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THE ROYAL SOCIETY

The Scientific Century: securing our future prosperity

(Final report of the Fruits of Curiosity inquiry)

Responses to Call for Evidence
Part I

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Introduction

The Call for Evidence was published on 21 July 2009. We received 44 responses, from individuals, universities, the third sector, learned societies, industry and business. Please refer to the links on the Royal Society website for a copy of the original Call for Evidence document.

Responses to Call for Evidence

1994 Group

The following is a submission of evidence from the 1994 Group in answer to the Royal Society's inquiry 'The Fruits of Curiosity'. For more detailed information, and for specific examples of institutional practice, please contact the 1994 Group using the details above.
Please note that we have answered a selection of the questions listed in the consultation document.
Members of the 1994 Group are: University of Bath, Birkbeck University of London, Durham University, University of East Anglia, University of Essex, University of Exeter, Goldsmiths University of London, Institute of Education University of London, Royal Holloway University of London, Lancaster University, University of Leicester, Loughborough University, Queen Mary University of London, University of Reading, University of St Andrews, School of Oriental and African Studies, University of Surrey, University of Sussex and University of York.

The long-term direction of policy for science
1. What role should curiosity-driven research play in the UK science base in the next 15-25 years?
The UK is currently facing many serious challenges. We not only have to address issues relating to our future environmental sustainability, global threats to security, and an ageing population, but we have to do this at a time of considerable global economic instability. We need to do more to combat global warming, find new sources of renewable energy, secure our future food and water supply, improve our life-long health and well-being, tackle widespread poverty, ensure public security, and support changing modes of communication and ways of doing business.
We are fortunate that we have a first class research base, much of it located within Higher Education Institutions, that can play a major role in helping to address these challenges. Indeed, we remain the most productive in the G8, in terms of both number of publications and number of citations per-researcher, and rank second only to the US in the world rankings. It is vital that we do what is necessary to retain this position so that the HE research base can work with Government to address our most pressing challenges and help to ensure the UK's future economic prosperity. At the same time, we have to ensure that our universities are an asset to the nation in the long-term so that we are in a position to address future challenges. Our future sustainability and prosperity depend not only on addressing today's most immediate challenges, but also on the generation of knowledge and discoveries which our coming generations can apply for the good of their society.

Curiosity-driven research is crucial to developing that knowledge. We need to retain a system of funding the best research ideas, through responsive mode funding, in addition to supporting research that is directly aimed at addressing the problems that we currently face. We must retain a significant funding stream for what might currently seem like fundamental, curiosity-driven research, but may well enable us to think in new ways, to train new skills, and to provide some of the answers to tomorrow's problems. As John Denham, former minister for Higher Education, noted in his speech to the Royal Academy of Engineering in February 2009, "any research base which does not include a substantial element of fundamental, curiosity-driven research, conducted by researchers who simply want to know, will not be economically relevant in anything but the shortest of terms"[1].

2. Which elements of policy for science and innovation over the past 10 years have been successful and should be maintained? Where is there room for improvement?

The Government has rightly recognised that increased investment in research is crucial and that Higher Education is more critical to our future prosperity and well-being than ever before. The funding for STEM subjects and medicine has also been enhanced, since these disciplines are clearly vital for key sectors of the economy. They encourage new technological developments and drive economic growth, and improve population health and well-being. It is essential, however, that resources are available for a broad and

[1] Staying ahead – Investing in research in the down. Speech by John Denham. Royal Academy of Engineering, London, 19 February 2009

robust research foundation in order that we can compete effectively in the new global economy and ensure future sustainability and prosperity. There are several elements which Government policy should seek to address:

a) The Government must increase its investment in research, but not solely through short term initiatives aimed at addressing immediate challenges. We should resist introducing incentives that distort the research base in inappropriate ways. Research must be funded on a longer-term basis to enable universities to retain the scope to respond flexibly and rapidly to emerging challenges.
b) Investment must be made in new ideas and world leading research in the arts, humanities and social sciences, in addition to STEM subjects and medicine. Innovation draws on the entirety of the research base and, accordingly, the whole academy must be sustainable financially.
c) The Dual Support system has contributed to the international success of UK research to date, and it is essential that the Government retains this. As part of this, there need to be appropriate levels of QR and responsive mode funding, to ensure sufficient autonomy and flexibility, and the capacity to drive innovation. In addition, the Government must continue to distribute QR funding according to excellence, but at the same time it must not spread resource more thinly, as a result of the new assessment methodology in the REF, so that we risk damaging our world class research areas within our research intensive universities.
d) As part of REF, it is also important that the Funding Councils recognise the widest range of impacts that excellent research might have across different disciplinary areas, rather than focusing overly on economic impact interpreted in its narrowest sense.
e) In addition, the Government should continue to support Universities in their enterprise development and interaction with businesses through the discrete Higher Education Innovation Fund, which has been very successful in providing the platforms for HE – industry interactions.[2]
f) The Government needs to provide an under-pinning to enable Universities to work in partnership with, and be co-funded by, other bodies including charities, the European Union, and NHS. It also needs to facilitate our ability to collaborate with world leading teams across the globe by removing any unnecessary barriers.
g) Finally, the Government must provide support for the development of new researchers, through the Research Councils, and through ring-fenced funding that supports the necessary advanced skills training and career development of postgraduate research students and early postdoctoral researchers.[3]

It is clear that research at UK universities is already playing a major role in helping the UK to address major challenges and ensure future economic prosperity. However, we recognise that there are ways in which we as universities could be better organised in order to ensure that the very best use is made of our world class research.
We need to continue to address the sustainability of our research infrastructure. As part of this, we need to ensure that we have the mechanisms in place to understand the costs across the portfolio of our activities, and also to adopt more flexible attitudes to pricing. We need to enhance the extent to which we are working globally, collaborating with the best research groups across the world, and attracting leading researchers here, to ensure that we develop as truly global institutions.
We also need to do more to foster research collaboration between UK universities to build the scale needed to compete globally.

5. How should we assess the long-term social and cultural impacts of scientific research?
Universities need to enhance their ability to demonstrate the wider economic, social and cultural impact of their research, and work actively to ensure that any potential impact is realised, in line with the increased emphasis on impact in the REF. This will involve continuing to review our reward and incentive structures to ensure that we reward engagement with government, business, and the wider public.
The UK's universities play a central role in helping society, not only to meet our most pressing immediate challenges but also to ensure that we are able to address future challenges. The world class, innovative research at our universities underpins our prosperity and improves our quality of life. It helps to develop greater understanding and discover novel approaches and solutions to many of our current problems, while at the same time expanding the knowledge base in new areas that may well be needed in the future.

[2] Evaluation of the effectiveness of HEFCE / OSI Third Stream Funding: Report to HEFCE. 1 May 2009.
[3] Survey of the impact of the Robert's Fund at 1994 Group institutions. 1994 Group Research Report. January 2009.

Innovative research generates new ideas that can boost fast-growing modern industries such as those focused on the digital economy, environmental solutions and green energy. Knowledge is the new currency of economic growth, and our universities, as a source of new knowledge, are at the core of this, and are central to taking society forward. HE research is also fundamental to informing public policy making and improving Government decision making. Our universities contribute to the effective delivery of public services and the proper organisation of the welfare state and the formation of international aid policy and foreign policy. They offer evidence-based solutions to help improve and refine current policy developments, and provide independent scrutiny of Government initiatives.[4]

Greater efforts must be taken to communicate the outputs of our research work more effectively so that we can work better with Government and NGOs, and feed into public policy making, by adding value and offering insights to key issues of concern for policy makers.

Investing in tomorrow's talent in schools, universities and in the FE sector
6. How much progress has there been in the past decade in the delivery, content and assessment of education in STEM (Science, Technology, Engineering and Maths) subjects?

There is feeling within the University community that there has been a general decline over the past two decades in numeracy and literacy, and a less broad base of basic scientific knowledge, often even in students with good entry grades. Discussions with teachers seems to indicate restriction of the curriculum at A-level and modular structures, meaning students learn in bite-sized chunks and are not required to integrate or synthesise knowledge (teaching to the test; lateral thinking and "open" answers seemingly discouraged). There has also been a major decline in practical experience (either laboratory skills or field courses) within the A-level experience of most students.
It is well-documented that mathematics is problematic at the school/university interface, particularly for students entering STEM subjects. This problem affects the full spectrum of universities (Hawkes & Savage, 2000).[5] The Smith Inquiry (2004) noted that *"higher education has little option but to accommodate to the students emerging from the current GCE process"*.[6] Consequently, there is an on-going need to support those STEM students who struggle with mathematics. Many other reports come to the same conclusion (e.g. Institute of Physics, 2001).[7]
Furthermore, the Durham University CEM centre (national evaluation centre for teaching in UK) reported strong evidence that standards in Maths A-level assessment had very significantly dropped between 1988 and 2006.[8]
Anecdotally, it seems to be the case that some students are not confident in working through what should be regarded as very simple and straightforward mathematical manipulations.
This has a couple of effects – the students avoid where possible choosing the questions which involve this kind of work, and lecturers can find themselves teaching in ways that avoid mathematics if at all possible. Of course, quantum mechanics and thermodynamics are mathematically based and so it is not always possible to do this. Pedagogically, lecturers feel uncomfortable about lowering their expectations, because it can lead to a cycle of lower lecturer expectation feeding lower student attainment.
There is a general willingness to embrace the use of Diplomas for entry into 1994 Group Universities, along with a natural concern in some areas that the standard that is achieved by the students will be sufficient for the students to take maximum advantage of the programme.[9] The Diploma in Manufacturing and Product Design will provide a valuable, alternative route into college or University for those students who are not currently enthused by traditional secondary courses, perhaps because they are unable to see the practical application of what they are being taught. By providing an education that teaches material in the context of the manufacturing industries, these students will be encouraged to learn and will ultimately achieve at a higher level than they might have done through a more traditional approach. Such students will have a better appreciation of the programmes onto which they can

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[4] How academia and Government can work together. Council for Science & Technology submission to HE Debate, 2008.
[5] Hawkes, T., & Savage, M., (2000) (eds) *Measuring the Mathematics Problem*, (London, Engineering Council)
[6] Smith, A., (2004) *Making Mathematics Count – the Report of Professor Adrian Smith's Inquiry into Post-14 Mathematics Education*. (London, The Stationary Office)
[7] Institute of Physics (2001) *Physics, building a flourishing* future – *Report of the Inquiry into Undergraduate Physics*. London, Institute of Physics. Available from http://policy.iop.org/UPI/index.html [Accessed 6th July 2004]
8 CEM Centre Durham University, *Change in GCSE and A-Level: Evidence from ALIS and YELLIS,* April 2007.
[9] 1994 Group Research Report, 'New Foundations, Enduring Values: Undergraduate Education, Research-Intensive Universities and the Government's Reforms of 14-19 Education in England,' Jan 2008:
http://www.1994group.ac.uk/documents/public/NewFoundationsEnduringValues.pdf

progress, they will make more appropriate choices and then be more likely to succeed on the programmes they choose.
A further dimension to the 'mathematics problem' is the 'mechanics problem'. Articulated very clearly at a seminar in Cambridge in July 2008, it has become clear that each year more students arrive at University with little or no experience of Newtonian mechanics. The problem and recommendations for its solution are described in the symposium report - *Newton's Mechanics – Who Needs it*? (MSOR Network).[10]
The picture may not be all bleak, however. Perhaps, we are seeing the tail end of students who have not benefitted from the systematic, early teaching of English and mathematics within the literacy and numeracy hours. Perhaps, in approximately 5 years time, when those students have worked through the system, it may be that Universities do not need to spend as much time on such basic skills. And if we look to other key skills for scientists then we find evidence that, contrary to received wisdom, there is an emphasis on practical work and problem solving in subjects such as A level Biology that can really be of assistance to students at undergraduate level.
Universities have responded to the challenge of falling standards in entrants' numeracy and literacy skills with a range of remedial measures. The 1994 Group has collected examples of this activity, which are available upon request.[11]

7. What are the future challenges for STEM education at primary, secondary andtertiary levels? How should these challenges be addressed?
While many of our members remain strongly selecting Universities, even in STEM subjects with increasing entrance standards, many 1994 Group members have experienced the impact of changing patterns of demand and qualifications for STEM subjects.
Many institutions experienced pressures a few years ago, particularly in mathematics, physics and chemistry, which in a number of cases resulted in closure of these departments. However, a national growth in interest in these areas, combined with extensive efforts of institutions to preserve this activity, has led to an upturn in activity and in students applying, entering and graduating in STEM subjects.
Sustaining this level of interest and recruitment has required a determined and focussed effort, both on recruitment and conveying messages about STEM subjects and careers and also, as importantly, sustaining quality delivery over many years. The success experienced can be attributed to a combination of institution specific initiatives building on wider awareness work on a national basis.
Undergraduate applications in science at **Loughborough University** have risen steadily over the last three years and for 2009 entry they are up by 25% on 2008. Engineering has a similar trend, and applications are up around 10% on last year. Mathematics demand has been so high that consideration has been given to capping numbers.
At **Lancaster University,** applications for maths and physics have increased significantly over the past year, and those for computing and engineering have also increased.
There has been something of a resurgence of interest in studying mathematics post-A-level in the last few years, and the **University of East Anglia** has certainly experienced this.
Playing a role in this will have been the University's efforts to get more students studying further mathematics AS and A levels through schemes such as Mathematics in Education and Industry (MEI) and the Further Mathematics Network. Many other 1994 Group institutions have experienced such rise in demand for STEM subjects.
It is hard to establish a 'cause and effect' link between rising applications for STEM subjects and current national activities on STEM subject uptake, but these admissions trends may help indicate that that STEM policies are working. However, there is real concern that this trend might be undermined through the stringent enforcement of the recent cap on home student numbers by HEFCE.
There are also clear signs that the nature of student demand for STEM subjects is changing, with a shift in applications from traditional areas to more applied subjects.
The **University of Essex**, like many institutions, has seen a general decline in the uptake for "traditional subjects", such as chemistry and biology, and increased student interest in more applied subjects, such as biomedical science, sports and exercise science.
Students also tend to have a wider range of A-level subjects within their portfolio, including less quantitative science subjects, such as environmental studies and physical education.
Traditional entry profiles made up of biology, chemistry, maths and physics are much less common.

[10] MSOR Network (2008) Newton's Mechanics – Who Needs it? Report of a symposium held at the Moller Centre, Cambridge, July 2008
[11] Please contact Tom Norton (tom.norton@1994group.co.uk)

However, reflecting a positive trend, of the students that **Loughborough University** accepted across the university in 2007/08, the most common A-Level possessed, by some margin, was mathematics. Of accepted students, 1,316 held A-Level mathematics, compared to 808 in physics, which was the second most common subject. This shows the ubiquitous and fundamental nature of mathematics as it feeds into a wide range of subjects.

The University of Essex has recently merged Computer Science and Electronic Engineering into a single Department (they were previously separate departments until 2006), which is now beginning to revive, but still recruits less students in total than either of the two departments did individually 10 years ago.

The schools IT curriculum is seen as very harmful to computer science by many in the academic community, including the Conference of Professors and Heads in Computing. The curriculum is seen to be very much about training future office workers to use simple IT – databases, Microsoft Office, browsers – in ways that make them easily absorbed by employers. Pupils then believe that what they are learning is computing, and are then contemptuous of degrees that they believe is three years of more office IT.

The decline in the number of actual physical experiments in school science has been seen as a cause of declining interest in building real physical circuits and gadgets, and so in interest in engineering and electronics.

8. How do we ensure that adequately qualified science and mathematics specialists are attracted into the teaching profession at all levels of education (primary through to tertiary)?

We hope that increased up-take of STEM subjects at University will lead to a wider (and therefore better-qualified) pool of those seeking to take up STEM teaching as a career. Until the majority of teachers at secondary level are strong subject specialists in STEM subjects, Universities alone will not be able to make the improvements the Government is seeking.

Building and sustaining research careers

9. How can we make research careers – within academia or industry – a more attractive option for young people, both within the UK system and from abroad?

Our universities play a major role in ensuring that we have the right stock of skilled, talented and flexibly-minded people who will be needed to ensure our future intellectual sustainability and to provide the necessary workforce to enable the UK to compete effectively in a changing global economy. In addition to producing the next generation of researchers, we train large numbers of individuals to have the skills needed to interpret and use research evidence appropriately, and to apply questioning minds to address new challenges. As noted in the recent Government report, New Industry New Jobs, innovative businesses need educated, entrepreneurial and skilled people.[12]

The research-based teaching in our universities is a significant source of knowledge transmission, and the close relationship between research and teaching is central to providing students and society with the skills needed to engage with the growing complexities of the world.[13]

Funding and support for postgraduate research students and other early career researchers is essential to ensure that we have adequate numbers of appropriately trained people, who will be needed to replenish the research base and provide necessary skills in the wider workforce.14 To achieve this it will be important to ensure that we do our best to implement the new Research Careers Concordat. We also need to protect against the loss of vital expertise in particular disciplinary areas to overseas countries.

Individuals who set out with a goal to forge a career in the research industries are plagued by one thought: securing funding. With a lack of funding restricting potential research options, it is vital to ensure that the funding is present to provide curiosity-driven research with the resources required to benefit society at large. The Roberts Fund has helped this.

Since its inception, The Roberts Fund has had a beneficial impact on the skills training and career development opportunities for postgraduate research students and postdoctoral researchers.

The receipt of Roberts' funding has considerably increased the amount of financial resources available for skills training and development of PGR students and Postdoctoral researchers at the 1994 Group institutions. Such training and development opportunities are now firmly embedded within institutions' structures and practices. Clearly, there is good evidence that Roberts' funding is achieving what it set out to do. It is helping universities to improve the provision of generic development opportunities for early career researchers and to enhance their personal, professional, and career management skills. Allocation

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[12] New Industry New Jobs: Building Britain's Future. HM Government. BERR. April 2009.

[13] Rammell, B. Exploring research based learning. Presentation at Research based Learning in Higher Education. Higher Education Academy, University of Warwick, 25 October 2006.

[14] Survey of the impact of the Robert's Fund at 1994 Group institutions. 1994 Group Research Report. January 2009.

of Roberts' funding is also having wider beneficial effects by encouraging universities to develop innovative approaches, collaborations and projects to i) enhance the generic development of early career researchers, ii) improve their awareness of and skills in knowledge transfer, and iii) facilitate better employer engagement and researcher-specific careers' advice.
As a result of the provision of Roberts' funding, institutions have also invested, sometimes considerable amounts of, their own financial and other resources to support the skills training and development of their early career populations. Given the progress demonstrated in member institutions documented in the 1994 Group's Jan 2009 study,[15] and also evident elsewhere in the sector, there is clearly a need for this funding to continue. This would enable the excellent innovations that are being put in place, many still at early or conceptual stages, to be fully developed and implemented for both the benefit of our early career researchers and of the wider UK research community.

Science, innovation and wealth creation

12. How can we strengthen science and innovation in all parts of the private sector in the UK, and further improve the exchange of knowledge and expertise between the public and private sectors?

Universities need to enhance both the extent to which, and the way, we are working with business and industry, at a regional, national and global level. As part of this, we need to be more flexible and responsive to changing business demand.
As a result of the challenges brought about by global competition and the changing emphasis on research and development, UK businesses are increasingly drawing on the university sector in order to achieve competitive advantage and reduce financial risk.
Collaborations with universities are enabling businesses to gain access to expertise they do not have in-house and to specific markets, renew and expand technology, leverage internal research capacity, and make contact with potential employees.[16] The science base is a key resource for the high tech companies and start-ups that will grow into the world leading businesses of the future.[17]
In parallel with the on-going provision of QR funding, we need to build on the advances made in terms of enterprise development and interaction with business that have been enabled by the Higher Education Innovation Fund. As noted in a recent report to HEFCE, investment in third stream activity in English Universities has yielded benefits worth many times the investment.[18] Encouraging closer ties between the UK's growing pool of talented researchers and industry and private investors is now key to ensuring that we are able to benefit economically from ground breaking science.[19]
STEM activity at Universities is of significant importance to the UK skills base, through the production of graduates and postgraduates that fill key areas of the economy (e.g. pharmaceuticals, health-related, and environmental sectors). There is also a huge impact through provision of graduates entering the teaching profession, and postgraduates into blue skies research and R&D.
Clear evidence of the importance of the 'STEM skills pipeline' is shown by the companies who have set up sponsored programmes at many 1994 Group Universities to ensure that they can secure a sustainable flow of graduates into their industry.
Loughborough University have several programmes with consortia of major construction firms in Civil and Building Engineering and the Systems Engineering programme (developed with BAE Systems).
Within **Lancaster University's** InfoLab, a 'culture change' has been seen during the past couple of years. This has taken a bit of time to build up momentum, but it derives from the activities in the Knowledge Business Centre and we can point to the Graduate Academy and Student Academy as major prime movers. Both of these, at their different levels, are addressing the issue of making graduates more employable by providing new experiences and also new skills. The target beneficiaries, as well as the students, are companies – mainly SMEs, and almost exclusively in the North West region. The University works hard to place students and graduates on placements within SMEs. For small companies it can be difficult to recruit STEM graduates and placement links are crucially important here.
Lancaster University's Engineering department has close relationships with local companies, which come to the department looking for graduates to recruit. Currently there are more openings than there are students to fill them.
Durham University has an "Industry Bridging Fellowship" scheme to tide regional companies over the recession. This has had most interest in the STEM area, from polymer processing to geological surveying.

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[15] 1994 Group Research Report, 'Survey on the Impact of the Roberts' Fund at 1994 Group institutions', January 2009: http://www.1994group.ac.uk/documents/public/Research%20Policy/090115_RobertsFundReport.pdf
[16] Universities, Business & Knowledge Exchange. Council for Industry & Higher Education Report. 2008.
[17] New Industry New Jobs: Building Britain's Future. HM Government. BERR, April 2009.
[18] Evaluation of the effectiveness and role of HEFCE / OSI Third Stream Funding. Report to HEFCE. 1 May 2009.
[19] New Industry New Jobs: Building Britain's Future. HM Government. BERR, April 2009.

Industrial engagement in University research peaks around STEM topics. A total of £1.5M industrial funding was raised by one project in Molecular Polymer Processing alone. Over the last 10 years the research staff on that project have been increasingly from outside the UK.
An obvious and important contribution of STEM subjects is to the creation of knowledge and the transfer of that knowledge to business, industry and the wider community so that it has impact. An often forgotten but important contribution is to the creation of scientific thinking and citizens who understand, value and respect the scientific process. Over a wide range of issues it is important to take a scientific view and to rely on people who take an impartial perspective as well as having expertise. Trust and confidence are often engendered by scientific opinion and make a valuable contribution to our society which could easily be underestimated.

The ecology of research funding

15. How do we maintain an appropriate funding balance between curiosity-led, response-mode research, and more targeted or programmatic funding?

16. What would an ideal research funding landscape look like in 20 years time? How would funding be allocated? What would the funding bodies look like? How would they relate to one another?

As universities we need to protect our ability to drive innovation and respond flexibly to the needs of others. We must be able to retain our autonomy and capacity to invest in new and emerging areas, grow and support new talent, protect declining but important subjects, and initiate collaborations with new academic, business, and other partners. The provision of QR income is vital to all of these, in that it brings a necessary element of continuity, supports forward planning, and enables institutions to develop local strategies. The Dual Support system has helped us to reach our current enviable position in the world rankings, and is needed to ensure that we retain it. In this context, we support the decision to distribute QR according to excellence but recognise that it is vital to retain critical mass in those areas necessary to deliver world leading research. In line with UUK's position, we believe that the level of research concentration prior to RAE 2008 was appropriate.20 We would not want to see any further dilution of funding as a result of the new assessment methodology that will be introduced in the Research Excellence Framework (REF).
We need to complement investment in STEM subjects and medicine with continuing investment in new ideas and world-leading research in arts, humanities and social sciences to support the culture and heritage on which so much of UK GDP depends, and to support research on national priorities. We cannot afford to conceive our 'science' base too narrowly.
We must protect our entire research base. Addressing current and future global challenges depends on the successful interplay of all subjects. Increasingly, success in markets, which have frequently been assumed to be dominated by technological advances, depends just as much on factors such as design, economics, branding, and consumer understanding and changing behaviour. Innovations in the form of new products, processes and services will inevitably occur at a faster rate when technical feasibility is allied with an understanding of cultural and social change. Thus, the sciences, technology, arts, humanities and social sciences complement one another; they do not exist in a hierarchical relationship. Furthermore, the boundaries between the natural sciences and the social sciences and humanities are becoming increasingly fluid as research at the frontiers of knowledge become increasingly inter- and multidisciplinary. If we are serious about identifying national priorities and making new investments in solving global problems, we will need to retain a comprehensive research capacity and make greater effort in trans-disciplinary initiatives.
This in turn will require resources to be allocated in such a way as to sustain a comprehensive research capacity, and enable flexibility and inter-disciplinarity to flourish.
The Government must develop national research policy and target funding and support mechanisms to create an environment in which UK research productivity and impact is world leading and our universities remain internationally competitive.
The 1994 Group has made clear, sustainable long-term research policy recommendations to the Government and the HE sector. [21] These include:

- Increase Government investment in research on a longer-term basis to enable universities to retain the scope to respond flexibly and rapidly to emerging challenges.

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[20] RAE 2008 outcomes and funding. Research Policy Committee Report. RPC/09/03

[21] 1994 Group will be publishing a Policy Report on 'The importance of the HE research base in addressing major global challenges and ensuring the UK's future prosperity,' on 5 October 2009. Please contact tom.norton@1994group.co.uk for more details or go to www.1994group.co.uk/researchenterpriseexcellence.php

• Protect and enhance QR funding to allow universities autonomy and the capacity to invest in new and emerging areas, grow and support new talent, protect declining but important subjects, and initiate collaborations with new academic and business partners.
• Distribute QR funding according to excellence, while ensuring critical mass in world class research areas within our research intensive universities.
• Complement investment in STEM subjects and medicine with continuing investment in new ideas and world-leading research in arts, humanities and social sciences, as innovation draws on the entirety of the research base.
• Ensure our future intellectual sustainability by providing the necessary resources to train the world-leading researchers of the future.

The Society for the Study of Artificial Intelligence and Simulation of Behaviour

Response to the Royal Society Call for Evidence on The Fruits of Curiosity: innovation and future sources of wealth

By The Society for the Study of Artificial Intelligence and Simulation of Behaviour

Introduction

This response is by the executive Committee of The Society for the Study of Artificial Intelligence and Simulation of Behaviour (SSAISB or AISB), which is the main academic society in the UK for the discipline of Artificial Intelligence.[22]

Founded in 1964, the society has an international membership drawn from both academia and industry, and from a wide range of disciplines, such as Philosophy and Psychology, as well as Computing. It is a member of the European Coordinating Committee for Artificial Intelligence (ECCAI).[23]

Some of the ways in which the issues in the Fruits of Curiosity enquiry engage AI are shared with ways in which they engage the discipline of Computing. This response therefore leaves some issues to be addressed in responses such as the the one by the UK Computing Research Committee (UKCRC).

We use the name Computing in this document to refer to the science concerned with computation, not to the activity of using or managing software tools, or to routine software-tool development that does not require advances in deep knowledge. We use the term in preference to Computer Science in order to align our terminology with the UKCRC, the CPHC (Council of Professors and Heads of Computing)[24] and the projected Academy of Computing under the banner of the British Computer Society.[25]

Also, the distinction between Computing on the one hand and Information [and Communication] Technology (IT or ICT) on the other is crucial though unfortunately obscured in the educational, professional and governmental landscapes.see the Question 7 section below, subsection on Education in Schools.

AISB broadly endorses the views expressed in the UKCRC response. The present response concentrates largely on issues that engage in a special and notable way with AI.but the comments that we are led to make nevertheless illuminate the general issues of the consultation, not just AI-specific versions of them. While Computing is the main discipline within which AI is structurally lodged within universities and funding councils, AI also strongly intersects disciplines such as Philosophy, Brain Science, Psychology and Linguistics. The comments in this response therefore highlight the issue of cross-disciplinarity (not only of the AI sort and but also generally).

The cross-disciplinarity of AI extends to Humanities as well as scientific disciplines. An example of this is the concern in AI with artistic activity and with creativity more broadly. Nor is AI confined to emulating purely human qualities (in cognitive, perceptual, emotional, artistic, ... domains): there is a strong interest also in related qualities that are exhibited by other organisms or that emerge through collective activity of organisms.

The sections below and the question numbering used follows the organization and numbering of the questions posed in the Call for Evidence. Only those questions on which we wish to make a distinctive comment are included.

The Long-Term Direction of Policy for Science

Q1: What role should curiosity-driven research play in the UK science base in the next 15-25 years?

Short answer: A huge role.

AI has always been a curiosity-driven research discipline par excellence. The main targets of curiosity have been large, beyond-blue-skies questions such as what thought and consciousness are, how the human mind works, and how we could create artefacts that emulate the mind. Yet the discipline has led to: large industrial sectors of global significance (e.g., automated translation of documents, automated mining of product-user opinions expressed in vast collections of documents, intelligent image understanding

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[22] http://www.aisb.org.uk. Comments on this response should go to the main author and society chair, Prof. John Barnden, School of Computer Science, University of Birmingham, B15 2TT. The response has been informed by valuable input from various Fellows of the society as well as from the society Committee.

[23] http://www.eccai.org

[24] http://www.cphc.ac.uk

[25] Now known as .BCS, The Chartered Institute for IT. (http://www.bcs.org). The Academy was announced in a press release by the BCS Press Office, 21 September 2009. Accessible at time of writing at http://www.bcs.org/server.php?show=conWebDoc.32253.

applied, for instance, to face detection and skin disease diagnosis); systems that affect many if not most ordinary people's direct engagement with life (e.g., intelligence in search engines, with Google in particular being based from the start on AI technology; and AI in computer games, virtual worlds, etc.); and systems of major practical and economic import but that are more hidden from the public (AI technology used in fraud detection by credit card companies, etc.). AI is also of central importance in other areas of science such as space exploration, where automated planetary explorers must intelligently plan their own detailed activities.
AI therefore stands as one example of a discipline where having a basis in pure curiosity goes hand-in-hand with making advances of major economic and societal benefit. Indeed, it would be dangerous to imagine that those benefits could have arisen from some much less curiosity-driven version of the discipline. The more ambitious the aims of a discipline then, as long as deep and detailed work is done in pursuit of them, the more impressive the outcomes (pure and applied) are likely to be. Short-termism and lack of ambition in aims, with too much adherence to current assumptions about the world and to short-term industrial, economic and political goals, is likely to lead to advances of only short-term significance. Connection to industrial and economic goals is of course valuable and has inspired much important, fundamental AI research; rather it is the short-term nature of some goals and of many cycles in industry and elsewhere (e.g., product development cycles, governmental spending review cycles, planning cycles in universities) that is the issue.

Q4: How should science be governed to maximise benefits to society while acknowledging public questions, uncertainties and concerns?
Short answer: (A) Science should be overseen by independent learned societies that nevertheless include: the pro-active engagement with understandable public concerns as a main aspect of the societies' governance; in particular, alerting of the public to new dangers; and the acknowledgment of scientists as themselves part of the public. (B) Some types of currently unregulated application of AI and other sciences should be regulated by scientifically, politically and industrially impartial ethical bodies where appropriate.
There are legitimate concerns about how science, including AI, may affect the world and in particular how it might be misused, and it is important for the AI and other scientific communities to engage with them and not react defensively. By .legitimate. we include not only concerns that are scientifically justified but also concerns that are perfectly understandable even if not actually justified: the issues may be too difficult for the public to be able to grasp without major effort and without extensive guidance from scientists. While the public may often be misled by misinformed, biased, mischievous or opportunist media coverage, some public concerns, including about AI, are at least understandable because of genuine difficulty, and some concerns are profoundly justified.

For the purposes of this consultation we can put aside science-fiction scenarios of humankind being destroyed or enslaved by humanoid robots, and we can put aside feelings of humiliation when faced with the works of future automated scientists and poets. But the use of AI in ongoing efforts to develop automated, armed guards, soldiers and other military units.or even just automated aids for human soldiers.is surely a legitimate cause for concern.[26] Another legitimate concern is to ensure that AI in mass surveillance of email and voice communications does not lead to misuses and abuses. Other more traditional, legitimate concerns include issues of responsibility and accountability in the use of AI in such areas as Medicine and Law.
A new problem arising, or at least only now revealing its dire effects in the current economic and financial crisis, is that of automated agents operating within real markets, doing automated stock trading or bank risk management, for example.
The consequent speed and complexity of transactions, and opaqueness to human understanding, is liable to produce massive, difficult to manage, qualitatively profound changes in the nature of economic/financial reality, if it has not done so already. The use of more and more sophisticated AI techniques in such agents can only exacerbate the problems.
The following quotation from an article by Martin Taylor, the former chief executive of Barclays bank, is pertinent to the use of Computing in general, and by extension AI, in banking, at least without appropriate expert human supervision:

[26] Such concerns have been articulated by many within AI and without, and notably by Noel Sharkey (Professor of AI and Robotics and Professor of Public Engagement, University of Sheffield). See for instance the Opinion Interview with him in New Scientist, 29 August 2009, pp.28.29, and article .Danger, Danger,. Times Higher Education, 13 August 2009, p.22. (We should stress, however, that the AISB does not endorse Sharkey's sceptical views about the in-principle capabilities of AI.)

In the last decade, alas, [the function of determining the overall risk appetite, etc.] has come to be seen as .technical,. or subject to computer modelling. Human judgment has not been applied, sometimes not even to the decision not to apply human judgment.
Bank board members, usually experienced leaders from other business sectors, are ill-equipped to understand the risk-growth tradeoff. ... They quite literally do not know what they are doing, as much empirical evidence suggests.[27]
It would be perfectly appropriate therefore to have a national ethics committee.impartial scientifically, politically and industrially.that has at least an advisory capacity in the nature and application of AI research, and similar bodies for other currently unregulated research. (A current example of such a body, at least approximately, is the HFEA.[28]) Such a body could, on the applications side of a science, have statutory power to require certain types of public enquiry, legal process or parliamentary process to take place in order to decide whether to allow product-development or product-installation work to proceed when the societal dangers may be great. The body would also need to be in dialogue with other similar bodies and with bodies such as financial regulators, utility regulators (given the emerging use of AI in utility network design and distribution), etc.
Such a body would not only help ensure that AI is used wisely but, by pre-alleviating public concern, ultimately give AI researchers and their collaborators in many disciplines more overall freedom to pursue investigation.
These investigations could even include theoretical or experimental investigations that could in principle lead towards products that would not be legal or would not pass the scrutiny of the ethics committee. After all, and apart from any other consideration, the AI technology involved in such investigations would share much with that needed for parallel developments within virtual worlds (e.g., military units within them). Presumably the regulation of what is developed for virtual worlds should be looser than that for the real-world case. Of course, when the virtual world impinges upon or intersects the real world.such as when valued items in virtual worlds also have real economic value.then the real-world regulation needs suitably to encompass parts of virtual worlds.
The nature of AI itself implies that an ethical body would need to be multidisciplinary, at least in its advice-seeking and preferably in its make-up. Expertise in all the AI-intersected disciplines is potentially needed. But this raises the question of whether ethical bodies for other scientific areas could benefit from being multidisciplinary as well. Being multidisciplinary may be necessary anyway because of the nature of the ethical problems faced, which cannot be relied upon to respect traditional disciplinary boundaries. But as a side-effect the multidisciplinarity could also help to bring down inter-disciplinary barriers within science, as scientists would need to understand more about each others areas in order to engage fully with relevant ethical bodies.
Sciences must not be governed by government, and it is not clear they should be governed by anyone, if this word is taken in any strong sense. They are, or should be, led by excellent scientists, with learned societies sometimes also playing an inspirational role but more generally playing facilitatory, oversight, advisory, communicative, and (in limited, specialized respects) regulatory roles. Learned societies should work within a framework of well-conceived, democratically-managed ethical regulation that has statutory operational impartiality towards scientific communities, industry and political groups (while of course taking information and advice from those sectors).
On the other hand, there are issues for the scientific societies and professional bodies themselves. We mention this because of a subtle, unfortunate feature of Q4 as posed, namely the use of the defensive-sounding verb .acknowledge.. The verb .address. would have been better. The flavour of Q4 as it stands is of scientific bodies pressing forward somehow within an obstacle course of public objection. But it would be better for scientific bodies to cooperate visibly, sincerely and proactively with the public. Indeed, it would be beneficial for the governance of all learned societies to include structures and mechanisms geared to addressing, cooperatively when at all possible, the concerns and uncertainties of the public. (Of course, this will often involve disagreeing with the concern.and therefore suitably educating the public.) It is important that this aspect of the governance should be clearly evident to the public.
Some learned societies no doubt already do a good job in these respects, but all too often scientists are at least perceived by the public as being defensive in the face of legitimate concerns, rather than really taking the concerns on board from the start and from the heart.
Quite apart from the case of the public raising a concern and demanding an answer, there is the case of an issue about which the public should be concerned but are not, because they do not yet have the right

[27] At p.35 in .Reflections on the Crunch,. Prospect magazine, August 2009, pp.34.36.
[28] The Human Fertilisation and Embryology Authority, http://www.hfea.gov.uk.

information. Learned societies (AISB included) should play the proactive role of alerting the public and relevant ethical bodies to dangers discussed among scientists, not just reacting when dangers are pointed out by others.[29] Such a proactive function would itself do much to allay public mistrust of science and scientists.

One point the public may need to be alerted to is that, while fanciful fears about AI tend to focus on physical robots, and while the comments about military AI above were addressed mainly at AI-controlled physical hardware, the more pressing dangers for society at large are arguably in the form of intelligent software agents on the web.

Of course, regulatory bodies can also, and sometimes do, serve an alerting role, cf. the annual Horizon Scanning process performed by Human Fertilisation and Embryology Authority.[30] But we hold that learned societies themselves should also engage in alerts.

Finally, scientists themselves are part of .the public. with regard to areas outside their own, and are capable of exhibiting deep misunderstanding and ignorance of these, despite the commendable efforts of multidisciplinary organizations like The Royal Society. (Hence part of the difficulty of doing cross-disciplinary work.) It behoves the scientific community at large to do more about this problem. Perhaps the lessons learned would help with dealing with the non-scientific sector of the public.

In short, in counterpoint to the often-sung theme of the Public Understanding of Science, we need voices carrying three other motifs. First, we need: Embrace by Scientists of Public Worries about Science. Secondly, we need: Alerting by Scientists of the Public about New Worries. Thirdly, we need: Understanding by Scientists of Self as Public.

Investing in Tomorrow's Talent in [all education sectors]

Q7: What are the future challenges for STEM education at primary, secondary and tertiary levels? How should these challenges be addressed?

Short answer [Schools]: AI has a special role to play in efforts to show primary and secondary students that Computing is an exciting, deep research area, not just a matter of developing (or, worse, merely using) bread-and-butter IT products, and has fascinating connections to other disciplines such as Psychology, Brain Science and Evolutionary Biology. [31]

Short answer [Universities]: A major challenge at the tertiary level is cross-disciplinary courses, both amongst different STEM subjects and between those and others. Additional care is needed, including on the part of scientific learned societies and professional bodies concerning the educational constraints they impose via course-accreditation policies.

Education in Schools

It is widely acknowledged that the teaching of IT and Computing in schools in the last few decades has failed to engage students. Students are given the impression that computers and computation are merely useful tools, to be used but not studied in depth. This is partly engendered by an emphasis on .skills. (worthy as these are in themselves). Recently the

Council of Professors and Heads of Computing (CPHC) produced a report revealing worrying problems in the perception and/or ignorance of Computing at schools, particularly around up to the GCSE level and amongst students who do not go on to do AS or A level study in Computing, partly based on an extensive survey performed in 2006.[32] It is worth quoting segments of the report at length:

[On p.1:] [There is] a more serious and potentially damaging issue over the ICT and Computing curricula at Key Stages 3 and 4, leading to GCSE examination. Feedback from school pupils and University students [references cited] indicate that enthusiasm for Computing as a subject is being stifled at this point in their studies, with the result that they find the subject .boring. and eliminate it from consideration for further study. This can be evidenced from the decline in pupils taking A-level Computing and applying to study

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[29] A similar point has independently been made by Noel Sharkey.see for instance the recent Times Higher Education article in footnote 5.

[30] See the press release at http://www.hfea.gov.uk/5397.html and Scientific Horizon Scanning at the HFEA: Annual Report 2008/09 at http://www.hfea.gov.uk/docs/Horizon Scanning Report.pdf. The Introduction says: .Horizon scanning is an early-warning system which allows the HFEA to consider the legal, ethical and regulatory implications of any techniques that researchers or clinicians may wish to use in the future in HFEA-licensed research or treatment. The Authority can then be prepared with information to make a decision on the potential licensing of techniques, or have guidance in place to ensure that new treatments are carried out safely and appropriately. The HFEA can also ensure that patients and the wider public are suitably informed..

[31] The connection to Evolutionary Biology is that one technique used in many successful AI applications is algorithms that automatically evolve solutions to problems and designs for robots and for software entities, using processes inspired by DNA recombination and mutation (B¨ack, T., Hammel, U., Schwefel, H..P. (1997), .Evolutionary computation: comments on the history and current state,. IEEE Trans. Evolutionary Computation 1(1): 3. 17).

[32] A Consideration of the Issues relating to the Revision of the GCSE ICT and Computing Curricula, CPHC, February 2009. Available at http://www.cphc.ac.uk/docs/cphc-gcse-ict-curriculum.pdf.

Computing/Computer Science at University, as reported by CPHC [reference] and e-Skills UK [reference].
... Perhaps most worryingly, the evidence is that pupils are emerging from Primary School with enthusiasm and interest in ICT and Computing, both genders, and within three years the majority have lost that enthusiasm, find the subject boring, and only a relatively small percentage, predominantly male, will continue to study it at A level and on to degree level. Teachers need the learning resources, content and skills to provide pupils at Key Stages 3 and 4 with subjects that are exciting, motivating and really show the power and creative potential of the tools that are available to them, and it is clear that this is not currently happening.
... [A]nother major issue identified is the conflation of the ICT curriculum with Computing, with the effect that pupils see no difference between the two. The analogy is often made, in considering this issue, with the use, maintenance, design and development of motor cars [roughly, ICT as driving, A-Level Computing as design and construction].
[p.2:] From the foregoing, it should be clear that the view held by the CPHC community is that, while there is some crossover and mutual support between the subjects, ICT and Computing should be seen and treated as separate subjects. Perhaps most importantly, this distinction should be made early in the curriculum, to ensure that pupils are aware of the distinction and don't believe that the use of application packages, such as Word, Excel and PowerPoint, represents the major focus of Computing. [p.4, quoted from a survey report:] .Many of the students who were taking neither CS nor ICT at AS/Alevel stated that their negative experience of GCSE ICT was a primary reason for this. Common themes in criticisms of GCSE ICT included: ... The content is repetitive ... The content is uncreative or mundane ... ICT involves doing things `that you can do already' ... its main function was to support studies in other areas..
Also, the lack of awareness amongst school students of what Computing involves, and negative public perceptions created by government security lapses and large-IT failures, are discussed in an earlier British Computer Society report.[33]
Surely, given the targets for curiosity mentioned in answer to Q1 (nature of thought, etc.), together with the actual and potential practical outcomes and deep impact on society, AI is in a position to inspire school students at all levels. Further, it is in a specially favoured position here compared to areas of Computing whose deep and long-term significance is more indirect or requires considerable technical or scientific knowledge to appreciate. Therefore, in future advances on the Computing aspects of STEM (and other) education, it would be beneficial consciously to give AI a major role.
This does not exclude other areas of Computing being given such a role.another candidate could be computer security and electronic voting, especially as the latter has important consequences for matters such as social inclusivity and the underpinning of democracy in insecure or corrupt environments.
The cross-disciplinary ramifications of AI into areas such as Psychology, Linguistics, Philosophy, Literature and Art should also be stressed. AI could be an integral part of a broad, humanities/social-science rich curriculum. It would need to be stressed that AI can be an exciting subject even for students who do not have a technical/scientific bent.[34]
However, the changes implied by these comments would require considerably more flexibility in school curriculum design.
Because of the high level of diversity of topic, technique and disciplinary background within AI, making it unreasonable to expect teachers to be uniform in their grasp of the subject, national curricula and policies would need to allow considerable divergence between schools as to the portions of AI covered, the time spent on AI, and the impact on the teaching of other subjects.
We should stress that we do not see schoolteachers as primarily to blame for deficiencies in Computing education at schools. The essence of the problem lies within curricula and misunderstanding by policy makers and the public at large.

Education in Universities

Funding pressures, budgetary competition between disciplines, course-definition bureaucracy and excessive regard to the philosophy of modular delivery and credit-awarding can make it hard at universities to sustain minority courses. This is especially so for multidisciplinary courses, which tend to have complex multi-department timetabling problems, to upset a department's module prerequisite

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[33] McGettrick, A., Boyle, R., Ibbett, R., Lloyd, J., Lovegrove, G. & Mander, K. (2004), Grand Challenges in Computing - Education, The British Computer Society. Available at http://www.bcs.org/upload/pdf/gceducation.pdf. Additional commentary, including explanation of the Computing/ICT distinction, can be found at the website of the Computing at School Working Group, http://www.computingatschool.org.uk.
[34] More on this matters and others in this section can be found in A. Sloman, .Teaching AI and Philosophy at School?. (http://www.cs.bham.ac.uk/.axs/courses/ai-syllabus.pdf) to appear in the Philosophy and Computers Newsletter of the American Philosophical Association, Fall 2009. Sloman is a Fellow of the AISB.

structure and to push beyond normal credit-total limits. These issues are familiar to most people who have been involved in the process of developing such courses.
However, an additional serious problem whose origin is external to universities as such is the constraints on curricula and employment imposed by accreditation philosophies of bodies associated with particular disciplines. While these philosophies have good intentions, they can impose constraints that make it difficult to define multidisciplinary courses that either satisfy the accreditation requirements or that, if they do not, remain attractive in practice to students in view of the deleterious consequences for employment, whether those consequences are real or perceived. We give one example of the problem, though in anonymized form to avoid pointing the finger at individual organizations, something that is not our aim.[35] A thriving half-and-half AI-and-X course run by a Computing department and a department of X (a science) at a particular university collapsed in the early 2000s because it no longer became possible to acquire accreditation for it from what we will call here the BXS (the British combined learned society for X and professional body for the practice of X). This was because of the amount of material that did not formally count as X. This meant that the X department was no longer willing to put resources into the course, and students were not attracted to the course because of X related employment opportunities requiring BXS-accredited degrees, or simply because the course lacked any formal accreditation. This is despite the fact that it would in fact have equipped students well for other types of employment.
We can certainly see the need for stringent accreditational links between education and some forms of employment. But it appears that there is a general problem amongst accrediting bodies in confining the notion of accrediting a degree for the purpose of its being a qualification in a particular line of professional work rather than accrediting a degree because it is a well-designed, valuable educational experience.an experience whose particular professional usefulness cannot be accurately foreseen but that is therefore all the better suited to novel types of career and to innovative emerging and future developments in society.

Q8: How do we ensure that adequately qualified science and mathematics specialists are attracted into the teaching profession at all levels of education?

Short answer: Complementary to the Schools answer to Q7. AI is especially promising for grabbing the imagination of teachers.
However, to ensure that AI succeeds in being a usable imagination-grabbing tool, teachers need to be convinced that exciting teaching about AI can be done without a great deal of technical knowledge of Computing or even IT.
Again, it would also be useful to stress to potential teachers the cross-disciplinary ramifications of AI. In fact, AI could be one main avenue for delivering cross-disciplinary education and for conveying the interplay of sciences with each other and of sciences with the humanities.

The Ecology of Research Funding
Q16: What would an ideal research funding landscape look like in 20 years time? How would funding be allocated? What would the funding bodies look like? How would they relate to one another?
Short answer: Cross-disciplinarity and curiosity need to be much more systematically and comprehensively involved in funding policy and practice, and in the very philosophy of what universities and government research funding are for.
Our comments here are inspired in part by the extremely cross-disciplinary and curiosity-driven nature of AI, as outlined above. However, the comments are not specific to the case of AI.
There are several dimensions as regards the nature of possible funding schemes, notably the following: the time-period of the grant; whether it is in responsive mode or targeted in some way; whether it is .project-level. . given to an individual researcher or small team . or .organization-level.. to a department, university or consortia of universities and (possibly) other bodies; whether it is for a specific, agreed research topic or for whatever the recipients wish to investigate as time goes on; and the extent to which it covers some of the time of academics on existing open-ended contracts versus supporting specially-acquired research assistants or students. These dimensions are in principle largely independent of each other.a point that itself needs emphasizing.although practicalities dictate that some regions in the

[35] Details can be supplied confidentially on request.

multidimensional space are more justifiable, practical or effective than others; and a given region is likely to be advantageous from some points of view and disadvantageous from others.
In the following we mainly address the project-level/organization-level dimension and the question of lead investigators' own time versus that of assistants and students, with less attention to distinctions along the other dimensions.
Ordinary individual research projects (with a small number of investigators over a small number of years), especially in responsive mode where there is no push to thematic cohesion between different grants, are usually at too small a grain and too small a scale to be genuinely assessable on likelihood of real, long-lasting societal/economic benefit, or for it to be reasonable to expect them to have it. Rather, it is universities as wholes, not individual projects, that might be expected in the long term to produce a decent amount of economic/societal benefit and to be able to put forward a well-evidenced, plausible case that their research programmes will provide such benefit. Thus, to the extent that government funding for research is tied to having some assurance of economic/societal benefit in the foreseeable future, it is logical to focus on university-level funding, whether through QR-style funding, grants under targeted programmes such as that for Digital Economy Hubs, or other mechanisms. The roughly-QR-style case of general support for staff research is an important element in the mix here as it allows for innovative research beyond what the government has already foreseen, and has a regular, ongoing quality that is important in view of the fact that innovative research ideas can be inspired at any time and can need long periods of mental incubation.
But, in a similar way, QR-style funding is also important for curiosity-driven research. It is much easier for a university as a whole to make a case that its purely curiosity-driven research is something the country should fund than it is for an individual grant proposal to justify the worth of the specific curiosity-driven research it proposes. A university can point to examples over many years of where its curiosity-driven research has led in the past. Again, the point is one of grain and scale: it is a curiosity driven research as a whole, or at least in large chunks, that can best be argued to be in the nation's interest.
Furthermore, by its very nature curiosity-driven research is risky, and especially in its initial stages is best served by ensuring that academic staff in universities are given substantial blocks of time in which to do their research as part of their paid contract, without having to secure funds from outside to cover that time. Securing these funds involves making a case for worthiness that may in principle not be able to be made and that is dependent on the lottery of the particular academics elsewhere chosen as reviewers having the right sort of vision to approve the work. It is up to the university to attract and nurture excellent staff who can be expected to do excellent research. Some of that research can be, or can become, linked to programmes in the university that are aimed at particular types of expected societal impact. Some of it can be, or can become, riskier and more open-ended. And the balance here in the case of any specific academic is not entirely predictable on appointment. Indeed if it were predictable one might question the wisdom of the appointment.
Better built-in funding for research at staff-initiated research at Universities would remove current tremendous pressures on early-career academics in research universities to spend precious time on chasing scarce funding, time that should be devoted to expanding their research horizons (not to mention becoming excellent teachers, administrators, and outreach agents). One important time-consuming activity here is studying related disciplines.
Cross-disciplinarity strengthens all these points. The panoply of possible mixtures of disciplines in cross-disciplinary projects (in AI or elsewhere) is too great for it to be reasonable to expect national bodies to service it properly and fully.
It is universities, not government, that are . in principle at least . in the best position to set up (internally or by interuniversity links) flexible, context-sensitive, imaginative arrangements for cross-disciplinarity, where these arrangements may be unpredictable in structure and may go beyond the scope of mechanisms that a national body has thought to set up. This is not to negate the important role that grants from national bodies could play. For instance, apart from some of the cross-disciplinary initiatives that RCUK has at times commendably set up, we are attracted by the idea of Structured Interdisciplinary Research Programme grants from the government, as proposed in the (independent) response to this consultation by John Fox (Professor of Engineering Science, University of Oxford, and Fellow of the AISB).
We believe these considerations suggest is the great importance of, roughly speaking at least, enhanced QR-style funding: organization-level, per-staff-member funding enabling universities standardly to have their academic staff devote large portions of their working time (over each year) to research devised on their own initiative. (Of course, there is a need for suitable monitoring practices to ensure diligence.) Universities should not be dependent on external, additional funding to support this mode of operation. Such research activity by its staff is a large part of its central mission and should be paid for as part of the staff's normal salary. We are therefore calling for more of a recognition that it is the nationally crucial job of universities to undertake research, and to include risky, imaginative research alongside research of

more assured, more obvious and prompter societal impact. Finally, the needed recognition is not just on the part of government and other national policy leaders but also by university administrators and academics themselves.

Of course, to the extent that staff need assistants or other additional resources for their research, there remains a role as at present for applying to research councils, charities, companies, etc. for the necessary funds, whether in targeted programmes or under responsive mode, and whether the research is strongly curiosity-driven or not.

One upshot is that, against the current trend towards full economic costing of the lead investigators' time, this time should in many cases already be provided by better core funding of universities. This does not of course itself prevent academics from applying for external funds to buy additional research time. Another corollary is that in responsive-mode project-level government funding there should be little if any pressure to demonstrate likely economic or societal impact. Such impact would be more the responsibility of (some) targeted programmes, (some) university-level funding, and third-sector funding. The likely impact that should be required to be argued is impact within the scientific or other disciplines involved in the research.

We are aware that the ideas expressed here do not sit well with the current economic circumstances of the country and in particular the current threat of spending cuts in HE, but we rely on this consultation truly being about the next 20 years not the next two. In this connection we should comment on the views reportedly expressed by David Lammy, HE Minister, at the Universities UK Annual Members Conference in September 2009.[36] We can certainly support Lammy's call for more UK universities to emphasize their economic and social contribution in their publicity material. However, his statement that [as reported] .Research funding will depend increasingly on demonstrating the potential impact [of an economic or social kind, presumably] of academic work to panels of businesspeople and policymakers. is highly questionable if the envisaged panels are not just for restricted types of funding but extend more generally. Why business people and policymakers? There is no evidence that businesspeople and policymakers are in more of a position to judge likely economic/social impact than academics are, in long-term cases at least. Indeed, many academics have authoritative knowledge about economic and social impact of advances in their field. Moreover, the independent advice of academic historians of commerce, society and science would be important. In any case businesspeople and (politically biased) policymakers have their own vested interests that it would be difficult to believe they would simply put aside, especially when it comes to long-term impact (cf. the comments above on short-term cycles in the subsection on Question 1).

Finally, whether the above ideas are followed or not, the better support of curiosity-led and/or cross-disciplinary research may require changes in culture and practice within universities themselves, both amongst the administrative bodies and amongst the academics. In particular, while deep changes in funding ecology may be called for, these will probably require deep changes in funding digestion.how universities manage the use of whatever funds are acquired. Although the issues are too large to go into here, there are consequences for university structure, budget-apportionment practices, other aspects of internal governance, and promotion practices. We would point in particular to the dangers of having rigidly organized research groups, a large role for individual funding success in academic promotion, and lack of imaginative management provision for bottom-up creation of cross-disciplinary initiatives.

[36] Image is everything, Lammy tells v-cs,. Times Higher Education, 17 September 2009, pp.10.11.

Association of Medical Research Charities

RE: Call for Evidence – Fruits of Curiosity: science, innovation and future sources of wealth

I am writing in my role as scientific adviser to the Association of Medical Research Charities (AMRC). AMRC is a membership organisation of the leading medical and health research charities in the UK. In 2008-09 AMRC's 119 member charities spent over £900 million on medical and health research in the UK aimed at tackling diseases such as heart disease, cancer and diabetes, as well as rarer conditions like cystic fibrosis and motor neurone disease. This makes up approximately one third of all public expenditure on medical and health research in the UK – the other two thirds coming from the MRC and NIHR respectively.

AMRC's membership includes a diverse range of charitable organisations. All share a commitment to funding the highest quality research for patient benefit. Many have a strong patient group allied to them. The sector is unique internationally in terms of its scale and impact

We welcome the initiative being taken by the Royal Society in launching this inquiry and announcing your intent to look ahead to assess the long-term direction of UK science and innovation policy and the role that science will play in equipping Britain to meet the economic, social and environmental challenges of the next fifty years.

It is important to focus on our end goal for science in the UK to set the shape of the debate to lead us through the next general election and into the new government. This will allow us to identify and tackle the current problems that are preventing us from achieving this direction of travel rather than becoming overwhelmed by the sheer breadth of current challenges.

Speaking as I am on behalf of AMRC I will focus on the medical sciences and the role of charity-funded research. Predictions in medical sciences have always been rather fraught, making any long-term forecast of direction difficult, but one fact that is absolutely clear is that we are all living longer. And the evidence is that the extra years gained will not mean a longer period of ill health and dependency before death. We will remain healthy longer too. And at least 50% of this life extension is due to the application of medical science. **Creating an environment which continues to foster and support new developments in medical science is vital.**

Currently, in medical research – despite problems and perhaps because of the multiplicity of funding sources – the UK does well and punches above its weight internationally.
We are ahead of the rest of Europe but others are catching up fast, especially in China, India and Singapore and as they rise we are falling behind. We cannot be complacent.

The value of medical research to the UK is considerable. A recent report commissioned by MRC, The Wellcome Trust, and The Academy of Medical Sciences *Medical Research: What's it worth? Estimating the Economic Benefits from Medical Research in the UK*[37] looked specifically at cardiovascular disease research in the UK, concluding that each £1 investment in public/charitable research produced a stream of benefits equivalent in value to earning £0.39 per year in perpetuity.

And the impact such investment in research can have on transforming the treatment and care of patients and their hope for the future is considerable. AMRC members focused on specific diseases have charted huge steps forward as they provide ongoing support – for example Parkinson's Disease Society is currently celebrating 40 years of investment in research with *Four Decades of Discovery: Finding a cure for Parkinson's*[38].

Charities play a big role in this. In 2008-09 AMRC's 119 member charities spent over £900 million on medical and health research in the UK aimed at tackling diseases such as heart disease, cancer and

[37] The Wellcome Trust, MRC, The Academy of Medical Sciences, *Medical Research: What's it worth? Estimating the Economic Benefits from Medical Research in the UK,* November 2008 - http://www.wellcome.ac.uk/About-us/Publications/Reports/Biomedical-science/WTX052113.htm
[38] Parkinson's Disease Society, *Four Decades of Discovery: finding a cure for Parkinson's,* 2009 - http://www.parkinsons.org.uk/pdf/research_fourdecadesofdiscovery.pdf

diabetes, as well as rarer conditions like cystic fibrosis and motor neurone disease. This makes up approximately one third of all public expenditure on medical and health research in the UK.

There is much excitement about the potential for the basic sciences, cellular and molecular biology, stem cell biology, imaging and so on. But we cannot afford to wait while the dividends from that work come along. Medical research has always been focused on outcomes which are potentially valuable to the population no matter how blue skies it might seem. **Charities can play a strong role in supporting research looking at how existing information can be best translated into effective action.**

A UK Clinical Research Collaboration (UKCRC) study analysing health research funded by medical research charities in the UK illustrates the spread of charity funding across research activity. The majority of charities participating in the study were found to spend the largest proportion of their funds supporting aetiology research into the causes of disease and 93.7% of their combined funds were focused in disease specific areas. However they were also spending a greater proportion of their funding on the development of treatments, diseases management etc. than other public funders.

For many, their research funding strategy is decided in conversation with their patients – creating the drive and incentive to fund research leading directly to patient benefit. For example, Asthma UK and the British Thoracic Society helped bring together groups of patients and clinicians, in a James Lind Alliance partnership, to decide which areas of uncertainty around treatments should be prioritised for research going forward[39].

There is concern that the Medical Research Council (MRC) must continue to fund fundamental research while keeping a foot in the translation field. Working alongside charities supporting research to translate existing information into effective action can ensure that MRC is not forced to move away from its basic research and response modes of funding and charities – more flexible and diverse as they are by nature in their funding streams – can help create the pull through the translation gaps to bring basic research towards healthcare delivery for patient benefit.

To ensure this can be achieved effectively, collaboration between charities and other research funders, particularly the NHS R&D funders, the MRC and the Office for the Strategic Coordination of Health Research (OSCHR), must be maximised.

In the medical and health research arena the main thrust of Government policy, as enshrined in Cooksey and OSCHR, is well-aligned and responsive to these priorities. We welcome the partnership approach embodied in the UKCRC and the practical steps that are being taken by OSCHR to bring the National Institute for Health Research (NIHR) and MRC closer together. **However – despite welcome steps to actively involve all stakeholders including medical research charities in setting National Ambitions on Health Research - there is a need to actively work more closely with the charity sector and ensure that they are involved in practice.**

If UK medical sciences research is to flourish, there is a need to ensure that industry is also able to co-ordinate its efforts with public and charity funders. We welcome OSCHRs work in this area and the current work of the Office for Life Sciences (OLS). But there is a noticeable focus in all this work on research/industry interaction and less attention paid to promoting cooperation by industry with the charity sector despite the large amount of funding charities represent and promising instances in which they have worked together successfully in the past.

More could be done at a high level to encourage closer working between industry, charities and other public sector funders. At present, where work is taken together between charities and industry, it is generally opportunistic and not planned in any systematic way. AMRC has undertaken work to support such initiatives including producing *An Essential Partnership: Principles and Guidelines for Working with Industry* (http://www.amrc.org.uk/HomePage/Default.aspx?Nav=815,553) but many problems – such as issues around VAT cost incurred by collaborative projects – will require further Government intervention. A forum enabling discussion, putting in place incentives and promoting better working relations between all three would be valuable and could improve the scale and contribution of private sector R&D to the UK.

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[39] March 2007 - http://www.lindalliance.org/Asthma_Working_Partnership.asp

Demonstrating the potential of this, a report soon to be published by the Alzheimer's Research Trust *Forward Together*: *Complementarity of public and charitable research with respect to private research spending* concludes that public and charitable research stimulates additional private R&D that would otherwise not have been carried out. Based on US data the study estimates that a £1 increase in extra public medical research can lead to an increase in private pharmaceutical industry R&D spending in the range of £2.20 - £5.10.

Ensuring we harness the benefits of our unique charitable sector will be vital to maintain the UK's international standing in medical research. But in order to do this, the UK must make ensure the environment remains conducive to charitable funding.

The sustainability of charity-funded research in universities is an important issue which must be tackled. Universities and charities require secure funding arrangements to plan for the future. The current lack of a clear, ongoing government commitment to existing mechanisms – such as the Charity Research Support Fund and its equivalents in Scotland, Wales and NI designed to support charity funding of research in universities - fosters concerns over the robustness of these mechanisms going forward and their ability to keep track with the changing funding landscape.

If the Government wishes to continue fostering this diverse funding landscape in the UK's universities, they must commit to a healthy future for the Charity Research Support Funds in step with charity ambitions for research to ensure charities can continue to compete with other funders to fund the best research in Universities while ensuring universities receive vital infrastructure support.

Also vital to encouraging charitable funding in the UK is ensuring the UK remains an attractive place to do research. Reducing bureaucracy involved in research regulation to ensure processes are as simple and efficient as possible will be a key part of this.

In an environment where charities play a key role in the development and direction of science policy and are supported to work on a sustainable footing with other funders, the UK will be able to harness other benefits from the charity sector beyond the considerable economic boost to our research capacity.

Many medical research charities have a strong patient group allied to them. An Ipsos MORI poll commissioned by AMRC in October 2008 showed that a majority (57%) of British adults 15+ have donated money to a medical research charity. When further questioned "How interested are you in medical research in general?" 58% responded that they have an interest in this area[40].

As this demonstrates, medical research charities provide a direct link to the public who choose to support medical research through them and are therefore directly interested in the medical research that they fund.

Many issues constantly arise and place hurdles in the way of research and solutions need to be found that maximise benefits to society while acknowledging public questions, uncertainties and concerns. As the 2008 BBSRC/MRC funded *Stem Cell Dialogue* report[41] recognised medical research charities inspire high levels of confidence and support from the public and can play a key role in engaging the public with science. As science develops in the future, charities can play a key role involving the public in the development of a regulatory environment for research which draws the right balance between conducting the best research with the aim of improving health and wellbeing while respecting patient confidentiality and safety.

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[40] **Question:** Some medical charities concentrate on providing care, information, education, doing medical research. Would you be more or less likely to give money to a charity that uses its donations to pursue medical research into a cause or cure?
Results: very interested 12%; interested 46%; not very interested 30%; not all interested 10%; don't know 2%; interested (net) 58%; not interested 41%

[41] BBSRC, MRC, ScienceWise, *Stem Cell Dialogue*. Dec 2008 – http://www.bbsrc.ac.uk/society/dialogue/activities/stem_cell_final_report.pdf
Recommendation 3 "…*There is a significant opportunity for a coordinated campaign by medical research charities to raise the resources and profile of stem cell science.*"

Recognising patient desire to be involved in research, AMRC has recently completed a large piece of work examining how medical research charities involve patients in their all aspects of their research work. The soon to be published *Natural Ground* Report gives many examples of how charities develop meaningful relationships to engage with patients.

This public involvement not only offers the potential to directly involve the public in deciding the direction research should move in but also – as an artefact of this involvement – is an opportunity to inspire and open individual's minds to science as a career path.

Charities themselves recognise the need to support the development of skilled researcher to fund in the UK and directly support and mentor many researchers throughout their careers. Medical research charities in the UK have funded more than 90 Chairs or Professorships over the last 3 years[42] and support initiatives across the science community to invest in tomorrow's talent in schools, universities and the FE sector.

The UK will maintain its international standing and attractiveness if it can maintain the cross-discipline cohesiveness and co-ordination it is starting to build. To achieve these changes for science in the long-term, science needs strong leadership in Government. AMRC would instinctively welcome the establishment of a Department for Science recognising that science is by nature cross-departmental and with a remit to provide leadership across Government – led by a cabinet-level science minister - forging strong cross-departmental links and ensuring consistency of approach and thematic emphasis.

We look forward to the debate.

Yours sincerely

Lord Turnberg
Scientific Adviser, AMRC

[42] AMRC grants database figures – 2006-2009

Bangor University

Royal Society policy study - Call for Evidence – The Fruits of Curiosity: science, innovation and future sources of wealth

Views of Professor S J Hawkins – Head of the College of Natural Sciences at Bangor University

Long-term direction of policy for science

Curiosity driven research is vital to the science base. We do not know what will be the pressing issues in 20-50 years time. Pure science can also inform the policy agenda – scientists were aware of issues such as ozone depletion, global environmental change and acidification of the ocean and put them onto the policy agenda. Strong basic science cascades out into more strategic and applied research, technology and engineering. Many individual scientists have both pure and applied research interests – basic understanding of mechanisms or process usually informing application. Applied and strategic research can also be driven by curiosity – this is often forgotten. It is better to train young scientists on curiosity driven topics; in this regard ensuring adequate funding for Research studentships is crucial to the health of curiosity driven sciences.

The RAE has had many benefits. It has raised expectations and ambition in terms of quality of science; most importantly it has emphasised the importance of fewer but more significant outputs in general journals. The RAE also created a transfer market for talent, prompted less active staff to retire and enabled more younger scientists to be recruited. It has also led to devaluation of teaching in many HEIs, which needs to be reversed. It also has done much to promote selfish behaviour in HEIs. Applied research does not get valued so much and is difficult to judge (I was an RAE special advisor). The RAE has also swallowed much time and energy.

Initiatives such as JIF, SRIF also reversed the lack of spend on infrastructure across the HEI sector. They did lead to one or two white elephants as kit is only as good as the technical support to use it. National facilities as operated by NERC and other research councils are particularly important and good spend of public money, moderated by light touch peer review. Such schemes need to continue, but it is important that major investments are open to a wider community via regional nodes forming networked national facilities. In any successor to SRIF the funding councils need to also enable technical support and maintenance contracts to be costed into bids.

There is a real risk that over concentration of resources into "centres of excellence" may stifle individual talent in less favoured institutions. In the 50s, 60s, 70s and 80s there were Fellows of the Royal Society sprinkled across the HE sector, including smaller institutions such as Bangor. In the most part many talented younger individuals thrived in these less favoured institutions or departments; it is more difficult to do so today. Having real research talent broadly spread over the HEI landscape is crucial for the health of science. Departmental closures have not helped this spread and there are knock-on impacts on adjacent disciplines if a University closes its physics, chemistry or maths department.

Research Council funded institutes have undergone much change and there has been lack of clarity on what the Research Councils wish to do with their Institutes. This uncertainty has led to a variety of models ranging from absorption into HEIs, hosting by HEIS through to independent charitable status. Former networks of institutes have been dissolved (eg the NERC marine laboratories). There is also a parallel universe of Government funded institutes, sometimes established as Agencies (i.e. CEFAS). Research Institutes are important stewards of National Capability but also excellent vehicles for strategic long-term research. Perhaps integration of the Government with the Research Council Institutes would be the most cost-effective vehicle for strategic and applied science? Similarly a single National Research Council or Foundation promoting and funding curiosity-driven research could be a good way forward. This should be more arms length from Government, and the Royal Society could play an important role in Governance of any such Council.

The key to dealing with the US, China and growing economies such as India is to work with them on joint projects and schemes. For the UK to remain attractive, it needs to have open, transparent and fair

funding mechanisms with a success rate better than 1 in 5. The risk at the moment is that we spend more time applying for funding than actually doing science and writing papers.

Rather than assess impacts it is important to demonstrate impacts to society. This needs to be done by some skilful narrative engagement with Society. A flat screen TV or mobile 'phone could be used as a starting point to illustrate the importance of physical sciences and engineering. Two or three widely used prescription or over the counter drugs could be the kick-off point for biomolecular sciences. Sunscreen could integrate cosmology, environmental and biological sciences. Honey could be the start of illustrating biodiversity goods and services. A tropical fish tank can illustrate evolution. A groyne on a beach for earth systems and climate science by emphasising sea level rise. Society takes innovation and innovators for granted – we need to better communicate the pace of change and how discovery affects our lives.

Investing in tomorrow's talent

In Higher Education increased numbers has diminished the amount of time spent in the laboratory, on fieldcourses and in doing stimulating individual project work. Increasing risk averse Health and Safety regulations have particularly affected individual investigations in the environmental and earth sciences. The RAS has raised the standard of British Science, but coupled with larger classes and less resource student practical experience now does not compare well with the past. Standards of lecturing are much higher and non-practical teaching is much more innovative. 4 year degree programmes will put this back in place for the ablest students.

The major challenge is to continue learning by doing. Many individuals only get turned-on by science when doing individual or small group research projects. More resource needs to be made available to support STEM – physical, biological and environmental sciences need to have a much higher unit of resource than non-laboratory/field based subjects.

As far as attracting and retaining excellent science specialists at all levels, there are four simple things: better pay, better conditions including less bureaucracy and less evaluation, performance indicators etc, better status – and better work-life balance. It is impossible to be a highly successful University academic without spending 50-60 hours a week working – 10 each week is probably spent on unnecessary administrative/management activities. A major challenge remains in the narrowness and specialised nature of UK education, particularly in England and Wales. The system in Scotland, Northern Ireland, Eire and much of the Commonwealth with a broader education (Higher in Scotland) at pre-University level, before entry to a four year degree benefits scientists. It also enables non-scientists to have a broader view including some appreciation of science. To be a good biological or environmental scientist competence in maths, physics, chemistry, biology and geography/geology are required. No set of "A" levels does this well. It also helps to be able to write and be IT literate. Our biggest challenge is to find a replacement for "A" levels and various combinations lading to 4 year undergraduate degrees – with exit after 3 years for those that wish to have a general liberal education. Specialism at University level also needs to be reversed – many students end up leaving University knowing an awful lot about a little.

Building and sustaining research careers

Research has to be made attractive by better pay, better progression (via more junior and advanced fellowships), better conditions and more job security. It is a real risk learning highly specialised skills and acquiring narrow expertise. HEI lecturing is now perceived as a tough job by postgraduates and puts people off from the highly competitive research track. There have also been substantial redundancies in recent years in the research institutes (i.e CEH downsize).

Once off the "career track" it is difficult to get back in so time out of academia in industry and business does not help unless the individual has skills that are in shortage (i.e. mathematical modelling, biomolecular skills).

Progression of female researchers is particularly problematic. To be a success these days and secure a permanent position 2-3 post-docs are required. This route is not compatible with starting a family. In my own case I have supervised/hosted about 30 British PhD students and postdocs, with about equal numbers of each sex. Several of the males have gone onto Chairs (2), Readerships (2), Senior Lectureship (1), Lectureships (2), Institute senior researcher (2) at home and overseas. None of my female students

have progressed beyond post-docs, eventually going into more family friendly positions in conservation agencies (2), teaching (3), Church of England priest (1), consultancy (1). It is often the second post-doc that is the final one for females.

Science, innovation and wealth creation

Co-funding initiatives between the private sector and HEI's supported by tax breaks would work well and provide talent for industry. The SMEs are quite vibrant in the environmental sector and schemes tailored to enable consultants to dip back into academia to do research as part of CPD would be valuable.

The ecology of research funding

As an ecologist I am not sure this is the right term to use – perhaps the research landscape would be better? It is crucial that the Research Councils (perhaps one big foundation) ring-fence at least 50% (60% would be better) for responsive mode funding – but that this could also address strategic and applied research. Targetted and programmatic funding needs to avoid "insider trading" and be transparent and open to peer review. The UK should value its Institutes but their resources and infrastructure should be available to the HEI sector. Valuable interfaces between HEIs and Institutes occur and these should be encourage and build upon by fit-for-purpose hosting arrangements (eg the NERC Proudman Oceanographic Institute at Liverpool and NERC CEH at Bangor are good examples of best practice. The Institutes retain independence but interact a lot with the host via joint positions and other initiatives. I personally feel that there should be a consolidation of the Research Council and Government institutes to provide strategic and applied research capability. One research council would simplify things and stop research dropping down cracks between them.

Funding should be allocated through peer review, moderated by Committee. Both projects and programmes could be allocated this way. Some countries support individual scientists and their programmes, rather than projects. Modest funding allocated in this way would encourage academic to work themselves at the bench or in the field and provide continuity between grants. Such a scheme could be administered by the Royal Society but be front-loaded to give bigger grants to younger researchers but also allow established researchers to apply for £5-10k per year for 5 years to support their research.

Dr Gerald Brooks

'The Fruits of Curiosity 09'

Dear Dr Wilsdon,

Recent sight of the Royal Society of Chemistry's article 'Improving the Chemical -Biology Interface' (RSC Policy Bulletin, September 09) together with your recent call for evidence re the above, prompt me to offer the following, as a case history illustrating an outcome of curiosity driven research. It is perhaps relevant to the **long-term direction of policy for science** item and it demonstrates that the fruits can be unexpected and take a take a long time to appear.

This research, arising from the problem of insect resistance to DDT and other insecticides, began in the DSIR laboratory at Slough in the mid-1950s, leading subsequently into research on hormonal methods for insect control at the University of Sussex.

It led in turn to a search for inhibitors of certain enzymes involved in these processes, already believed to be concerned in inflammation and vertebrate carcinogenesis.

Professor Bruce Hammock at the University of California at Davis initially worked on insect problems but in recent years developed this research in pharmacological directions of potential human benefit, as shown in the attached review. His review illustrates the long-term outcome of research in what seemed at first to be a somewhat narrow field. It summarises the history and current status of research in this area and incidentally shows (cf the RSC's 'interface' article) that US scientists do not feel constrained by disciplinary boundaries.

Bruce Hammock has generously credited me with the pioneering discoveries on epoxide hydrolase (EH) and the long-term developments since then seem to offer an excellent example of the fruits of uninhibited, 'blue sky' research. Furthermore, our former Group at the University of Sussex (1969-1987), provided an early example of interdisciplinary effort bridging chemistry and biochemistry, before talk of such approaches became more fashionable in the UK !

Yours sincerely,

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Pest Management Science Pest Manag Sci **64**:594–609 (2008)

Review

Gerry Brooks and epoxide hydrolases: four decades to a pharmaceutical

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Abstract: The pioneering work of Gerry Brooks on cyclodiene insecticides led to the discovery of a class of enzymes known as epoxide hydrolases. The results from four decades of work confirm Brooks' first observations that the microsomal epoxide hydrolase is important in foreign compound metabolism. Brooks and associates went on to be the first to carry out a systematic study of the inhibition of this enzyme. A second role for this enzyme family was in the degradation of insect juvenile hormone (JH). JH epoxide hydrolases have now been cloned and expressed from several species, and there is interest in developing inhibitors for them. Interestingly, the distantly related mammalian soluble epoxide hydrolase has emerged as a promising pharmacological target for treating hypertension, inflammatory disease and pain. Tight-binding transition-state inhibitors were developed with good ADME (absorption, distribution, metabolism and excretion). These compounds stabilize endogenous epoxides of fatty acids, including arachidonic acid, which have profound therapeutic effects. Now EHs from microorganisms and plants are used in green chemistry. From his seminal work, Dr Brooks opened the field of epoxide hydrolase

research in many directions including xenobiotic metabolism, insect physiology and human health, as well as asymmetric organic synthesis.
2008 Society of Chemical Industry
Keywords: xenobiotic metabolism; juvenile hormone; cardiovascular diseases; asymmetric organic synthesis
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(*Received 5 July 2007; revised version received 10 August 2007; accepted 14 August 2007*)
Published online 28 March 2008; DOI: 10.1002/ps.1583

The British Academy

A Submission from the British Academy to the Royal Society's call for evidence

The Fruits of Curiosity: science, innovation and future sources of wealth

Introduction

1. The British Academy, the UK's national academy for the humanities and social sciences, is pleased to respond to the Royal Society's inquiry to assess the long-term direction of UK science and innovation policy.

The long term direction of policy for science

2. As we are sure our colleagues at the Royal Society will agree, any long term policy for science (in its narrow sense – i.e. science, technology, engineering and medicine – STEM) must recognise that scientific and technological advances can be used effectively only if political, social and cultural understanding is deployed and all disciplines are able to work together. For example, the involvement of humanities and social science (HSS) disciplines in the debate on climate change (as demonstrated by the Stern Review on the Economics of Climate Change) increased public awareness of both the economic and social threats of climate change, and the measures that might be employed to mitigate the problem. We were therefore delighted when the Royal Society used a number of recent opportunities, such as the recent debate on the reprioritisation of science funding, to demonstrate its commitment to the appropriate support for all disciplines and their ability to shed light jointly on the challenges we face.

3. Expertise in the humanities and social sciences (HSS) provides an understanding of the historical, cultural, social, economic and political environment that is necessary for the full benefit of science (in its narrow sense – i.e. science, technology, engineering and medicine (STEM)) to be realised. Just as any strategy for HSS research needs to recognise the importance of effective interplay and collaboration with the natural sciences, the same is true for any policy drawn up for science (in the narrow sense). The inquiry may also be interested in the way the Department for Business, Innovation and Skills (BIS) has defined 'science':
"By 'science' we mean all-encompassing knowledge based on scholarship and research undertaken in the physical, biological, engineering, medical, natural and social disciplines, including the arts and humanities, which is underpinned by methodologies that build up and test understanding about our world and beyond."

4. The Academy believes that it would be helpful if the Royal Society could consider ways in which the inquiry might also explore ways in which HSS contributions could be better exploited in science policies in order to:

- place scientific and technological developments in a social, cultural and historical context;
- understand the ethical implications of scientific and technological advances;
- provide a historical perspective to scientific problems and issues (e.g. give the historical context to the climate change debate);
- understand the history of scientific developments undertaken overseas, to help foster international collaborations;
- analyse issues of public accountability and improve public engagement with science;
- improve our understanding of the role of the media, as well as the way in which the public understands the messages presented by the media;
- identify the misuses of the full range of the sciences, from natural science and technology to social science and the humanities sciences;
- contribute to a critical understanding of research, working practices and the conditions of innovation in the full range of the sciences;
- explore and articulate issues of trust and trustworthiness.

5. HSS research has not merely studied the effects of scientific innovation. It has addressed the social, economic and political conditions that lead to the pursuit of some STEM questions not others, together with the ways in which scientific knowledge becomes codified and recognized as reliable and, indeed, scientific. Donald Mackenzie, FBA, is a leader in this field (e.g. his books *Knowing Machines,* and *The Social Shaping of Technology).*

What role should curiosity-driven research play in the UK science base in the next 15-25 years?

6. A national research framework is unlikely to be world-class unless it provides sufficient support for curiosity-driven research alongside strategically planned research programmes. The British Academy is delighted that the inquiry will seek to "challenge the separation of 'pure' and 'applied' research and move towards a richer understanding of how a vital and diverse research base creates value in many different ways: through the supply of skilled individuals; through contributions to wealth creation and quality of life; or through discovering more about the world we live in." The term 'curiosity-driven research' does not only cover research which emanates from individual curiosity, but may also encompass research which responds to identified needs of various types which may arise at many different levels of society. Applied research relies on the foundations that have been developed by basic research. Both basic and applied research have to be funded properly and on the basis of excellence, if the UK research base is to prosper. The worst of all possible worlds is to have poor quality research with high impact.

Public engagement with science

7. In recent years, the debate about public engagement with science has moved away from the concept of one-way communication with the public (the "deficit" model – communicating scientific advances to the public will lead to understanding and acceptance) to a two-way interactive model ("upstream" public engagement, where the public can be involved early on and throughout research and development processes). These developments draw on concepts and techniques developed in HSS, but they need to be properly evaluated, to ensure that these technologies of social engagement really do deliver on their promise.

8. The Academy therefore believes that more research is needed on whether upstream public engagement works, and the conditions in which it can work. More work also needs to be undertaken on the best ways of consulting the public, especially as there is no single template for public consultation, with each approach offering particular strengths and limitations. We believe that government departments need to develop a better understanding of what each approach has to offer, so that it is better placed to maximise the effectiveness of government commissioned consultations and evaluations.

9. Given that scientific advances often raise complex social, political, economic and ethical questions, policies for science and innovation need to incorporate these dimensions from the outset. In particular, the ethical and social dimensions of emerging technologies need to be appraised if they are to deliver on their promise.

10. The British Academy would be happy to provide the inquiry with further support and advice on public engagement issues.

How should science be governed to maximise benefits to society while acknowledging public questions, uncertainties and concerns

11. The Academy supports efforts to ensure that research is conducted to the highest possible standards, by fostering and reinforcing principles of good research conduct. We consider Sir David King's *Rigour, Respect, Responsibility: A Universal Ethical Code for Scientists* is a good starting point for a debate on ways in which the UK can strengthen the culture and working practices of its researchers. The code has been devised as a tool for formative assessment and cultural change in the natural sciences.

12. There has been considerable debate about the most effective means of ensuring that there is public confidence in the governance and use of science. For example, last year's Academy report (chaired by

Professor Alan Wilson, FBA, FRS) *Punching our Weight: the humanities and social sciences in public policymaking,* set out a number of ways in which the Government might better exploit the HSS academic research base. Baroness O'Neill's, FBA, has made a series of notable and fundamental contributions to the debate on trust and trustworthiness including her BBC Reith Lectures of 2002, *A Question of Trust.*[43] The Royal Society may be interested in the way in which Academy's summed up and framed the issue in its response to the DIUS's consultation, 'A Vision for Science and Society':

"trust is well placed only if research, evidence, policies and institutions are trustworthy. The first task for those who invite others to trust them is to be trustworthy; the second is to show that they are trustworthy;

trust in scientific work - in the broadest sense of the term - and in policies based on that evidence will therefore be well placed only if both are trustworthy, and are demonstrably anchored in **s**cientific understanding, broadly understood, underpinned by appropriate and rigorous methods of inquiry;

the Government cannot directly improve trust, since it is for others to give or refuse. However both Government and the research community can make it more feasible for others to place trust by showing clearly that scientific work and the policies and institutions that rely on that work are trustworthy."

Building and sustaining research careers

13. The Academy is pleased that the inquiry will look at ways in which research careers – within academia or industry – can be made a more attractive option for young people, both within the UK system and from abroad. In this context, it should be noted that OECD (Organisation for Economic Co-operation and Development) data show that the proportion of researchers per thousand FTE (full-time equivalent) employed in the UK is lower than both the EU average as a whole and the OECD average.[44] In addition, the UK proportion of researchers per thousand employed has increased only slightly in the last 25 years, whereas for some of our major international competitors the proportion has increased significantly.

14. Many of the postgraduate researchers studying in the UK are drawn from overseas. The Academy (in line with many others in the sector) is concerned about the increasing international competition for postgraduate and early career researchers. We note that the Royal Society's report, *A higher degree of concern*, found that registrations for science doctorates by UK students dropped from 65% to 57% of all science (in the narrow sense) PhDs over the last 10 years compared with a 79% growth in doctoral degrees overall. The British Academy itself has drawn attention in a number of its reports (including *A Review of Graduate Studies, 2001)* to its concerns about the shortage of UK-born PhD students in certain HSS fields (particularly Economics, Financial Management, European Languages, and the lack of social scientists with quantitative skills) and the difficulties of attracting the most talented postgraduate researchers into many of these fields when salaries offered by the City are so much higher than those for academia.

15. The competition for overseas students is likely to intensify in the future, with growing competition from countries such as China (which is currently a major source of the overseas students studying in the UK) as its own universities continue to improve and develop. The UK therefore has to think imaginatively about the incentives it provides to overseas students to study in the UK.

16. The Academy believes that more can be done raise the profile of postgraduate research and also the academic profession. It also considers that there is scope for universities, research funders and learned societies to work together to promote more effectively the opportunities that are available, and that more information should be provided to undergraduate students about research careers. The Academy also endorses many of the recommendations in the last year's report by Professor Thrift, FBA, *Research Careers in the UK: A Review*, including:

    - the need for Government to develop a more sophisticated long-term understanding of the supply of and demand for researchers across all sectors and disciplines.

[43] http://www.bbc.co.uk/radio4/reith2002/
[44] OECD Science, Technology and Industry Scoreboard 2008

- the enhancement of the opportunities offered by existing programmes and international relationships between universities, learned societies and professional bodies to identify and support talented young scholars from around the world.
- ways in which there can be greater transferability of researchers between academia and industry where appropriate.

17. The Academy's recent position paper, *Language Matters*, drew attention to its concerns that poor language skills may limit the ability of UK-born researchers to contribute to international projects, and may also limit the career opportunities to them. We believe this is an issue of concern to the Royal Society as well, and the Inquiry may therefore wish to consider how UK-born postgraduate researchers can be better equipped to compete with their counterparts from overseas.

Conclusion

18. The British Academy welcomes this important inquiry. We are delighted that the inquiry will challenge the current (and in our view unhelpful) perception that there is a division between applied and basic research. The Academy also thinks it would be helpful if the inquiry considered ways in which HSS contributions could be better exploited in science policies. Consideration should also be given to the training and support given to postgraduate researchers, to enable them to engage and compete more effectively with their counterparts from overseas. The British Academy would be happy to discuss any of these points in more depth, and to provide any further assistance to the inquiry.

30 September 2009

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Dr David Dent

The Fruits of Curiosity: Science, innovation and future sources of wealth

The Royal Society Call for Evidence
Submission by Dr David Dent

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1. What role should curiosity-driven research play in the UK science base in the next 15-25 years?

The role of curiosity-driven research must decrease in importance over the next 15-25 years as we move from an emphasis on science-supply-led innovation (curiosity driven) to more market-led scientific innovation to meet the challenges of food security and climate change. Curiosity-driven research dominates UK science and needs to be rebalanced with more market-led science and innovation where the outcomes (which may be technologies, products or services) are defined by the needs and specifications of the market. With market-led innovation market needs are defined and research undertaken, innovating to meet these needs. An extreme example of market-led innovation occurs during wartime. Few would "have imagined the spectacular technologies which the second world war unleashed on the world, all of them full of potential good in spite of their martial origins: nuclear fission, the jet engine, antibiotics, radar and electronics and the most important of all (although it did not seem so at the time) the computer" (Waldegrave 1999 *Science in Parliament*) The reason for this plethora of inventions was the market (although we rarely see war time needs in these terms) – there was a very definite requirement for the products and technologies meeting the stringent demands of wartime Britain. The scale of the problems facing us over the next 15-25 years, the current concerns of climate change and food security should be considered no less demanding.

2. Which elements of policy for science and innovation over the past 10 years have been successful and should be maintained? Where is there room for improvement?

The introduction and monitoring of research output through the Research Assessment Exercise (RAE) concentrated effort on publication of research in high 'impact' academic journals which has enabled the UK to develop a reputation for science excellence on the world wide stage (King, DA. (2004), The Scientific Impact of Nations. *Nature 430, 311-316*). However, the downside of this has been to apply RAE as criteria for success across all of UK research establishments with little or no differentiation between universities and national research institutes. This approach has been seriously flawed for the simple reason that it has created a single amorphous, inflexible UK one-size-fits-all research capability. As a policy it has been successful in transferring costs and responsibilities to universities through the amalgamation and incorporation of research institutes into university departments. However, during a time when we have been looking for economic development through innovation, such amalgamations have lost the opportunity to imbue our national research institutes with a more market-led research role and objectives, appropriate culture, systems of assessment, reward and the types of scientist required to maximize benefits through innovation.

The UK approach to publicly-funded research has been dominated by the values of academic curiosity-led science for scientific benefit rather than those of the market and market-led scientific innovation for economic benefit.

This means that scientists rarely look to solve particular needs of the market but to solve problems of scientific interest; their purpose, not the development of a product but rather the publication of a scientific paper, the advancement of good science, the contribution to the great knowledge pool of humanity. And if in addition, almost by chance it leads to the possibility of a product or service that may have commercial value then that is a bonus – not the primary objective but an additional bonus. Our whole process is a rather *ad hoc* means of innovation. For example, in the UK system of curiosity/science-led innovation, a product or service may be ensue if someone:

- can identify and assess an innovation and understand its value
- determine if Intellectual Property (IP) that's generated may be protected,
- identify a market for the IP, assess its size and potential
- Conduct any additional research that may be needed to turn the IP into a product or service that will meet market requirements and price
- Link with networks to identify potential commercial partners
- Secure funding or develop licensing or commercial venture with industry.

This whole system of science-led innovation represents a rather indirect, unfocussed approach that relies rather heavily on good fortune to match innovation against unsatisfied market need. This is not to say that science-led innovation does not have value as an approach because there are simply too many success stories in the UK that argue otherwise – you only have to look at the achievements of Imperial College, Oxford and Cambridge Universities to know it can work. However, one is led to question whether the science supply-led approach might be complemented by a more targeted and focused approach to scientific innovation, one where the market (demand) rather than science (supply) acts as the starting point. That is the economic model for innovation where:

- Innovation meets unsatisfied market needs and increases customer or producer value

Successful innovation often starts with the needs of customers rather than in the laboratory with the interests of scientists. Market-led innovation provides the most direct route to product and service success. The market is assessed, opportunities in the market are identified, and requirements of that market specified (including price), innovative approaches sought to meet the opportunities and products and services developed for sale into a pre-defined market with an extant demand. If the solution required is to meet a particular customer need, the product developed must satisfy the customer and hit a target market price.

It helps to understand the issues through three categories of scientific innovation
- Curiosity driven
- Problem driven
- Outcome driven

Curiosity–led science, or pure research is curiosity driven science, there is no end point other than satisfying the curiosity of the scientist and adding to the overall knowledge pool and out of this an innovation of commercial value occasionally materialises.

Outcome driven scientific innovation is the equivalent of an engineering project where there is a need to bridge a river of given dimensions with a particular load bearing capacity and a limited amount of resources available – it is innovation working to specification.

Problem driven scientific innovation sits in between curiosity and outcome driven innovation – it is what we usually think of as applied science – where a solution will be delivered but it will be one that solves the problem but not necessarily one that will meet a market need – it is the equivalent to engineers knowing approximate dimensions required of a bridge, but working with no load bearing specifications and assuming cost is not an issue.

Applied science often only provides half of the answer because it rarely asks the whole question – it concentrates on the problem and a solution that is feasible scientifically rather than a solution that will deliver a product or service meeting the stringent specifications required by the market (affordability, availability and accessibility for users).

Applied scientists often expect "others: to modify and adapt their solution to meet the market needs – hence collaboration with industry, technology transfer networks etc. To focus research and innovation on what is needed in the market you have to ask key questions at the very beginning of the process not half way through and certainly not at the end and expect a commercial company or any other body to pick it up and run with it!

Universities have a role in curiosity and applied driven research whereas our national research institutes (NRIs) should have a different role of applied and outcome driven research – with universities working

with TTOs and KTNs while the NRI will not require these processes because they will innovate and develop technologies which will have been designed to the specifications of a particular market.

The recent trend towards multidisciplinary research recently has been positive but these are rarely underpinned by an ability to work and manage science at an interdisciplinary level, gain appropriate levels of recognition in trans-disciplinary publications and journals (single author, discipline based journals, other than *Nature,* are considered preferable) and achieve a definitive specific output of economic value. This should be the role of our National Research Institutes. A simple example would be to ask what would a perfect fertilizer look like in 2020 – e.g. no green gas house emission, no fossil fuel requirement in its manufacture or delivery, no runoff, sustainable high yields, readily available and cheap. Then one innovates to design and develop such a fertilizer.

Our research institutes need to be more problem and solution focused and involve scientists with abilities to solve problems using a wide range of scientific skills and abilities. However, innovating to a market need utilises different skills to that required to carry out curiosity driven research and our current training is inadequate for this purpose.

3 How will increasing support for science in the US, China and elsewhere impact on the UK's international standing and attractiveness as a place to undertake world-class science?

The UK is promoting itself on the basis of its scientific reputation supported by our ability to publish high quality scientific papers (see above). We think these criteria are important but the rest of the world does not necessarily share our enthusiasm for this measure. China and a number of SE Asian countries are organizing and restructuring their research capability towards market-led innovation (the Thailand National Science and Technology Development Agency BIOTEC Institute is a good example) and are looking to the UK as a source of curiosity-led science to underpin their own weaker capability in this area.

In my role of Sector Specialist for the UKTI funded IATC, I initiated and managed the process that has led to the establishment of a Brazilian Labex (laboratory exchange programme) with the UK at the BBSRC Institute Rothamsted Research. The experience of the Labex programme in France and USA would suggest that this model is one that the UK should consider adopting to develop strategic collaborative international relationships. The Brazilian Labex which is run by their National Research Organisation EMBRAPA, send a senior scientist to work on a collaborative programme of research for 50% of their time and for the other 50% the individual visits other research organizations and programmes with the objective of identifying interesting strategic opportunities for collaboration relevant to EMBRAPA and Brazilian agriculture. This strategic commitment by EMBRAPA has proved so productive that the programme which started in the USA, followed by France (four senior scientists are currently on placement in France) has been extended to the Netherlands and now the UK.

7. What are the future challenges for STEM education at primary, secondary and tertiary levels? How should these challenges be addressed?

Secondary and Tertiary

In order to ensure we reap economic benefits from our science and innovation there is a need for a greater emphasis on skills related to entrepreneurship.
The teaching of learning and study skills that have been introduced in secondary schools over the last 10-years need to be developed further in order to teach students how to be creative and how to identify opportunities and gaps and constraints in our knowledge, processes, capabilities and technologies. These are the skills required by innovators and entrepreneurs.

There has been much debate about the whether it is possible to teach entrepreneurship – some like the idea that entrepreneurs are born not made. While it may not be possible to inculcate the tenacity and drive required to be a successful entrepreneur it is possible to teach creativity and the techniques required to identify opportunities. Courses such as those at Nottingham University's Institute of Enterprise and Innovation have thankfully started to address the former, although to my knowledge no one is yet addressing the latter.

Overall, the approach advocated so eloquently by James Dyson and his approach to design to meet market need is one that should be adopted widely throughout STEM education rather than constrained to specialist academies.

9. How can we make research careers – within academia or industry – a more attractive option for young people, both within the UK system and from abroad?

Careers are attractive to young people provided the role is seen to be respected within society, has kudos and status, has a definite career structure with a good salary and opportunities to progress to the highest levels.

The recent trend in the media to present a positive image of science, scientists and engineerss will have enormous impact in encouraging young people into a scientific career. There are many initiatives encouraging a positive portrayal of science in the media and among the public and these activities need to be maintained – it takes time but it will ultimately have a positive impact. This needs to be complemented by a positive portrayal of science by our politicians, of whom sadly too few understand even the basics of scientific process and methodology.

Many people are attracted to high salaries and the opportunity to become rich. When you compare science to a number of other career options there do not appear too many options for securing wealth. Science careers should include within their structure, opportunities for wealth generation through exploitation of innovations. This opportunity should be made more explicit as part the career promotion of science, and we need to actively encourage scientists throughout their education to seek this route – emphasizing some of the commercial benefits of scientific innovation, the value of creating spinout companies and of market-led innovation.

10. What sorts of incentives can we develop to keep talented students and postgraduates in science? Does the standard career-track model need to be re-evaluated? Should we take more account of the movement of skilled individuals between academia, industry and business?

The opportunity to generate wealth through spin out companies and commercial exploitation of innovation needs to become a genuine component of career development for those scientists who are interested in more commercial aspects science and innovation but it means assessing success and achievement in different ways to just the publication of scientific papers.

12. How can we strengthen science and innovation in all parts of the private sector in the UK, and further improve the exchange of knowledge and expertise between the public and private sectors?

We have to break down this concept in science and innovation of public and private sector. Rather there needs to be a continuum where our national research institutes undertake the strategic market led innovation that crosses the boundary between academia and industry that we have tried to fill with by supporting curiosity-led science with Technology Transfer Offices, Technology Strategy Boards and Knowledge Transfer Networks.

The missing element in all of our existing structures is the ability to identify the gap in the market, the opportunity that has commercial value for which innovation is required. One of the constraints and difficulties faced by SME's that enables them to grow is securing a second product or third product. However, often at a time when they are trying to maximize the benefit of the primary product they rarely have the resources to invest in the second. Resources and targeted assistance to help companies identify new market opportunities and subsequent needs for innovation to exploit the opportunity will go a long way to ensuring small companies can increase their product portfolio and growth.

One of the constraints that industry faces in working with academia is the different cultures between the two types of organization. Academics rarely fully appreciate the time and financial constraints with which companies operate and although research programmes are agreed, in practice academics are too often concerned with the value of the scientific output from the research than the commercial value. The more widespread introduction of research managers utilizing appropriate socio-cognitive frameworks to ensure

outcomes that meet specific needs of industry within large interdisciplinary programmes of research that combine industry, universities and research institutes may be the way forward here.

15. How do we maintain an appropriate funding balance between curiosity-led, response-mode research, and more targeted or programmatic funding?

The balance between these types of funding can only be determined by the goals for the nation. It depends on the value placed on contributing to global knowledge relative to wealth generation and how direct and focused we wish to be in use of innovation to secure economic development. At the moment for the latter, the whole process is disjointed involving too many separate bodies, the route to commercialization is *ad hoc*, unfocussed and undirected. Question 15 arises because we have created an amorphous body of research organisations all assessed by the same criteria rather than having different organizations with different functions, different means of assessing achievement and output relevant to function and different types of funding.

With the current structure, the future will need to be based on interdisciplinary, mulit-institute programmes led by market need if we are to develop solutions to the challenges we face. It is difficult to assess how much curiosity led research contributes to market-led innovation. The story of the discovery, manufacture and use of penicillin is an excellent and salutary example but for the large part, when the market defines what is needed (whether the market is determined by wartime need or future food security) then science and innovation properly focused by extreme need, can deliver. Therefore the emphasis that should be placed on response-mode, targeted or programmatic funding is dependent on the perceived scale and urgency of the challenges we face. This isn't about the niceties of maintaining a curiosity-led science base but rather ensuring we have the capacity to innovate to ensure the nation can sustain itself in the future.

16. What would an ideal research funding landscape look like in 20 years time? How would funding be allocated? What would the funding bodies look like? How would they relate to one another?

The increasing devolution of government to the Regions (driven by closer integration across Europe) will focus research spending and effort on scientific innovation that will meet the needs for regional economic development. Hence there will be a much greater emphasis on market-led science and innovation. This will make it easier for industry and SME's to influence the research agenda, priorities for funding and will encourage clustering of industry built around sector specific research and innovation capability. Regions across Europe having similar priorities, industries and aims will collaborate on research initiatives and secure European funding to do so building on networks such as ERRIN that operates at this time.

National government will retain responsibility and funding for curiosity-led science and for strategic interdisciplinary research programmes which will increasingly involve multinational funding and partners.

Professor David Gann

Call for Evidence - The Fruits of Curiosity: science, innovation and future sources of wealth

Professor David Gann, Chair in Innovation and Technology Management, Imperial College Business School, Imperial College London – 11/9/09

Te long-term direction of policy for science

1. What role should curiosity-driven research play in the UK science base in the next 15-25 years?

I do not think one should detach 'curiosity' from 'research' in any field of study. In a sense then, all research should be driven by some degree of curiosity. For example, engineers solving problems in say structural collapse should be doing so from a perspective of being curious as to how failure occurred, if not, they are acting as technicians following pre-determined rules. But I think the Royal Society is trying to present a case for what we sometimes call 'fundamental' or 'basic' research in science. This is essential and should play a full part in developing and informing science (widely defined), engineering, technology, medicine, business, economics and social science in the next 15-25 years.

I object, however, to the artificial divide between what people sometimes call 'basic' and 'applied' research. Of course there are different drivers, requirements and degrees to which researchers are working with unknowns and risks. But the notion of trying to separate these elements of enquiry are problematic for two reasons: they give rise to a fictitious linear model of innovation; it also obscures the many opportunities for new scientific questions to emerge from domains of practice and technology-in-use. There are many examples where curious minds have found exciting new scientific principles and theories because of the ways in which we interact with the natural world through technology (e.g. environmental sciences).

2. Which elements of policy for science and innovation over the past 10 years have been successful and should be maintained? Where is there room for improvement?

UK research has done well in spite of its organizational set-up. It has benefited from stable/increased funding and it is obvious we should not let this drop off.

UK research has been hindered by a sometimes 'UK plc' approach – e.g. making it difficult to support foreign PhD students or to obtain research funds to work consistently in other countries. We need a much greater international perspective and positioning on how we use our funds.

In relation to this, our research may also be hindered in future because international businesses may not choose to locate their R&D in the UK and UK researchers will need to support to ensure that they team-up with leading companies wherever they locate. Government should also work harder to create conditions to attract inward R&D investment.

There is much room for improvement. What we need is much better integration between so-called upstream and downstream sciences, between lab-based research and technologies in use, and between disciplines. I think the division of funding between different research councils is out-moded and now causing problems for real progress in exciting areas that lie between disciplines (e.g. bio-chemistry, bio-engineering, ICT and business model innovation etc). We need more space for interdisciplinary and concurrent research processes that enable 'aiscovery' and ideas to flow into practice without artificially dividing domains.

3. How will increasing support for science in the US, China and elsewhere impact on the UK's international standing and attractiveness as a place to undertake world-class science?

Research is an international business and more resources invested in science around the world should create better knowledge more rapidly, increasing a healthy competitive environment.

There will be increasing opportunities to employ top scientists from other countries, but we need to make sure that funding streams are in place for this. Firms may also be attracted to lower-cost R&D locations which may further damage UK science-industry collaboration.

4. How should science be governed to maximise benefits to society while acknowledging public questions, uncertainties and concerns?

We need new business models for science to connect with the economy and society. The UK form of organizing decisions on what and where to invest and how to engage with 'the public' is rather quaint

and old-fashioned and certainly now out of date. Science needs to reach-out in new ways, exploiting the benefits of digital economy technologies to engage on risk and uncertainty.
Scientists need a broader educational base to understand the consequences, opportunities, business and social risks and benefits of their work.

5. How should we assess the long-term social and cultural impacts of scientific research?
New metrics are required that will be somewhat specialized by fields of endeavour – e.g. Health (hedonics, well-being indicators), Environment (CO2 emissions, sea-level rises … many more), Energy, Digital Inclusion etc. Social and business benefits should be included. The role of STEM in Services is of paramount importance – see 'Hidden Wealth'.
Investing in tomorrow's talent in schools, universities and in the FE sector

6. How much progress has there been in the past decade in the delivery, content and assessment of education in STEM (Science, Technology, Engineering and Maths) subjects?
I do not think this issue has been taken seriously enough and the UK has failed to improve noticeably at all levels of education (see 'Hidden Wealth' report for importance of this). We need to be much clearer about when people are using 'curiosity' research methods and when they are following technical rules and routines in maintaining ever more complex technical systems and infrastructure. I think this is muddled in academic and vocational education outside of the elite universities.

7. What are the future challenges for STEM education at primary, secondary and tertiary levels? How should these challenges be addressed?
A much broader and deeper understanding of maths, physics, chemistry and biology – equally, a better understanding of how things work – i.e. technology in use.

8. How do we ensure that adequately qualified science and mathematics specialists are attracted into the teaching profession at all levels of education (primary through to tertiary)?
I don't know. Pay them more? I'd be happy to advocate differential pay for scarce/important subjects.

Building and sustaining research careers
9. How can we make research careers – within academia or industry – a more attractive option for young people, both within the UK system and from abroad?
Science and technology should be exciting for anyone who has been enabled to understand principles through a good basic education. We need to continue to stretch people's imaginations and become better communicators of STEM.
We need to open up our funding channels to attract the best talent, no matter where people come from.

10. What sorts of incentives can we develop to keep talented students and postgraduates in science?
Pay them more, provide exciting opportunities, ensure multiple career structures in place between science and industry. Work more closely with industry to develop broad career opportunities combining theory/enquiry/curiosity with practice – so that careers can span academe and industry.

11. Does the standard career-track model need to be re-evaluated? Should we take more account of the movement of skilled individuals between academia, industry and business?
Yes – see 10 above.

Science, innovation and wealth creation
12. How can we strengthen science and innovation in all parts of the private sector in the UK, and further improve the exchange of knowledge and expertise between the public and private sectors?
See points above. UK is in danger of ossifying in relation to science-business relationships (some recent evidence shows relations are declining c.f. AIM Report). UK has to build on excellence in its top universities, investing in talent and ensuring that talented scientists have the funding to engage with business wherever business is located. At the same time developing an attractive environment for inward R&D investment.

13. How can we improve the scale and contribution of private sector R&D?
IP regimes need better understanding and clarification, especially in ICT, digital economy, services and business model innovation. UK science funding and policy also needs a more enlightened view on

international markets. I've heard far too many officials talk about 'UKplc' without a real sense of what a UK company is these days.

14. What initiatives (e.g. tax credits) have been successful or not with regards to supporting innovative businesses in the UK? How can the UK better support business?
I don't think tax credits make a huge difference. They are helpful but not the answer. Evidence of results flowing from talented research to support wealth generation is what attracts and supports business investment and involvement. Most scientists/researchers find it very difficult to articulate the 'impact' of their work in a way that attracts further industry engagement, particularly in recession and in service sectors. Business also knows it can buy ideas from elsewhere, so scientists need to be better able to work quickly and argue the competitive benefits of working with talent in the UK.

The ecology of research funding
15. How do we maintain an appropriate funding balance between curiosity-led, response-mode research, and more targeted or programmatic funding?
The formulation of this question represents all that is wrong with UK research funding. It is indicative of a fictitious linear model (of labs-to-riches) that is unhelpful to scientists and can be deeply unattractive to business.
Abolish the current research council structure. Integrate funding and support interdisciplinary work. Back scientists and teams of scientists that demonstrate talent and creativity. They should only be funded if they are 'curious' (see point 1).

16. What would an ideal research funding landscape look like in 20 years time? How would funding be allocated? What would the funding bodies look like? How would they relate to one another?
No idea in 20 years (this should emerge through practice, evidence analysis and debate). What we need now is an integrated research funder that is internationally enlightened and that has the wit to support a variety of types and styles of research.

17. What role should public sector R&D outside the ring-fenced science budget (e.g. departmental spending, government procurement and national laboratories) play in supporting the UK science base?
Public sector R&D should be no different from any other in terms of quality and its drive to break new ground. Too much public R&D is spent on parochial matters associated with small-minded short-term questions. This supports a tier of mid-range work that is largely irrelevant.

Dr Ernst Alexander Heuer

Q1.
Curiosity driven research science should be central to the UK science base

Q2.
In the past 10 years the creation (based on the German Doctoral Engineering degree) and the pairing up of ever increasing numbers of UK Eng.D Centres at many of the top UK Universities acting in partnership with many diverse companies, has, to my mind, been a very successful exercise. The further deployment and development of schemes of this, or similar nature, are to be encouraged.

Q5.
The social and cultural impacts of scientific research should be felt by society as a whole, if this research is performed in a transparent and ethical manner. Be this not the case, the negative repercussions would be wide-felt. But equally some socially important research, if not undertaken could actually be detrimental for the whole of humankind. A case in point: stem cell research, which recently received financial backing from the US and is being allowed to take place there. Some research laden with moral dilemmas should not be dismissed out of hand altogether; as with proper safeguards in place, it should still be perfectly acceptable to pursue these avenues of enquiry.

Q6.+Q7.
STEM subjects have been diluted when taught in the national curriculum and as a consequence these have seen reduced take up at university. Many pure science departments have either had to close or fuse at certain Universities in order to survive. i.e. the closure of chemistry at Exeter and other universities as an example. Biology and Environmental Sciences which were offered as sole subjects at the then University College Worcester (now University of Worcester), despite being popular courses, were threatened with closure, but they have since had to adapt, pare down the breadth of their subjects on offer, widen their links with local colleges and entirely re-form both the curricula they offer.

Q13.
In my opinion much of private sector R+D is somewhat isolated and conducting research on its own accord without taking account of the wider environment in which it's operating. Also little, if no exchange with University is taking place. By this fact also little cross-fertilisation is taking place. The mutual feed-back loop between the two is little developed, but it should be encouraged.

Elsevier

Submission to Fruits of Curiosity Call for Evidence

We will supply a substantial number of traditional statistics about the research output of UK authors, and also offer a unique way to identify and analyze interdisciplinary strengths. With clear identification of specific competencies accompanied by actionable information, the information will provide a bottom-up assessment of the current state of UK science for targeted investment in specific sectors. The interdisciplinary approach is discussed further below.

To identify areas of research strength and global leadership, we suggest an approach based on a unique algorithm which uses co-citation analysis and innovative visualization techniques. This approach, accounts for the increasingly interdisciplinary nature of science, and for the broader changes in science over time Using Scopus, the world's largest abstract and citations database, as the source for citations and abstracts, a bottom-up analysis is done on the article level that looks at references in order to identify the specific subfields papers are referencing. This approach makes interdisciplinary research visible in a way that traditional methodologies cannot (i). In a recent sample Scopus was found to have more citations than a competing database because of more extensive coverage of non-English journals (ii), a key attribute for taking account of the changing global research landscape, and long-term global collaboration and competition.

UK National Research Strengths and Global Leadership – Distinctive and Emerging Competencies

While the United Kingdom's top distinctive competency exists in the business area of resource management, many of the top ten competencies, as ranked by global research output, are in brain research, medical specialties and related life sciences. The second largest distinctive competency is in the area of computer science, related to the disciplines of data mining and web services (SciVal Governor (iii), 2008 data). With a 9% average growth rate over the last five years, this competency may be a promising candidate for further investment.

Source: SciVal Governor

Global Collaboration and Competition

Investigating the closely intertwined topics of collaboration and competition starts with the question, "Who is working on the same problems?" Existing collaborations both within an institution and between institutions, regions, and nations can be tracked using the co-citation methodology. For each of the UK's

current and emerging research strengths, we will supply the top collaborating and competing nations, institutions, and authors on a competency specific basis.

Image A: Example top Nation list of UK Distinctive Competency 2

Image A: Example top Nation list of UK Distinctive Competency

Source: SciVal Governor

Sectoral mix of the UK research output: a case example

What is the sectoral mix of UK research output? The mix is diverse and multidisciplinary, as evidenced by the scattered distribution of the UK's strengths presented in Image B. This "Wheel of Science" map represents the UK's map of distinctive competencies, namely the subdisciplines in which the UK is a global leader or a strong global competitor. It may be noted that a significant number of the competencies are to be fund in the left upper and lower quadrants, which consist of social and health sciences disciplines. There are also many emerging strengths in engineering and chemistry disciplines, and these areas may represent fields in which targeted investments can be made to build capability and position the UK as a global leader in these fields.

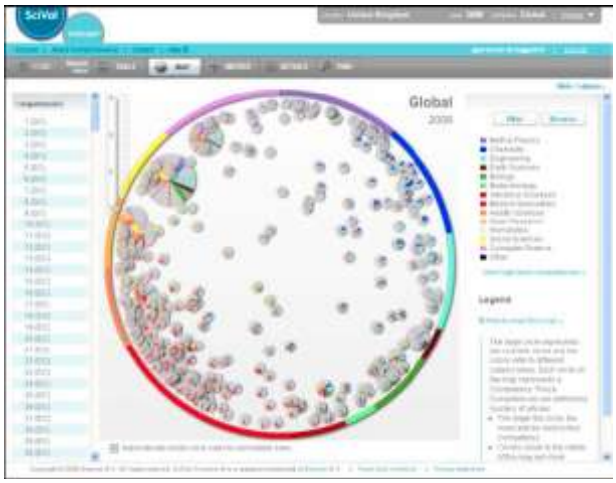

Image B: UK Wheel of Science map
Source: SciVal Governor

Where are the opportunities to invest? To identify opportunities for new or expanded investment with the goal of diversification, consider the case of UK's smallest competency, "Distinctive Competency #366 (DC 366)" from the UK national map (Image C). Disciplines clustered at the circumference of the circle represent traditional subspecialties, while circles closer to the center indicate highly interdisciplinary work.

Judging by its location within the circle, DC 366 is one of the more interdisciplinary of the UK research competencies.

Image C: Distinctive Competency 366
Source: SciVal Governor

With the smallest global market size of all UK competencies, DC 366 is in one of the fastest growing global markets (greatest year-over-year change in global article output) with a high relative market share held by the UK. In Image D below, it can be seen that DC 366 holds the most upper right position in the upper right quadrant, representing high relative market share and high market growth, indicating a potentially attractive sector for investment.

Image D: Matrix View of Competencies
Source: SciVal Governor

After review of the research output constituting the competency, further analysis can be undertaken to confirm this competency represents research in an attractive sector, with opportunities to commercialize research work or to rapidly extend the knowledge base in the discipline. This approach can be used to identify attractive sectors, like low-emission energy sources, that may be candidates for focused investment, expanded funding, or technology transfer.

In summary, we will be able to meet the Royal Society's request for actionable information on the state of the sciences in the UK by supplying the following information:

- Identify areas of science and research where the UK already has, or could soon occupy, a position of global leadership
- Identify global competitors and collaborators
- Analyze and make clear the multidisciplinary nature of UK research output, and identify the most interdisciplinary strengths in the UK scientific landscape.
- Support diversification in the sectoral mix of the UK economy

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iii Elsevier. Governor (working name) is a new SciVal product in development. Full functionality is available for this project. Commercial launch in 2010. More on SciVal: http://www.scival.com.

Geological Society

The Royal Society 'Call for Evidence – The Fruits of Curiosity: science, innovation and future sources of wealth'

Response from the Geological Society

The Geological Society welcomes the Royal Society's major inquiry into the roles science can pay in meeting long term national economic, social and environmental challenges, looking beyond the current 10-year Investment Framework in considering how science, research and innovation should be funded and governed. We are pleased to offer a brief response to some of the issues raised, and would welcome the opportunity to discuss some of these issues further as the project progresses.

We support the Royal Society's wish to move beyond simple distinctions between 'pure' and 'applied' research. This is hardly a novel idea (see Ben Martin's work on 'strategic' research, dating back to the 1980s, for instance), but lazy assumptions about the nature and characteristics of 'pure' and 'applied' work persist. 'Basic' and 'curiosity-driven' are similarly contestable terms. However, it is of course necessary to use terminology of some kind when discussing the variety of types of research – even if care must be taken that these categories are not reified.

The late 18th and early 19th century roots of geology, and its subsequent history, amply demonstrate the impossibility of separating basic and applied science, and the complex non-linear interplay between the development of theory and the drive to address practical and economic issues. William Smith, known as the 'Father of English Geology', was a surveyor, whose practical work in mines, quarries and canals was also the foundation for the first nationwide geological map – a conception which did much to define the modern discipline of geology. The exploration and exploitation of fossil fuels and other mineral resources, in particular, have continued to defy simple notions of pure and applied research, and there is a long and rich tradition of 'knowledge transfer' between academia and industry (though not always characterised as such), whether through collaboration, communication or migration of personnel.

Earth sciences, including Earth System sciences, are distinctive in being characterised by a high degree of idiographic research (that is, research which is to some extend restricted in time and space – focusing on a geological site or a period in Earth history, for example) in addition to nomothetic research (the pursuit of general laws), in comparison to most natural sciences. This distinction should not be confused with the 'basic'/'applied' dimension. Much fundamental or curiosity-driven research in Earth science is highly idiographic – studies of past extinction events or of the formation of particular planetary features, for instance.

The long-term direction of policy for science

1. What role should curiosity-driven research play in the UK science base in the next 15-25 years?

From recent discussions of research governance and funding on the Geological Society's Council and elsewhere, there is evidently consensus that a range of types of research, from curiosity-driven to highly applied work to address immediate problems, is essential to the long term health of Earth science disciplines and communities, and hence to society at large. However, a wide variety of views have been expressed as to what the appropriate balance in public funding should be between these categories of research, and the roles which should be played by central government, research councils, universities and others in their governance.

We would therefore not seek to take a particular view, as a Society, as to what the 'right balance' will be over the coming years. Especially in light of the heterogeneity of views on this matter, it is essential that that scientists from all sorts of institutional and disciplinary background are actively engaged in genuine and ongoing dialogue with government and funding bodies to determine priorities, and that their confidence in decision making and governance structures is nurtured. Welcome though the Royal Society's inquiry to address this issue is, it cannot hope to find 'the right answer' to this question and carry scientific communities with it – still less one which will continue to meet these demands in the long term. It should instead be regarded as a potentially important contribution to a continuous process.

4. How should science be governed to maximise benefits to society while acknowledging public questions, uncertainties and concerns?

This is a very broad question, only limited aspects of which are addressed here.

An important factor in ensuring benefits to society from scientific research are maximised is the establishment of fleet-of-foot funding mechanisms which can respond to redirect resources rapidly to emerging areas of concern and disciplines of science. To address the twin challenges of democratic and scientific legitimacy, it is essential that these mechanisms are open and transparent to the public, accountable to government, and actively engage scientific communities. Existing infrastructures may not meet emerging needs. For example, the Geological Society has encouraged the Committee on Radioactive Waste Management (CoRWM), in its forthcoming report on R&D needs, to recommend that a mechanism is needed for strategic co-ordination of research funding across the Nuclear Decommissioning Authority (NDA), the research councils and other bodies – the draft report recognises that this is necessary to ensure that research needs for this critical national problem are met.
Learned societies have a potentially significant role to play in engaging public audiences, scientific communities, and institutions with governance responsibilities (both governance of the political economy of science, and governance of scientific and environmental risk). The concerns of all these groups should shape the agenda for such engagement. Bodies such as the Royal Society and the Geological Society are likely to be regarded as more independent and trustworthy by public groups, as well as by scientific communities, than industrial, governmental or even academic institutions. They are therefore well placed to address public questions, uncertainties and concerns – not simply as irritants to overcome, but as a fundamental driver of their public engagement work – and to help equip the 'citizen scientist' to take part in deliberations about the major economic, social and environmental challenges which the UK and the planet will face.
Moreover, unlike the Royal Society, the Geological Society (in common with other disciplinary institutions such as the Royal Society of Chemistry and the Institute of Physics) functions not only as an international learned society, but also as the national professional body for geoscientists (and as a leading player in the international development of professional structures and standards). This dual role is of great value, not only in bringing those from academic, industrial and other backgrounds together in a shared forum, but in contributing directly to the scientific excellence and economic value of the work undertaken by our members. At many of the Geological Society's meetings, it would be impossible for an external observer to discern whether particular contributors work in universities, industry or elsewhere, and for us, such cross-fertilisation – through meetings, publications and wider networking functions – is normal practice. (It is not for us to comment on how widespread this *modus operandi* might be in other institutions.) We have made no attempt in the past to quantify the contribution the Society makes to the economy through enabling this interaction. But we are confident that our role in promoting understanding of the geology of offshore North-West Europe over the last 40 years, and its application in hydrocarbons exploration and production, for example, has had a tangible value over that time of tens of millions of dollars, and an intangible scientific and public value beyond reckoning. The Geological Society would be very interested in any work the Royal Society might undertake to identify the financial value of such interactions, and stands ready to assist.

Building and sustaining research careers

- How can we make research careers – within academia or industry – a more attractive option for young people, both within the UK system and from abroad?

Again, this is a very broad questions, which is only partially addressed here.
An important element in achieving this goal is to build research communities which those in the early stages of their careers see as attractive and sustainable. Flexible governance and funding structures which allow resources to be directed to emerging areas of societal and scientific interest and concern are essential to the formation of real research communities – for example, returning to the example of radioactive waste management, to revivify the dwindling community of UK Earth scientists with experience of the former regime, drawing in the new generation of researchers and practitioners who will meet the demands of the new programme. But young scientists are unlikely to commit themselves to a career in such a research community unless they believe that it is likely to be sustained over a reasonable period of time – so it is also important that funders clearly signal their priorities, behave strategically, and do not lightly switch funding streams on and off.
Supporting emerging communities is another area where learned societies may play an important role. They must be prepared to work together in new areas which may span traditional disciplinary boundaries.

11. Does the standard career-track model need to be re-evaluated? Should we take more account of the movement of skilled individuals between academia, industry and business?

It is not clear what is meant by 'the standard career-track'. In the Earth sciences, as noted above, the blurring of these boundaries is not seen as particularly novel, especially in some disciplines – whether through movement of personnel between sectors, long-term engagement of academic researchers with economic and industrial problems, or other means. Government is also an important employer of scientists – for example, through the British Geological Survey (BGS), whose parent organisation is a research council (NERC), and which bridges functions of research, consultancy and maintenance of national capability and infrastructure. Some geologists have spent their careers working for BGS – others move between it, other research and survey institutes, academia and industry.
It is worth noting that a significant number of those who have become Earth scientists did not set out with that intention. It is a highly interdisciplinary field, and it is not unusual for practitioners to study physics, chemistry or engineering at undergraduate or postgraduate level, or even to start academic careers in these disciplines, before their research interests draw them into the Earth science community.

The ecology of research funding
See comments against previous questions.

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Dr Amanda Goodall

'The Fruits of Curiosity' project, Royal Society

Response to call for evidence from: Dr Amanda Goodall, Warwick Business School, University of Warwick

Introduction

I am a Leverhulme Research Fellow at Warwick Business School. My research looks at who should lead research universities. The below suggestions and accompanying evidence are linked to this research. My main hypothesis, which evolved from having worked with university leaders, was that research universities should be led by truly top scholars. Using quantitative and qualitative data this hypothesis has been put to the test. The results are quite convincing: first, that the best universities in the world – Stanford, the Ivy League, Caltech, among others – are, overwhelmingly, led by outstanding researchers; second, that the performance of research universities improves after outstanding scholars take the helm. My study is being published by Princeton University Press into a book ('Socrates in the Boardroom: Why Research Universities Should be Led by Top Scholars', released in October 09) and it also appears in the Journals Research Policy and Journal of Documentation. Below are a number of suggested recommendations that are accompanied by evidence (attached).

Four Suggested Recommendations

To improve UK universities and the quality of research I have four recommendations:

1. UK research universities should be led by individuals who have been outstanding scholars -- not just good scholars -- in their academic careers. It is not sufficient for university vice chancellors to have predominantly management skills. In the words of one VC I interviewed, "What matters is scholarship not just management. We should take management for granted".
2. Organizations linked to university policy-making or funding should also be led only by noted scholars. These would include the Higher Education Funding Councils in Britain (HEFCE, etc), the Research Councils (AHRC, BBSRC, EPSRC, ESRC, NRC, NERC), private trusts and foundations, bodies such as the Royal Society, British Academy, Royal Economic Association, and the Russell Group.
3. It is my belief that managerialism has encroached too far in the UK. This may have happened partially because too much power has been handed to generalists rather than specialists. Management is a set of processes that should enable the smooth running of the core business of universities. It should support but, arguably, be subordinate to the core business. It is not an end in itself. If our universities are to continue to develop as powerhouses of innovation and creativity, then I believe they must be less encumbered by over-administration and red tape.
4. To attract and prepare for greater numbers of top scholars going into leadership positions, two things could be considered: first, jobs should be more appealing, for example, try and reduce the administrative burden especially from government and its agencies. Second, we need to encourage and train future scholar-leaders. Research universities are poor at training faculty in management and leadership. Therefore, we may like to consider developing short intensive courses (such that they do not require too much time and commitment) for up-coming leaders that may include department heads, PVCs, deans and future VCs. The Leadership Foundation for Higher Education offers courses that are designed for those in both administration and academic positions across all universities. I believe we need a more targeted approach, with programmes that are designed specifically for potential scholar-leaders in research universities. One possibility is that a modest sum be collected, from independent bodies such as the Royal Society, British Academy, Leverhulme Trust and Nuffield, and be used as an exploratory fund to develop a course/s for future academic leaders.

Evidence

Below I have supplied two pieces of evidence. Three chapters from my book and one appendix – sections that are specifically tied to the recommendations above (the book is not out until October). I have also attached my forthcoming Research Policy paper 'Highly Cited Leaders and the Performance of Research Universities'.

I hope the material is helpful.