion and developing ideas, practical work and well-chosen investigations. In trying to include everything within the curriculum, we have sometimes forgotten the students for whom differentiation or simplification of the existing GCSE is insufficient. But it is pleasing to see the range of models proposed for Key Stage 4.

We ought to prepare students better for GCSE as well as for the AS/A2 that follow it. In 2002 the Science Museum surveyed 16-19-year-old visitors, seeking views on science education. Seventy per cent of them believed practical and experimental work helped them to understand science topics, 47 per cent felt that there should be more emphasis on understanding why things work rather than how. More than half felt that GCSE science tested memory more than understanding. These comments from young people who had been through Key Stage 4 are surely important when considering a future curriculum.

Not everyone who studies science at school wishes to study science at university, so that it is good that the AS/A2 sciences are recognised as valuable even to young people not intent on a scientific career. We have heard how AS/A2 has been broadened by means of different syllabuses. My plea is that non-specialists should be as engaged, enthused and challenged by them as are the specialists.

discussion

Infrastructure. There was much concern that the new curriculum would strain the infrastructure of schools. There was already a shortage of technical assistants (who had a special skill), while the state of many school laboratories was deplorable. Already, schools were skimping on practical teaching. Where were the funds to rectify this situation?

If young people are to see the point of science, there must also be some kind of connection between school science and the real world. When young people meet real scientists, they are often taken aback by their normalcy — in contrast with images often seen on TV and in the press.

Work experience has a part to play here. We need to provide opportunities for young people to work in a scientific setting outside school. Geography can be a hindrance, so can be considerations of safety for 15-year-olds, while the standard 2-week work-experience period may be too short.

Children love to engage with problems, but such activity is often limited to science clubs. That is another argument for making the curriculum less demanding of time. Many of us feel that the bureaucracy of assessment limits the time available to carry out valuable and interesting work. Creativity needs to be back on the agenda.

Again, in that survey at the Science Museum I referred to, a majority of the young people believed that controversial subjects such as genetic engineering and cloning should be in the science syllabus and thought they should be introduced before age 16. They are already there, but frequently there is not enough time to discuss and develop these issues while covering the GCSE syllabus. My students find such issues relevant. They also promote interesting discussion and can lead to a better understanding of the science behind the issues. Yet it can be hard to fly with such topics in a way that truly develops the science beneath for lack of time.

The influence of assessment on teaching styles cannot be denied. Nevertheless, teachers are willing to engage in curriculum development, especially when it supports the learning and the future life chances of their students. But we shall not move forward if the assessment regime does not develop with it.

I agree with John Holman that the science curriculum should not be decided by any one group. But sometimes people feel that the curriculum is imposed rather than consulted upon, which is why the present consultation on Key Stage 4 is extremely welcome, as is the reduction of content. It is good to see a variety of models proposed, but should we really be deciding on courses before the pilot has started?

Is there any other profession the size of the teaching profession that has so successfully implemented change over the last few years? But nobody in school resists the principle of accountability. We are accountable by what parents want for their children, by what our children want and expect and by our examination passes, which sometimes force us into teaching against the grain. The role of a teacher is complex and multiple. It is not just about a subject; we are educating young people for the world of tomorrow, all of them with different aspirations. We must do our best to give each individual the skills, knowledge and understanding to engage fully with a future rich in science and technology ❐

discussion

Inspiration. Several speakers recalled that they had been drawn to scientific work by inspired high-quality teaching. How to get such highly qualified and inspired teachers into classrooms? What science graduate, faced with student debt and the prospect of less demanding work and higher salaries in industry and commerce, would want to teach? What school leaver interested in science would follow in higher education a course leading to employment in a poorly rewarded occupation?

There was only one answer: teaching must be made rewarding not only financially, but intellectually and emotionally. Too narrow a curriculum hindered good teaching. Many speakers held that the new curriculum would improve the situation.

science, clinical research and the NHS

On 6 November 2003, during a Foundation visit to Addenbrooke's NHS Trust Hospital, Cambridge, participants were able to meet leading researchers and the interface between science and the treatment of patients. Sir Geoffrey Chipperfield reports on the visit.

A visit to Addenbrooke's Hospital

At a Foundation discussion meeting on 30 April 2003 on medical research (*FST Journal* Vol. 18, no.1), participants had laid stress on the need for clinical research to be conducted through the National Health Service (NHS). The Foundation arranged a visit to Addenbrooke's NHS Trust Hospital where those leading clinical research at the hospital were able to demonstrate the importance of their work and how it melded with the priorities of the NHS.

A formidable array of scientists and clinical researchers (Professors Sir Keith Peters, Chatterjee, Compston, Ponder and Pickard) gave vivid examples of the clinical research being carried out at Addenbrooke's, described the immense value of the dedicated Wellcome Clinical Research Facility and extolled the unique "laboratory" that the NHS provided.

Researchers needed the statistics, which only networks of clinicians, asking the right questions and observing treatment, could provide. Patients needed the specialist centres where researchers could provide expert and innovative treatment. For both these groups, the NHS was essential. Addenbrooke's, closely associated with the scientists at Cambridge University, the teaching and research strength of the Cambridge School of Clinical Medicine and other bodies, was an exemplar of how science, research and patient care can work together. All that was needed were more — and ring-fenced — funds; surely there was enough in the huge NHS budget to provide them? The benefits must be obvious, not least the savings that would result from cheaper treatments, or more useful diagnoses.

It was difficult for participants in the discussions to give the speakers the challenge they might have hoped for. Too many of them were wholly in agreement with the essential need to develop clinical research, build on the collaboration of scientific, charitable and hospital resources and see ring-fenced resources devoted to clinical research.

Speakers tended to concentrate on why past efforts to ring-fence funds had failed and how better tactics might be devised. It was a pity that there was not an authoritative statement of how the NHS viewed clinical research among its priorities, whether managers in the system welcomed the idea of yet more ring-fenced funds and how building networks and developing specialist centres, with transfers from other hospitals, meshed with developing financial and other strategies (including foundation hospitals).

Advocates for more funds for clinical research would have a stronger case if they acknowledged that cash must come from somewhere within existing budgets and not assume that the sum was so small that it could easily be found. To assert that sufficient cash savings would come from different treatments or better diagnosis was unconvincing as these could equally lead to lengthier treatment or increased demand. ❒

events

Recent lectures and dinner/discussions organised by the Foundation are listed below. Sponsors, to whom we are very grateful for their support, are shown in italics below each event. Summaries of these and other events are available on the web at www.foundation.org.uk

2 December 2003

The Lambert Review and the DTI Innovation Review

Mr Richard Lambert, Chairman, Lambert Review for HM Treasury
Mr David Hughes, Director General, Innovation, DTI
Sir Colin Lucas, Vice-Chancellor, University of Oxford
The Lord May of Oxford OM AC FRS FMedSci, President, The Royal Society

BTExact, Fugro GEOS, Momenta, Qinetiq and Particle Physics and Astronomy Research Council

25 November 2003

Energy policy: the renewables targets

Dr Bernie Bulkin, Chief Scientist, BP
Dr Malcolm Kennedy, Chair, Energy Working Group, Energy Innovation and Business Unit, The Royal Academy of Engineering
Ms Claire Durkin, Director, Energy Policy Innovation and Business Unit, DTI

BRIT, National Environment Research Council, and The Royal Academy of Engineering

18 November 2003

Nanotechnology: threats and opportunities

The Lord Sainsbury of Turville, Minister for Science and Innovation, DTI
Professor Sam Stupp, Professor of Materials Science, Chemistry and Medicine, Northwestern University, USA
Professor Stephen Holgate FMedSci, MRC Clinical Professor of Immunopharmacology, School of Medicine, University of Southampton
Professor Ann Dowling CBE FRS FREng, Chair, Royal Society and Royal Academy of Engineering Study of Nanontechnology, University of Cambridge

Council for the Central Laboratory of the Research Councils and QineitQ

11 November 2003

Does manufacturing have a future in the UK?

The Lord Haskel, House of Lords
Mr Simon Edmonds, Director, Material and Engineering Sector Unit, DTI
Mr Tim Woodbridge, Chief Executive, Webdynamics
Professor Mike Gregory, Director, Institute for Manafacturing, University of Cambridge

Aerial Facilities Limited, SEMTA and the Textile Institute

6 November 2003

Visit to Addenbrooke's Hospital

Dr Mary Archer, Chairman, Addenbrooke's NHS Trust Hospital
Sir Keith Peters FRS PMedSci to Regius Professor of Physic, President, The Academy of Medical Sciences
Professor Krishna Catterjee FMedSci, Professor of Endocrinology and Director of Wellcome Trust Clinical Research Facility
Professor Alastair Compston, Professor of Neurology
Professor Bruce Ponder, Professor of Oncology
Professor John Pickard FMedSci, Professor of Neurosurgery and Chairman and Clinical Director of Wolfson Brain Imaging Centre
Dr Robert Winter, Medical Director, Addenbrooke's NHS Trust
Dr Richard Henderson FRS FMedSci, Director MRC Laboratory of Molecular Biology

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