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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 IV

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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

Royal Astronomical Society

The Fruits of Curiosity: science, innovation and future sources of wealth: response from the Royal Astronomical Society

The Royal Astronomical Society (RAS) works to encourage and promote the study of astronomy, solar system science, geophysics and closely related branches of science. It represents more than 3000 members ('Fellows') including scientific researchers in universities, observatories and laboratories as well as related professions such as historians of astronomy, teachers and science writers.
The Society welcomes the Royal Society 'Fruits of Curiosity' inquiry and the opportunity to provide further evidence. Together with this document, we have submitted the results of studies and consultations carried out over the last few years that we hope will help shape the inquiry report.
Our response is aligned to the questions in the consultation document.

The long-term direction of policy for science

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

The RAS believes that curiosity-driven research is an essential component of the UK science base. In the cases of astronomy and space science, the UK has a world-leading research portfolio with highly productive researchers.
British astronomers have a strong research record. In the latest set of citation indices, astronomers and space scientists in the UK published more papers and were cited more frequently than any other nation in Europe. Worldwide they are second only to their counterparts in the US (Sciencewatch 2009).
UK scientists with training beyond PhD level in these subjects are highly flexible and can be found in a range of professional occupations. The RAS is in the process of surveying Fellows who are doctoral graduates in astrophysics and space science, but no longer work in this field. Preliminary responses show that they hold a range of positions across the economy. They work in areas including adaptation to climate change, teaching in secondary schools, science communication and journalism, engineering, renewable energy, business and technology companies, finance and defence. All cited their PhD training as invaluable in their post-astronomy careers, where they use their postgraduate skills in mathematics, computing, data analysis and presentation. (Private communications from RAS Fellows, 2009).
Our science also has a strong and positive impact on the uptake of STEM subjects (see q.5).
Consequently, for the primary reason of scientific excellence but also the undoubted economic impact in the broadest sense, the Society believes that investment in blue-skies research like astronomy and space science should be a key component of Government funding priorities in the years ahead.

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?

In 2005 the RAS and Institute of Physics (IoP) published their most recent International Review of Physics and Astronomy. At that time the Review described the morale of the research community as high, reflecting the sustained investment by Government in the previous five years.
This has been accompanied by international collaboration in major organisations like the European Southern Observatory (ESO) and the European Space Agency (ESA) and the UK has become an attractive place for researchers across the globe.
By this year the atmosphere had changed somewhat, following the creation of the Science and Technology Facilities Council (STFC) and the ongoing budget shortfall in that Research Council. At the very least the resulting uncertainty is unhelpful and it seems likely to discourage a number of promising early career researchers from remaining in their field, at least in the UK.
The Society believes that unlike investment for reasons of crisis (e.g. the bailout of the high street banks), a stable research investment environment offers long term dividends. The commitment by the current Science Minister to ring-fence the science budget is therefore very welcome and we urge the inquiry committee to lobby for this to be continued.

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?

It seems inevitable that the UK will find it more difficult to compete if investment in science falls, at least in comparison with other nations. Firstly, financial pressures may ultimately lead to the UK pulling out of international collaborations that allow our scientists access to world class facilities and the data they produce. Secondly, the UK will be allowing investment in science to stagnate against a background of stimulus packages and ongoing to commitment by governments elsewhere.
We also believe that the deliberate decision not to invest in science in a stimulus package in the last budget was very much a missed opportunity. It did nothing to dispel the idea that a career in finance is the natural option for science graduates and postgraduates, nor did it help the Government to work towards its stated goal of rebalancing the economy.
Despite these concerns about the future, there is a good deal of evidence that the UK has a strong science base at present and this is certainly the case in astronomy and space science. The Society acknowledges that it is impractical to invest across the board at the level of nations with significantly larger economies. However, we believe that the UK should support and enhance areas of strength, favouring those areas that are essential for the development of UK science and particularly those in which the UK needs to be competitive in the long term.

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

The RAS explicitly acknowledges that it is right for central Government to set a framework of priorities for science investment and that those should respond to public concerns. However, we do not believe that an overly prescriptive top down approach to governance will necessarily be effective in identifying research that will meet immediate economic goals. Funding scientific research is not like investing to win Olympic medals, where specific short-term objectives can be set and achieved. In contrast, science advances on a broad front and has indefinite horizons that require a long-term vision.
The Society believes that it is better to concentrate on funding excellence and on ensuring that the funding is sufficient to achieve the ambitious scientific goals that should be set. We also draw the attention of the Committee to the economic impact of curiosity-driven research, where serendipitous discoveries are made that cannot be foreseen at the outset of these research programmes. Former researchers also use their training to contribute to a large sector of the economy (see q. 1).
Within the fields of astronomy and space science, the UK membership of large international collaborations like ESA and ESO gives British businesses access to worldwide markets at the cutting edge of technology. Examples include e2v Charge Coupled Devices (CCDs) and other imaging devices used by all major collaborations and space agencies (as well as in digital cameras and medicine), Surrey Satellite Technology and EADS-Astrium, a major global player in the world satellite business.
Data handling, storage, management and access are areas of growing importance in all fields, and astronomy is no exception. The international astronomical community is developing advanced tools through the Virtual Observatory (and the UK AstroGrid project) with the goal of making the world's huge astronomical data banks transparently useable, in just the same way that the World Wide Web makes documents all over the world feel part of a single interlinked system.
We cite these examples to demonstrate that assessing societal and economic benefit is no simple matter and to once again state that curiosity-driven research in areas like astronomy should remain a key part of the UK science base.

5. How should we assess the long-term social and cultural impacts of scientific research?

Science, particularly in areas like astronomy, has a high cultural and social impact. The RAS welcomes the decision by BIS and the RCs to include this in their assessment of economic impact.
We also draw attention to the particular interest of children and adults alike in blue skies research referred to time and again by practitioners working in the realm of science and society. Research by Osborne and Collins (2000) and more recently Jarvis and Pell (2005 and 2008) demonstrates that astronomy is unusual in that „hard to reach" groups like adolescents perceive it positively and that it appears to act as a spur to further study and careers in science in general.
There is undoubtedly a need to commission further research in this area, something recognised in the former DIUS consultation on Science and Society in the UK. Although carrying out such an exercise is not

trivial, a starting point would be to assess the long-term effectiveness of the plethora of activities to engage the public in science that are supported by the RCs, learned societies and other bodies.
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?

At university level there have been few structural changes in the delivery and assessment of undergraduate degrees in physics and astronomy. Physics-based undergraduate degrees are largely 4 years long leading to an MPhys/MSci qualification and this is the normal entry qualification for a research degree, now typically of three and half years' duration. This pattern is different to the 3+2+3 Bologna model which the UK and 28 other European countries agreed to work towards in 1999.
The subject benchmark statement, characterising the skills and achievements that graduates of physics, astronomy and astrophysics degrees should have, was published by the Quality Assurance Agency (QAA) in 2002 and these were reviewed in 2007. Wide consultation and input from a specialist panel convened by the Institute of Physics (IoP) indicated that the benchmark statement required only minor revision although further clarity of some statements and updating to reflect advances in technology-based learning and the addition of statements on ethical behaviour were added (QAA, 2008).
The RAS recognizes the continued concern that there is a lack of consistency in the standard of honours classifications between different subjects within a university, and between universities. It believes, however, that it would be extremely difficult to phase out the traditional honours classifications and some universities would continue to use them, creating even greater inconsistencies. The RAS strongly supports the use of Diploma Supplements and Transcripts that can be used in addition to the honours classification, as they do provide a more informative assessment of a graduate's study programme and achievements. It is not obvious they provide an automatic increase in consistency as Higher Education Institutions (HEIs) use different grading systems to represent performance at module level.
At school level there is mixed evidence of progress. The move to include a wider range of topics, e.g. in Twenty-first Century Science, is not necessarily helpful to the less able children as it includes a very large number of concepts. Teachers and education professionals in the RAS describe an „over-stuffed" science curriculum at both GCSE and A-level, which removes opportunities for the most able students to be sufficiently stretched or to study a subject in detail, as there is simply too much pressure to move on to the next topic.
School courses may also not be preparing entrants to undergraduate degrees in the way they should. In a recent Higher Education Academy survey (HEA 2008), students and staff agreed that a lack of experience in practical work and problem solving and a lack of mathematical skills were the greatest cause of difficulty for physics students.
On a positive note, the increasing uptake of GCSE Astronomy (more than 2000 candidates enter this examination each year) shows that science subjects in some areas can prove attractive to more enthusiastic pupils, particularly as it is usually studied out of normal school hours (Williams 2008). The National Schools' Observatory and Faulkes Telescope Project have also successfully used direct access to professional research instruments to inform student learning across the curriculum at primary and secondary level.

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

Unfortunately, physics-based subjects have not enjoyed the expansion in HE that has occurred across many other non-STEM subjects and many physics departments have relied on astronomy/astrophysics to maintain undergraduate intake. In 2002 there were 3779 accepted applications to physics courses with a slight rise to 4081 by 2008. Over the same time period the number of accepted applications to astronomy-related courses (most of which are centred on physics degrees) dropped from 993 to 810 (UCAS 2009).
Despite this fall, there is much anecdotal evidence that an interest in astronomy has led many students to take (pure) physics degrees. In preparing our evidence for the RCUK Review of Physics in 2008, the RAS received statements from admissions tutors in physics departments across the country supporting this argument and the Royal Society may wish to consider obtaining further evidence of the impact of astronomy and other blue skies topics in encouraging recruitment at HE level.
This interest is easily generated by the natural fascination with the Universe, helped by the wealth of exciting astronomical images available on the Internet, the relatively large number of TV programmes

based on astronomy and the large outreach programmes run by most university physics departments that offer astronomy degrees and/or carry astronomy research.
Even with the interest in astronomy, and it helping to maintain the intake to physics departments, it is clear that for many young people a career in STEM subjects is not seen as attractive. There are likely to be many reasons, many being interlinked: poor teaching in key subject areas exacerbated by a shortage of qualified teachers (the University of Buckingham found that half of inner city London schools have no physics specialists – see Smithers and Robinson 2008), STEM subjects are (perhaps correctly) perceived to be more difficult, the lack of obvious career opportunities (e.g. there is not an easily identified physics industry) and the perceived lack of high financial rewards compared to many other professions.
The question of teaching in schools must be the most important factor and is partly addressed in question 8. The perceived difficulty of STEM subjects (particularly physics) clearly links with the quality of teaching but the school curriculum is obviously important (see q. 6).
It is often said that an attraction of a physics based education is that it provides many job opportunities. Although this is essentially true (and in the fields of astronomy and space science there are plenty of examples) they do not seem to be obvious to many young people and the lack of easily identified physics industries doesn't help; „what jobs do physicists do" is a question that is often asked. This is supported by the Higher Education Academy survey where 80% of physics undergraduates stated that they do not choose their degree subject primarily for its employment prospects (HEA 2008).
Initiatives like the DCSF / Science Council / learned societies "Future Morph website on careers from science may help to tackle this challenge, but it remains to be seen how well this information disseminates to school teachers and hence students.

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)?

The Government recruitment campaigns have succeeded in improving the recruitment of science teachers, but there remains a serious shortage of physics specialists. The most recent Training and Development Agency (TDA) census showed that of the estimated final total of 3670 applicants for science teacher training, only 540 were physics specialists (TDA, 2008).
The RAS therefore strongly supports the continuation and expansion of the financial incentives used to encourage science and particularly physics graduates to consider a career in teaching. The centrally-funded bursaries used to attract entrants to the profession should be supplemented by additional rewards for teaching staff in shortage science subjects like physics – powers available to governing bodies cited in the Sainsbury Review of Science and Innovation (2007) but rarely exercised. However, we also caution that these measures will not be sufficient if those same teachers leave the profession within their first few years of employment.
One other approach to tackling the shortfall of physics specialists has been to upgrade the knowledge of graduates in other sciences. The Society supports this approach, but also recognises the risk it may not always deliver the enthusiasm those teachers need to be effective.
The efforts to place physics within a broader degree such as the courses supported via the IoP-led „Stimulating Physics" initiative (and now subsumed within the national STEM programme) are one example of where this is being tackled with the direct aim of increasing the supply of graduates with at least some specialist physics knowledge.
The Society strongly believes that work of this kind should continue, with the goal of producing a teaching workforce whose members see themselves as professional physicists as well as teachers of physics. Those Fellows who work as or alongside teachers advise that tackling this and other career status issues is of equal importance to the (welcome) focus on pay.

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?

Many of those taking a physics-based degree do so because they wish to carry out research. One issue that could make a career in research less attractive is the increasing emphasis on economic return currently promoted by BIS and the Research Councils. In many areas this is difficult to identify because any such benefits will be long term and not predictable. There are also many other benefits that are not readily quantifiable in economic terms but increase the skills base (e.g. via the supply of highly trained postgraduates into the wider economy.

The RAS has received some reassurance on this issue from senior RCUK and STFC staff through their statements that economic impact will not be a key factor in deciding the allocation of research funding. Nonetheless we wish to re-emphasise that it must remain a secondary consideration to scientific excellence if the UK is to retain its status as an attractive destination for world-class researchers.

10. What sorts of incentives can we develop to keep talented students and postgraduates in science?

The RAS report "The PhD and Careers in Astronomy in the UK" (2005) studied the prospects for PhD students in astronomy, many of which are likely to apply across science.
One key issue identified in this report was the time spent by the vast majority of researchers on temporary contracts (often a decade or more) before they were offered a permanent position. The spirit of the EU Directive for fixed-term workers who have been employed for four or more years (i.e. that there is a maximum time period that an employee can be employed on a fixed-term contract) does not appear to be widely adopted and indeed anecdotally it appears some institutions are reluctant to offer extensions to contracts if they are then required to offer permanent positions. This can work to the disadvantage of young researchers.
If it is not possible for HEIs to be more flexible in their recruitment of permanent staff, then at least those same researchers should be given honest and appropriate careers advice from the start of their PhD. The help available to postgraduates needs to be investigated, so that the 80% of them who will not progress to permanent posts in universities are given the best possible advice on opportunities elsewhere.
It also remains the case that women are still not progressing to senior levels in astronomy and space science, despite a large increase in the number of female postgraduate students. According to an RAS study, the proportion of female astronomy postgraduates increased from 5% in 1993 to 35% in 2003, but the proportion of female astronomy professors only rose from 2% to 3% in the same period (Walker, 2009).
One solution to this could be to increase the number of location-independent post-doctoral positions, so that researchers can balance the „two-body" problem (where both partners are professionals on short-term contracts). RAS Fellows identify the Dorothy Hodgkin Fellowship as a good model for this that could be adopted more widely by the various funding agencies.

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?

This is partly covered in q. 10. The RAS supports the strengthening of careers advice to postgraduate researchers across institutions. The Society recommends that the „transferable skills" acquired during a PhD are specifically accredited to allow postgraduates to more easily transfer to industry and business.
It should also be recognised that scientists can move from research to management and business, but it is generally very difficult to then go back to research at an international level. Those most productive in research need to see a career with continuity rather than it being a start-stop activity.

The ecology of research funding

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

Commenting on the overall balance in the science budget is outside of the remit of the RAS. However, we believe that the decision making process for that funding balance should be open and transparent and the reasoning behind the strategies adopted should be made public. The RAS endorses the key principles on this set out in Lord Drayson's recent speech to the Royal Society.

13. 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?

One specific area the RAS wishes to comment on is the funding of space activity. As a loosely defined partnership the British National Space Centre (BNSC) has not been an effective body in its promotion or coordination of this work. The RAS therefore believes that an independent space agency would be an appropriate response, provided it is not set up using funds that are currently directed towards research.

References

Country Rankings in Space Science 1999-2009, Sciencewatch, 2009.
http://sciencewatch.com/dr/cou/2009/09maySPA/
Evidence for the Wakeham (RCUK) Review of the Health of Physics: submission from the Royal Astronomical Society
http://www.ras.org.uk/images/stories/ras_pdfs/RAS%20submission%20to%20Wakeham%20Review.pdf
Future Morph http://www.futuremorph.org
Jarvis, T. and Pell, A. (2002). *Journal of Research in Science Teaching*, 979.
Jarvis, T. and Pell, A. (2005). *Journal of Research in Science Teaching*, 53.
Osborne, J. F. and Collins, S., 2000. *Pupils "views of the School Science Curriculum.* King's College London.
Qualifications Assurance Agency for Higher Education subject benchmark statement: physics, astronomy and astrophysics (QAA 235 02/08)
http://www.qaa.ac.uk/academicinfrastructure/benchmark/statements/Physics08.asp
The PhD and Careers in Astronomy in the UK: a report from the Royal Astronomical Society, 2005.
http://www.buckingham.ac.uk/education/research/ceer/pdfs/physics-teachers.pdf
Review of the student learning experience in physics, Higher Education Academy, 2008.
http://www.heacademy.ac.uk/physsci/home/projects/subjectreviews/physics
The Race to the Top: A Review of Government's Science and Innovation Policies, Lord Sainsbury of Turville, 2007.
http://www.hm-treasury.gov.uk/sainsbury_index.htm
Smithers, A. and Robinson, P. (2008). *Physics in Schools IV: Supply and retention of teachers*, Centre for Education and Employment Research, University of Buckingham.
http://www.buckingham.ac.uk/education/research/ceer/pdfs/physics-teachers.pdf
Training and Development Agency (TDA), *2008-9 census summary*. Available from http://www.tda.gov.uk
Universities and Colleges Admissions Service, 2009, *private data purchase*.
Walker, H. *Private communication.*
Williams I., *paper presented at the 2008 National Astronomy Meeting.*

Science Museum

Call for Evidence: Fruits of Curiosity: Science, innovation and future sources of wealth

Submitted by: Yasmin Khan, Curator Team Manager, Science Museum

This paper addresses the question from the original Call for Views:

How are public attitudes and the culture of public engagement with science and innovation changing?

The enduring historical role that the Science Museum has played in engaging the public with science

The roots of the Science Museum can be traced to the South Kensington Museum founded in 1857 on Great Exhibition profits. From their early years, the science collections combined attention to education in scientific principles with the historical roots of modern science, applied science and technology. The former was represented by the 1876 Loan Exhibition of Scientific Instruments whilst the latter was evident in the sub-Museum known as the Patent Office Museum, which contained such holy relics as Stephenson's *Rocket* locomotive and Richard Arkwright's textile innovations.

The Science Museum became an administratively separate organisation in 1909 and formally opened its own purpose-built building in 1928 (the current East Block). Within these buildings, the Museum pursued its science engagement role in three main ways: via permanent collections showing the historical evolution of different aspects of science and technology (but not medicine, which came to the Museum in 1976 with the Wellcome Collection); temporary exhibitions, which were historical, or dealt with novelties (such as television) or issues (atmospheric pollution); and the Children's Gallery, which was a general introduction to the Museum's concerns.

Gradually from 1909, the educational role of the Museum expanded, first with guide lecturers, then theatre-based lectures and demonstrations, film shows, a dedicated education service, and eventually from 1986, new interactive galleries, notably *Launch Pad* but also *Flight Lab.*

In 2000, the Museum opened *Making the Modern World*, its major object-rich statement on the history of technology and *The Wellcome Wing*, its showcase of contemporary science and technology. Here the visitor could enjoy state-of-the-art displays demonstrating not only how we have reached today's world, but also current science news and indicators for the likely future.

The Museum's Dana Centre, opened in 2003, has been a hugely successful centre for dialogue on scientific issues, appealing especially to regular audiences of young adults.

Science Museum Learning

Science Museum Learning teams are helping to realise the Museum's ambition 'to be the best place in the world for people to enjoy science'. We talk science in many different ways to many different audiences. In each case we set out to give people the confidence to find their own voice – to have their say in the science that shapes their lives.

Our philosophy of learning places a premium on curiosity and discovery. We believe that the experience of thinking, doing and sharing provides the best means of inspiring insight and understanding. Our long-term ambition is that by 2012 every child in the UK will have had a Science Museum Learning Experience.

Our impacts include:

- Every year 2.7 million people visit the Science Museum
- Over 350,00 people visit in pre-booked educational groups each year, keeping our position as number-one choice for school visits in the UK
- Over 450,000 people a year join our live events. 90,000 of whom enjoy our Workshops and Shows performed around the country
- In just 2 years, over 3.4 million people have played *Launchball*, our online game of physics puzzles
- Each month over 30,000 unique users enjoy our web-based learning resources for home or classroom activities

- More than 2,000 teachers participate in our Courses and Workshops each year
- Over 2 million people have visited Launch Pad, our hands-on science gallery, since its re-launch in November 2007
- Ever year over 5,000 children aged 8 -11 years sleep overnight in the Museum and take part in themed activities
- 24,000 adults have attended our Science Lates (aimed at 25 -35 year olds) – evening programme of activities/gallery tours and child-free time in the interactive Launchpad gallery
- 'Collecting Stories' project has us working with regional museums in the South East and the North to unleash the science in any collection, with Key Stage 3 students creating a display; a podcast or films as their response to the science story. This project forms part of the Science in Your World programme.

Science in Your World programme
The Natural History Museum, the Science Museum and MLA (Museums, Libraries and Archives) have formed a national partnership committed to enabling museums across England to develop broader and deeper science learning opportunities for schools and families - and to demonstrate that museums and out of classroom learning have a major role in delivering the STEM (Science, Technology, Engineering and Maths) agenda. Collectively we want to use museums and their collections and experiences to change young people's (aged 5-19 years) perception of science, inspire further study in science and interest in science careers and build ancillary skills such as communication skills, team-working skills, creativity and critical-thinking.

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Royal Academy of Engineering

Introduction

1. The Royal Academy of Engineering welcomes the opportunity to respond to the Royal Society's call for evidence in support of 'The Fruits of Curiosity' project. This response has been compiled by consulting with Fellows of the Academy who have particular expertise in the relevant fields. It also draws on a number of previously published Academy documents such as responses to Government consultations and correspondence with Government officials.

2. The Academy recognises that this is an issue of critical importance and is pleased to offer its assistance in any way possible as the Royal Society takes this project forward.

The long-term direction of policy for science

3. Curiosity–driven research should continue to play a major role in the UK science base over the coming decades. The UK has a strong research tradition in all areas of science and engineering through both individuals and institutions. Failure to support this basic research would seriously undermine the UK's ability to compete in an increasingly advanced and knowledge driven global economy. This is particularly true in the current climate of financial difficulties and fast developing countries such as China and India. However curiosity-driven research should not be assumed to have no economic impact, some such research will have direct economic impacts (such as DNA fingerprinting) and some will only have indirect impacts. Scientists should be encouraged to ensure that the potential impact is recognised and exploited.

4. The UK has a good reputation for providing graduate and postgraduate education and has numerous world renowned research establishments. However, the bridge between applied research and commercially exploitable products is still weak. The Technology Strategy Board has had some success in this area but is limited by the funding available to it. We would recommend that the TSB's budget be substantially increased to allow it to invest more heavily in the development of pre-commercial technologies.

5. Innovation and business are competitive and global, as are education and research. Increased support for science in other nations will only serve to heighten this competition. Ultimately, the standard of research is determined by the quality of the people engaged in it. The infrastructure and resources afforded to them are also important but unless the UK is able to attract and retain high calibre personnel the standard of research will fall and opportunities will be lost.

6. A strong research base is important for the economic prosperity of the UK but support from the wider community is crucial if it is to thrive. In order to gain this support the Government must adopt a clear and effective public engagement programme. The Department for Innovation, Universities and Skills addressed this issue with its *Vision for Science and Society*. It is a difficult and complex area and for a fuller account of the engineering community's position on the matter we would recommend the Academy's response[1] to the DIUS consultation on their proposals.

Building and sustaining research careers

7. Given the global nature of industry and academia and the importance of sufficiently competent and motivated personnel, the ability of the UK to offer attractive career opportunities is of the utmost importance. Obviously, one of the main concerns will always be money. However, for a lot of young researchers a desire to work on exciting and challenging projects is equally important. Stability and long-term career options coupled with a certain amount of prestige are also factors that could influence prospective researchers' choices.

[1] http://www.raeng.org.uk/societygov/policy/responses/pdf/Scienceandsociety.pdf

8. Companies, particularly large multinationals, are likely to be able to offer more in terms of financial incentives and future career paths. Indeed, it is difficult to see how academia could compete at this level. However, universities can compete in terms of the quality of the research, the experience of the teaching staff, quality of life and the breadth of research possibilities on offer.

9. It is also becoming increasingly clear that many young people are very concerned about the big issues of the day such as poverty or climate change and are highly motivated to try to help overcome these issues. Highlighting the role research can play in addressing these issues is therefore important and shows that, while remuneration is important, a broader range of incentives is needed to attract the best young people into research careers.

Science, innovation and wealth creation

10. In the call for evidence, the Royal Society states that they are keen to challenge the separation of 'pure' and 'applied' research. The Academy is supportive of this position but in the context of exploiting the products of scientific research as a source of wealth, particularly to the UK economy, it is of the utmost importance that this is not replaced by a new separation between 'research' and 'development'. There is a particular innovation pathway which stretches from the most speculative blue sky research to wealth creating products and services and it is important that it is thought of as a continuum with no distinction between what happens in university research department and what happens in commercial organisations seeking to exploit that knowledge.

11. It is also important to remember that within this continuum the innovation does not only move in one direction. Not only will ideas flow from the work done by researchers in universities seeking to develop new technologies or processes but commercial organisations, active in the market place, will also be able to identify new problems that require innovative solutions from researchers.

12. What is needed is a greater understanding between academia and business – a matching of expectations on both sides. Universities are, understandably, less focussed than industry on the potential commercial applications of their discoveries. But if scientific and technological ideas are to be successfully pulled through to commercial application universities need to understand the factors that effect the development of research into commercial products. Similarly, industry needs to be exposed to the full range of academic research being carried out in universities in order to fully exploit all possible applications.

13. As mentioned above, people are critically important in this process and it is clear that business-academic interactions work best when personal relationships evolve between industrialists and academics. It is also clear that the most effective mechanisms of knowledge exchange involve the movement of people with that knowledge.

14. The Knowledge Transfer Networks help with this but more could be done, particularly by placing business professionals in medium-term positions within UK universities. This would promote understanding and exchange of knowledge between business and academia.

The ecology of research funding

15. The arguments about the balance of targeted versus response-mode research are often polarised and when funds are tight. Arguably, the focus should be on research that addresses priority areas provided that those areas have been correctly identified. Priority areas can be funded through response-mode and managed programmes and in an ideal world, the two funding mechanisms should attract equal attention from researchers. The opportunity to support curiosity driven research that addresses the general themes of targeted programmes should not be ignored. It should be noted, however, that response-mode panel success rates are often less than 10% while some managed mode programmes have success rates in excess of 70%, indicating an general imbalance between the two modes. Whether this is a supply and demand side issue or an administrative issue is not clear. What is significant is the discrepancy in the numbers.

16. Public sector R&D and, in particular, Government procurement have a significant role to play in supporting the UK science base. Through this, the Government has the potential to push forward a number of crucial areas such as low carbon technologies. They have the funds to push all levels of R&D from basic research into new technologies like electric vehicles or to develop new skills and businesses in areas such as retrofitting buildings. In doing so the Government has the potential to increase the size of emerging markets by providing the necessary demand for new businesses to supply.

UK Innovation Research Centre (UK IRC)

Fruits of Curiosity Project Call for Evidence
Submission on behalf of the UK~IRC[2]
Alan Hughes (Director, UK~IRC),
Michael Kitson (Director of the Knowledge Hub, UK~IRC) and
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Introduction

The call for evidence issued by the Royal Society covers a great number of important areas. There is also a considerable evidence base behind many of these which it is not possible to address in a short note. We would be happy to discuss with the Review Secretariat how we might contribute to developing a review of evidence across a number of these areas.

In this short note we briefly address a number of issues which arise from the list of questions posed in the call for evidence. These relate in particular to the first two broad sets of questions. These are concerned with the long-term direction of policy for science and investing in tomorrow's talent in schools, universities and in the FE sector and to the questions listed under the heading *Science, Innovation, Wealth Creation and the Ecology of Research Funding*.

Curiosity Driven and User Inspired Research

There is an implicit or explicit notion in the questions under these headings that imply that there is a clear separation between ''curiosity driven'', ''fundamental'' or ''basic'' research and research which is user related or applied. There is, however, a substantial body of evidence which suggests that this set of distinctions is unhelpful. In taking forward the discussion of science policy and the appropriate institutional and incentive patterns to produce the effective translation of ''curiosity'' or ''fundamental'' research into applications it is essential to recognise their complemetarity and the feedback loops from one to the other. Both may be of course driven by ''curiosity'' in the normal sense of the word. As Rosenberg (1982) suggested, problems in the world of industrial practice may provide a powerful stimulus to curiosity-driven science as they pose interesting and challenges questions that require fundamental science to be better understood.

There is also implicit in the pattern of questioning a separation between research activity and teaching activity and the wide pattern of interactions with external organisations that academics are involved in. Each of them are central to knowledge exchange and wealth creation arising from the interplay between ''curiosity'' driven, basic research and applied research.

It is helpful in considering notions of fundamental and applied research to use the framework developed in the work of Donald Stokes in his analysis of post-War US science policy. This framework is captured in his well-known quadrant diagram in which the pursuit of fundamental research (which we hear take to mean curiosity driven or basic research in the terminology of the call for evidence) and the pursuit of applications which we take to be the area of exploitation and wealth creation. This is shown in Exhibit 1.

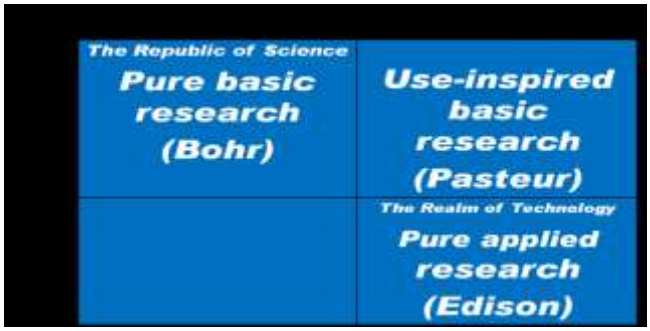

Exhibit 1Spanning Quadrant Boundaries

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[2] This submission is made as part of the programme of the UK Innovation Research Centre at Cambridge University and Imperial College (UK~IRC). The support for UK~IRC of the Economic and Social Science Research Council (ESRC), the National Endowment of Science, Technology and the Arts (NESTA), the Department of Business, Innovation and Skills (BIS) and the Technology Strategy Board (TSB) is gratefully acknowledged.

Source: Adapted from D. Stokes (1997) Pasteur's Quadrant Washington Brookings Institution

The fundamental point which Stokes makes is that there is a continuous interplay between the great bulk of academic research activity which is undertaken and considerations of use. The majority of scientific activity is mediated through or takes place in Pasteur's Quadrant and it could be argued that most academics are involved in more than one of these quadrants at any time. It is useful in this context to remember that these distinctions may also be applied beyond the fields of science and technology. For instance, in a recent survey of over 22,000 academics in all subjects in all UK institutions individuals were asked as to classify the t research they were undertaking. The choices offered - which distinguished between basic research, user inspired basic research and applied research - following Stokes's framework and using the widely accepted definitions in the field drawn from the *Frascati Manual* are shown in Exhibits 2 and 3[3].

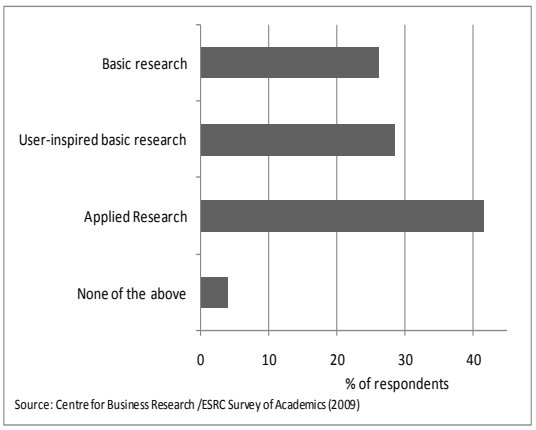

Exhibit 2 Stokes's quadrants
Source: Abreu, Grinevich, Hughes and Kitson, 2009

Exhibit 2 shows that in general most academics consider themselves as being involved in user driven basic research or in applied research.

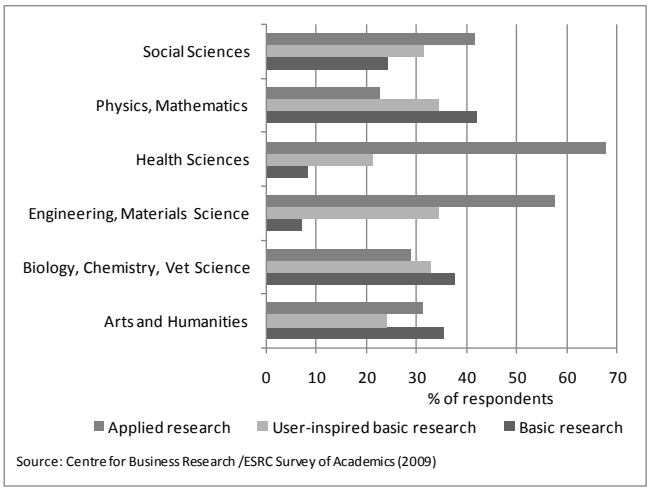

Exhibit 3 Stokes' quadrant by discipline
Source: Abreu, Grinevich, Hughes and Kitson, 2009

[3] These and later exhibits derived from Abreu et al. 2009 are based on the ESRC funded project *University-Industry Knowledge Exchange: Demand Pull, Supply Push and the Public Space Role of Higher Education Institutions in the UK Regions.*

Exhibit 3 shows that this is true across all disciplines. Higher proportions in Physics and the Biological Sciences, for example, consider themselves to be involved in basic research and this is true also in the Arts and Humanities. Even so in each of these areas they are outnumbered by those who consider themselves as primarily characterised by conducting user inspired or applied research.
The challenge therefore in relation to the allocation of resources is to find those institutional structures which best encourage the interplay between these quadrants and in particular which allow patterns of interplay which cross disciplinary boundaries in the pursuit of advances of both applied and basic knowledge.
In assessing the weight to be given to attempts to privilege user-inspired or applied research or the expense of fundamental or basic research it is important to recognise that cutting the latter will also impact negatively on the former.

Crossing the University-Industry Boundary
In thinking about the factors which inhibit the transition between quadrant boundaries in the Stokes' diagram two issues seem to be important. The first is that issues of cultural differences do not seem to be the key factor, at least when viewed from the perspective of the business community.

Category	All %	Micro %	Small %	Medium %	Large %	Significance
Lack of resources in the firm to manage the interaction	[illegible]	36.0	34.8	47.2	44.8	*
Lack of regional programmes that encourage interactions	29.1	29.0	29.6	18.9	35.8	
Difficulty in identifying partners	28.1	23.0	27.5	26.4	38.8	*
Insufficient benefits from interaction	27.3	22.5	22.5	35.8	40.3	**
Lack of central government programmes that encourage interactions	26.9	26.0	28.1	17.0	32.8	*
Lack of experience dealing with academics and/or HEIs	22.1	14.0	18.5	32.1	35.8	**
Bureaucracy and inflexibility of HEI administration	20.9	21.0	17.4	26.4	25.4	*
Lack of interest by academics and/or HEIs	19.3	17.0	18.0	15.1	29.9	**
Incompatibility of timescales for deliverables	[illegible]	12.9	11.2	26.4	16.4	*
Cultural differences	[illegible]	5.9	6.7	7.5	14.9	*
Difficulty in reaching agreement on intellectual property	[illegible]	3.0	6.1	11.3	9.0	
Independent firms that collaborate with HEIs	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	

Exhibit 4 Have the following factors constrained your interactions with HEIs in the last 3 years?
Source: Abreu, Grinevich, Hughes and Kitson (2009)

Exhibit 10 shows that for a large and broadly representative sample of UK businesses the perception of the factors which must inhibit the transition across university boundaries into applications and commercially useful activity is not seen as residing in the university sector, but in the business community itself. This raises very important questions about the way that the business community itself organises and recruits to effectively perform the boundary-spanning activities which link the UK industry to the science base. A particularly significant factor in the UK is that larger firms are more likely to report this as a problem. These firms are those which are most likely to be: able to take on a wide range of commercialisation processes; involved in collaborative arrangements with universities; participants in a wide range of policy initiatives designed to promote collaborative research. The fact that these firms believe themselves to be hindered by their own capacity and that they are more likely to report difficulties in relation to licensing and IP and timeframe issues and to perceive benefits from the interaction from that suggests this is an important policy issue to address.
This in turn may be related to important evidence that those firms which have been involved in collaborative EPSRC funded research projects are increasingly likely to report difficulties in the negotiation of these arrangements (Bruneel et al, 2009). Drawing on two waves large-scale surveys of manufacturing and service firms, this work shows that perceived barriers to university engagement among research collaborators have increased over time. The most important barrier perceived by collaborators was the long-term orientation of researchers, followed by lack of suitable government programmes. However, the largest increase in perceived barriers were for conflicts related to IP and 'unrealistic expectations by the TTO'.

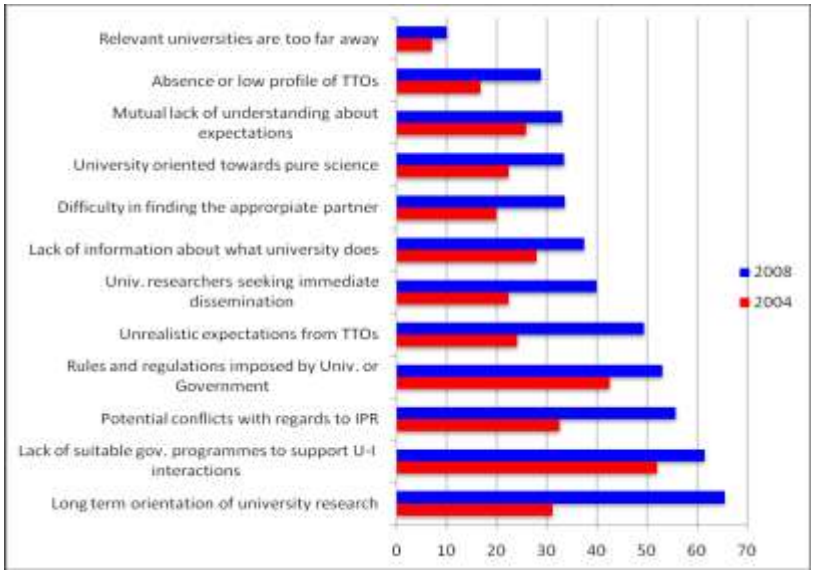

Exhibit 5 Barriers to collaboration among EPSRC industrial collaborators, 2004 and 2008

This important finding is consistent with a number of possible arguments. First, dissatisfied firms may be those with long-established patterns of interactions developed in a period in which universities did not have technology transfer licensing offices keen to impose standard contractual licensing to fit in with IP regimes. They may be finding it time consuming and difficult to adjust to new arrangements when they perceive them not needed in the first place. Secondly, it may reflect a more aggressive stance on the part of universities with an equally defensive reaction on the part of businesses. In a world in which the returns to research and development activity and patenting are exceptionally skewed such reactions are important. They are likely to be exacerbated by the introduction of higher costs of university research linked to the essential need to charge full economic costs. Once again, important issues are raised for the effective management of IP and the policy of university research.
They also point to need to understand the different types of experiences of firms in engaging with UK universities. It is critical to separate out the views of those firms in the wider economy, many of whom may not have engaged in direct collaboration with universities, from those firms that are engaged long-term research collaborations with academics. As CBR survey shows that, for most firms, it is the lack of internal capacity that limits their engagement with universities. For these organizations, the long-term orientation of universities appears to be a low concern when set aside other organizational constraints

and pressures. However, in the survey of EPSRC collaborators, i.e. those firms that have choose to participate on a research project, the barriers related to orientation of university researchers and conflicts of IP are at the forefront of their experiences of collaboration. This dual result suggests that policy needs to use different instruments to engage different parts of industrial sector. A 'one-size-fits-all' approach to industry engagement with academics will offer little return as for those firms that have never collaborated with universities will have very different needs from frequent collaborators. For those firms engaging in limited or first time collaborations, it may be necessary to ensure that they have requisite absorptive capacity. To be sure, efforts to support the development of this absorptive capacity among UK firms could in turn yield a greater number of firms interacting with universities. Yet, for those firms already engaged in collaboration, it is important to monitor the 'health' of these collaborative relationships to ensure that they are enabling rich and valuable knowledge exchanges. It is possible that such collaborations could be undermined by overaggressive IP regimes at the university sector. Policy efforts need balance efforts between promoting new collaborations as well as sustaining existing collaborative arrangements.

External User Interaction and the Impact on the Research Base

Academics in the UK are involved in a multiplicity of interactions with external organisations. These span the private, public and third sectors each of which may have an impact on wealth creation and a wider social impact.

As the following three exhibits show there is already a very high degree of interaction in terms of people-related, problem-based and community-based activities (*see also* PACEC/CBR, 2009).

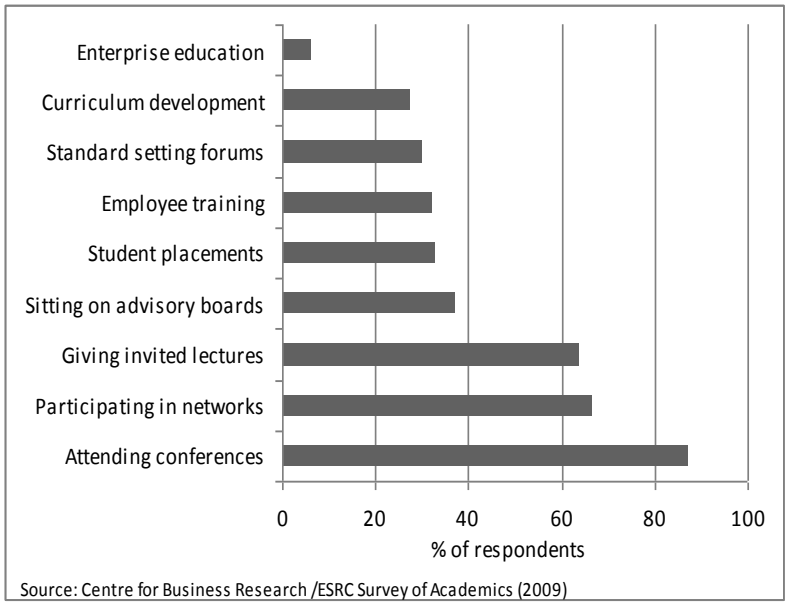

Exhibit 6 People-based activities
Source: Abreu, Grinevich, Hughes and Kitson, 2009

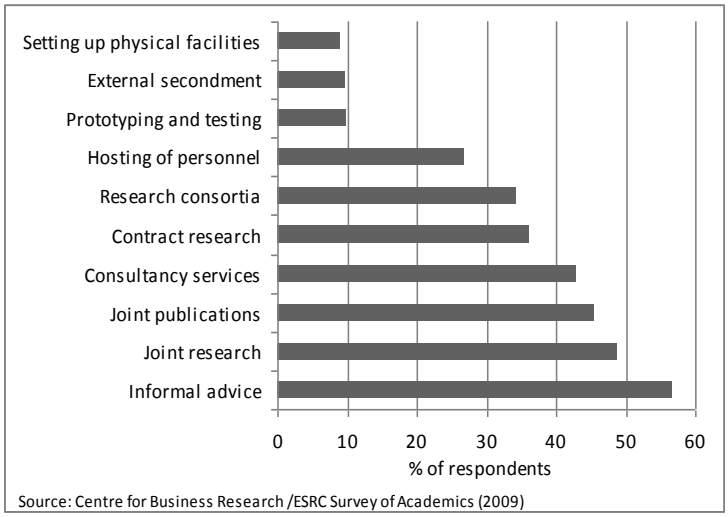

Exhibit 7 Problem-solving activities
Source: Abreu, Grinevich, Hughes and Kitson, 2009

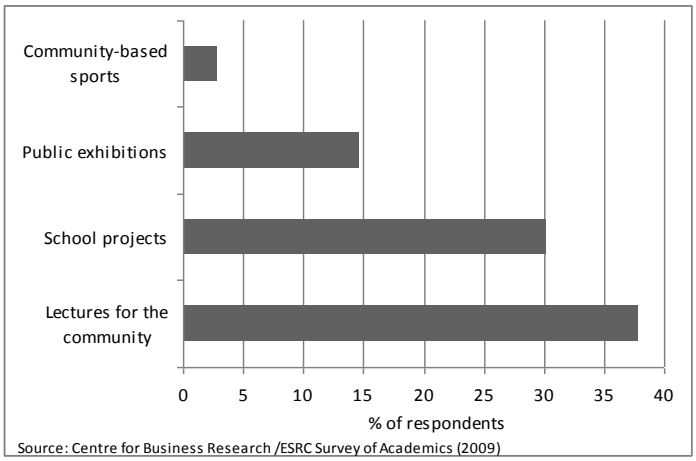

Exhibit 8 Community-based activities
Source: Abreu, Grinevich, Hughes and Kitson, 2009

The pattern revealed is consistent with the views of the kinds of activities that businesses state to be their most valued and frequent dimensions of interaction. In a large majority of cases these interactions are perceived as having a positive impact on the research activities of those taking part in them. (Abreu, Grinevich, Hughes and Kitson, 2009; PACEC/CBR, 2009).
Emerging evidence from two large-scale surveys (in 2004 and 2009) of the EPSRC-funded Principal and Co-Investigators, conducted by Imperial and Cranfield, supports these findings and suggests that patterns of engagement with industry may in fact be increasing over time. This work is still at its early stages of analysis, but it suggests a deepening of interaction between UK academics and their industrial partners. It also shows that the barriers and motivations for academics to engage with industry are relatively constant over time. The primary motivation to work with industry appears to be additional research income as an opportunity to increase the applicability of research outside the industrial sector. However, the importance of engaging with industry to building a professional network appears to have increased from 2004 to 2009.

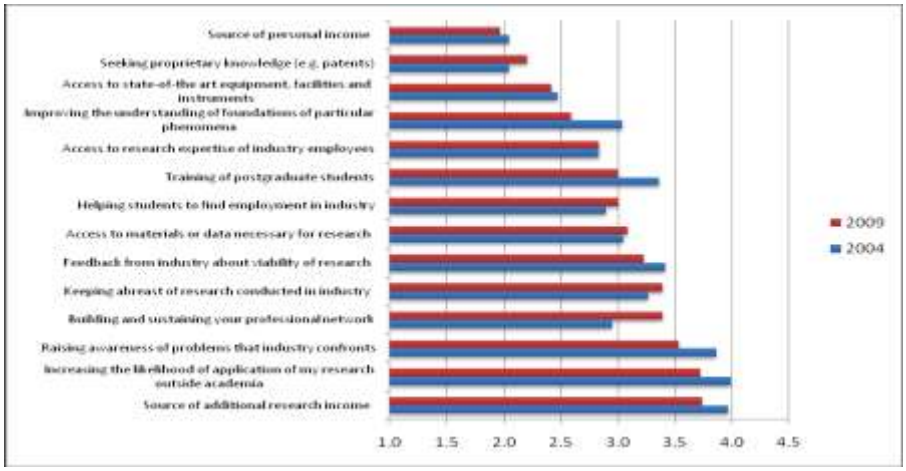

Exhibit 9: Motivations for working with industry, EPSRC PI/CO Survey, 2004 and 2009

Time Constraints and Barriers

An important issue in taking forward discussions about how changes in academic activity may occur is to bear in mind the constraints imposed by adding additional missions to the core missions of teaching and research and the incentive structures which would need to be introduced to produce patterns of academic career trajectory, promotion and reward which reflect different activities. Some degree of specialization is apparent already in the types of interaction that academics become involved in. The pursuit of activities across all dimensions by every individual academic is clearly not an efficient or feasible option. These constraints are amongst the most frequently cited factor for not engaging more extensively (Abreu, Grinevich, Hughes and Kitson, 2009; PACEC/CBR, 2009).

In view of the number of academics who may be involved in these activities and the ever increasing demands for them to take on additional missions or roles, it is worthwhile remembering that there are only around 125,000 full-time academics of whom the more senior and well-established are more likely to be involved in these interactions as their career develops.

Moreover, it is important to note that in spite of the range of extensive external interactions and the pressure on universities to alter their mission the internal promotion process remains almost entirely focused on research related issues and peer reviewed scientific citation criteria (Abreu, Grinevich, Hughes and Kitson, 2009; PACEC/CBR, 2009).

This is not to argue that this is inappropriate for particular purposes, but that any fundamental change in the structure of missions or activities of universities across the broad ranges of roles they play must be reflected in some rethinking of the pattern of university appointments and reward structures. Such efforts need to lead to a greater appreciation of the role of public engagement in career development.

This is consistent with a multi-faceted role that universities can play and within which this pattern of interactions can be located. Exhibit 5 presents one typology which reflects this.

Educating People

- Training skilled undergraduates, graduates & postdocs

Increasing the stock of 'codified' useful knowledge

- Publications
- Patents
- Prototypes

Providing public space

- Forming/accessing networks and stimulating social interaction
- Influencing the direction of search processes among users and suppliers of technology and fundamental researchers
  - Meetings and conferences
  - Hosting standard-setting forums
  - Entrepreneurship centres
  - Alumni networks
  - Personnel exchange (internships, faculty exchange, etc.)
  - Visiting committees
  - Curriculum development committees

Problem-solving

- Contract research
- Cooperative research with industry
- Technology licensing
- Faculty consulting
- Providing access to specialised instrumentation and equipment
- Incubation services

This exhibit provides an analysis of the role that universities may play in relation to wealth creation through industrial interactions in terms of the production of human capital through teaching the production of codified knowledge through publications, patenting, a wide range of long-established contractual consulting and other problem-solving activities and, finally, a range of what may be termed 'public space activities'. The latter allow the science base and the universities in which it is embedded to play an important mediating and mutual interaction identification process to take place which in turn can lead on to activities in the other three areas.

In relation to the Fruits of Curiosity it is important not to neglect the way in which there is an interrelationship between the pursuit of research and the development of activities in each of these areas and the way this can feed into both fundamental and applied research.

Bibliography

Abreu, M., Grinevich, V. , Hughes, A. and Kitson, M. (2009), *Knowledge Exchange Between Universities and the Business, Public and Third Sectors*, Centre for Business Research, University of Cambridge.

Bruneel, J., D'Este, P., Salter, A. and Neely A. 'Searching for Talent and Technology: Examining the attitudes of EPSRC industrial collaborators towards universities', Advanced Institute of Management, January 2009. Available www.aimresearch.org/index.php?page=the-search-for-talent-and-technology.

Cosh, A.D., Hughes, A. and R.K. Lester (2006), *UK Plc: Just How Innovative Are We?*, Cambridge-MIT Institute, University of Cambridge and MIT.

Rosenberg, N. 1982. *Inside the Black Box*. Cambridge University Press, Cambridge.

Stokes, D. E. (1997). *Pasteur's Quadrant: Basic Science and Technological Innovation*. Washington, DC: Brookings Institution Press.

UK Computing Research Committee

Royal Society Fruits of Curiosity
Response from the UK Computing Research Committee

Professor Muffy Calder, Chair UKCRC
University of Glasgow
Professor Ursula Martin, Vice Principal
Queen Mary University of London

UKCRC

The UK Computing Research Committee is an Expert Panel of the British Computer Society, the Institution of Engineering and Technology, and the Council of Professors and Heads of Computing. Its members are leading computing researchers from UK academia and industry. We respond in that context, though our responses may be more widely applicable.

Preamble

Few technologies, if any, have had a greater impact on the everyday life of humanity than ICT, Information and Communication Technology. The first stored-program computer, the Turing Machine, was invented by the British mathematician Alan Turing as a thought-experiment, and published in the British philosophical journal Mind. It proposed a law of computation that still lies at the basis of the subject. That it is only 60 years since the Manchester University "Baby", the first actual computer to run a program stored in its electronic memory, underlines the staggering speed with which this technology has moved from speculative research to global impact. Although the internet can be traced back to the early 1960s, it is only 20 years since it entered the consciousness of the general public as a result of a British computer scientist, Tim Berners Lee, inventing the world-wide-web. Yet already the web is a major vehicle of science and commerce, and of growing importance to government. Today most of the computing power on the planet is based on designs licensed from ARM, a medium-sized British company based in Cambridge, whose business has grown over the same 20 years from nothing to ten million microprocessor shipments a day.

The central role of ICT in everyday life is clear. For better or worse, every train carriage is occupied by people talking on mobile phones, listening to iPods, browsing on Blackberries, and absenting themselves from their physical environment to engage in virtual business, family or leisure through the medium of ICT. But these visible devices are just the tip of the ICT iceberg. They rely on an infrastructure of considerable sophistication whose capacity and capabilities are expanding at a stunning rate. And increasingly, this same infrastructure is being exploited to support services for government, health services, science, and pretty much the whole gamut of human activity. Many such applications involve increasing amounts of artificial intelligence, for example search engines, face recognition, or data mining.

The rate of progress of computer technology over its first 60 years has surely been impressive. Today's computers are a hundred billion times more power-efficient than their early forebears, and a million times faster. Devices can hold a million times more data and communicate a million times faster than they could just 30 years ago, while cost has dropped dramatically. That is just the hardware. Software advances on the back of this staggering progress deliver orders of magnitude more functionality than that of early mainframe computers.

Every tenfold improvement opens up dramatic new applications and markets, provided that it is backed by forward-looking and curiosity-driven research, and there is no sign that the rate of progress is decreasing. Moore's law continues to give us advances in computing power. Advances in software technology, and the means to construct and manage ever more complex hardware and software systems, mean that advances in computing over the next 50 years are likely to be even greater than those of the last 50 years. No-one can foresee what this will entail: Advanced machine intelligence? A merging of physical and virtual existence? Brain prostheses? Think back 50 years and try to predict mobile phones and iPods from the technology base of the 1960s, and you will see the problem. On a shorter timescale prediction is easier: for example using computer vision and sensors embedded in vehicles, we could, if we were minded achieve a tenfold reduction in road accidents and their associated costs and misery.

What is clear is that computing research is now more exciting than ever, and has more potential than ever to transform the future. The UK must aspire to sustain its position at the leading edge of computing

research, if it is to influence how this vital technology will take an ever more central place in the human experience, from the perspectives of both wealth creation and quality of life. Computing research is a global pursuit, and the UK's research contribution is just one component of the wider whole. The examples of ARM and the web show the difficulty of assessing the ultimate impact of current research, as it can take 20 years for the full impact of new research to become apparent. The 2008 Research Assessment Exercise showed that twenty per cent of UK computing research can be considered world-leading, and almost two-thirds was judged to be internationally excellent. The subject was found to be healthy and growing, and more rigorous, more interdisciplinary, more experimental and more user-oriented than in the 2001 RAE. EPSRC's international reviews of UK computing research have also found the subject to be thriving.

In addition to its current pervasive role, computing also contributes to the intellectual and cultural traditions of humankind. At the abstract level, computer science ideas ("computational thinking") increasingly pervade science, engineering and the humanities, for example philosophy and linguistics. Developments in computer science and technology have created a new vocabulary of concepts, models and metaphors that are finding increasing utility in other disciplines, and in everyday life. Complex systems, for example, are often best understood in terms of the dynamics of the information flows that determine their emergent properties. Understanding user behaviour, and the impact of technology on individuals and society, is a core part of the discipline, embracing psychology, sociology, behavioural economics and ethics.

Computer simulations and models play increasingly important roles in science, engineering, economics, climate modelling and the like. Advances in computing research contribute to advances in modelling, as these models are frequently limited in their fidelity by the efficiency of the computer hardware and software. These are core to the knowledge economy – central to this ambition is access to the most advanced computing capabilities that research can deliver. Ever more scientific research is now conducted by mining vast databases of experimental results, created either by central capital-intensive equipment, as in particle physics, radio astronomy and earth satellites, or amassed from the results of large numbers of independent experiments as in many areas of biology. UK computing research has already yielded significant advances in e-Science and Grid technology that support this research, but much more remains to be achieved. For all of these reasons, computing research will continue to be vital to progress in many disciplines, and maintaining a vibrant UK computing research capability will yield benefits across the entire domain of academic and industrial research, and in our ability to exploit the knowledge economy to maximum benefit.

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?

Curiosity-driven research is essential for the UK science base to maintain its competitiveness and creativity. Only curiosity-driven research contributes to the scientific and cultural traditions of humankind. Only curiosity-driven research makes the totally unexpected discoveries that trigger true innovation. Only curiosity-driven research can accumulate the understanding that enables us to meet the 'unknown unknowns' in our uncertain future.

In computer science, curiosity-driven research includes fundamental basic research creating new technologies and new theoretical underpinnings, alongside user-inspired research leading to new applications, and engineering research to understand and create systems which bring the pieces together. A recent report4 by the US National Academies on innovation in computing summarised the broader benefits of curiosity-driven research as:

o Research has kept paying off over a long period
o The payoff from research takes time - 20 years is often mentioned
o Unexpected results are often the most important
o Research stimulates communication and interaction
o Research trains people
o Doing research involves taking risks

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?

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[4] Innovation in information technology, National Academies Press, http://books.nap.edu/catalog.php?record_id=10795

Since 1997, UK science has enjoyed increased investment from government through RCUK, HEFCE QR and capital funds for buildings and equipment. Computing research has benefitted both from investment in programmes of basic research such as EPSRC's responsive-mode funding, portfolio and programme grants, and from major directed research programmes such as the Interdisciplinary Research Centres, e-science and digital economy programmes. Computing research has won significant European Union funding in recent years, and it would be good to see similar investment to promote UK-US collaboration, building on the success of initiatives such as the MoD/DoD International Technology Alliance for network technologies.

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?

Increase of funding for science in any country must always be welcomed. Science as a whole will benefit by tapping more widely the intellectual potential of a wider constituency of potential scientists. By maintaining the excellence of UK research, we will be able to exploit overseas advances, both for the benefit of science and for the benefit of the country. Many nations are investing in computing research as they see computing as a key enabler to economic growth. In this respect the UK cannot afford to fall behind. Participation by UK researchers in the research of the international scientific community will make more immediately available to UK industry a much larger flow of successful research ideas than those originating in the UK alone. It also seems inevitable that any decline in UK investment, contrasted with increases elsewhere, for example the US or Asia, will impact UK success in recruiting and retaining staff and students.

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

Modern ICT technologies lie at the heart of many innovations in government and policy, and the public have a lively and healthy interest in the capabilities and risks; consider for example debates on ID cards, e-voting, online security, or NHS IT. It is essential that government, policy makers and the public should be able to make informed choices in the light of the scientific and technological issues, and the impact these choices might have. Politicians and government should take the lead: they should have good access to expert advisors and listen to their advice. Thus, as well as government departments having chief scientists, they might consider chief computer scientists, and recruit policy advisers with appropriate technical background.

5. How should we assess the long-term social and cultural impacts of scientific research?

Science is in itself part of the culture of society, at least as important as entertainment, sport or music. Its social impact should be to give the general population a respect for the scientific method: the impartial pursuit of truth and the collection of evidence to decide important questions. The massive availability of misinformation, especially on the web, make this increasingly important. Modern IT and telecommunications have themselves brought about extraordinary changes in culture and society, the result of decades of academic, government and industry research in the UK and around the world, and it is hard to predict what will come next.

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?

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

The Committee of Professors and Heads of Computing published a study on the IT Labour Market in 2008[5] They showed that, despite the downturn, demand for IT jobs is predicted to rise by 20% over the next decade, in particular for technical and managerial staff. Yet numbers studying computer science in Higher Education dropped by 22% between 2003 and 2006, and numbers taking Computing A level have fallen by almost half in the same period.

Within the school system there has been widespread criticism of the content of the curriculum, and concern over a lack of specialist teachers. Parents, students and some teachers are confused by the difference between computer science and IT (akin to the difference between designing cars and driving them). We recommend the reintroduction of Computing, as opposed to IT, at GCSE level to encourage

[5] http://www.cphc.ac.uk/docs/reports/cphc-itlabourmarket.pdf

more pupils to persevere with the subject. At the same time course material and lesson plans can incorporate the principles of computer science into other school subjects. A general skills-based education in IT is also important, but the curriculum is often criticized as being pedestrian, and could be used to bring more awareness of broader issues needed to make informed choices, such as security and privacy. The cultural aspects of science and technology could also be emphasized to attract students into STEM. The enormous interest shown by schools in the cs4fn[6] campaign, run by Queen Mary University of London with support from the research councils and industry, is an indication of what is possible.

More can be done by HEIs, government and employers to promote computing degrees, and identify flexible offerings so that elements of computer science can be studied alongside other disciplines, and opportunities for reskilling and upskilling can be provided at undergraduate and masters level. The government policy on ELQs, which means such students are at a disadvantage compared to those entering higher education for the first time, should be reversed.

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)?
This is a significant issue affecting computing as much as science and mathematics. It is hard to see quick fixes, although the introduction of more interesting and rewarding curricula, and the inclusion of elements of computer science in teacher training programmes for all STEM subjects, might itself make a difference.

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?
10 What sorts of incentives can we develop to keep talented students and postgraduates in science?
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?
The UK research career, with a short PhD, and typically a pattern of short-term postdoctoral appointments, followed by the demands of an academic career combining teaching and research, is often said to be more demanding than the longer timeframe in the US or other European countries. In recent years this has been compounded by the difficulties early career staff, or those who take a career break, face in an increasingly competitive grant funding regime. For a fast moving field like computing, formal or informal interactions with industry, whether through secondment, or the movement of students, are key in staying ahead of research trends, and are broadly seen as healthy. Research laboratories such as Microsoft and IBM also work alongside universities in training young researchers through mechanisms such as Internships, Visiting Researchers and PhD Scholarship programmes.

Early career fellowships, such as the Royal Society University Research Fellowships, or the more generous European Research Council analogues, are extremely valuable in enabling an academic to establish their own career away from funding pressures, and the overly managerial approaches being adopted by some institutions in response to the RAE/REF.

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?
13. How can we improve the scale and contribution of private sector R&D?
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?
UK computing research has benefitted from the presence of world-leading commercial research laboratories, for example Microsoft and IBM, attracted to the UK by our research strengths. Their research is comparable to that in academia, facilitating the movement of researchers between the two environments and increasing the flow of technology transfer. Government needs to do more to attract inward investment from multinationals: Ireland is an example where tax incentives have worked well. The R&D tax credit scheme is highly regarded by business as a mechanism for stimulating research, and we

[6] www.cs4fn.org

support the CBI's recommendations4 for extensions. There is some concern among both industry and academia that the Technology Strategy Board has missed the opportunity to invest in stimulating the transition of research.

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?

To some extent the implied dichotomy between curiosity-driven research and targeted funding is a false one: big curiosity-driven questions in science, for example searching for the Higgs boson or the moons of Saturn, can require significant investment and planning to answer them. The extraordinary advances in computing over the past thirty years have been the outcome of sustained programmes of research by universities, government and industry, which none-the-less allowed scope for curiosity-driven research within them. Currently, for example, EPSRC funds research in our field through the ICT programme and the Digital Economy targeted initiative, with the former receiving about twice as much as the latter. The RCUK e-science initiative, currently being evaluated, received similar significant investment, and gave UK academia and industry a 4 http://www.cbi.org.uk/pdf/20090204-CBI-R&D-Tax-Credit-survey-report.pdf head-start in cloud and grid computing, an example of how such targeted programmes can create both good science and a healthy environment to benefit commercial progress. Thus we would welcome government investing more in the Grand Challenges of computer science. A major gap has been the support for major long-lived pre-competitive development programmes which would enable the translation of research: for example experimental software platforms. The use of computers in scientific research has changed, or even eliminated, the boundaries between pure and applied research and opened up a whole new, and much more rapid, route of technology transfer between basic research and applied research. The results of basic research can now be accumulated in the design and evolution of the scientific and engineering tools that are used for commercially successful innovations.

However, while such targeted investment programmes have a significant role to play, we know of no evidence that they contribute more to research impact, quality of life, or the development of trained people, than responsive mode funding. Certainly, well managed responsive mode allocations, driven by scientific judgement rather than bureaucratic assignment processes, encourage a diversity of speculative and risky approaches, with the imagination, drive and prioritization coming from scientists themselves and not from centralised planning. It is vital that funds are retained, despite the downturn, for responsive mode research allocated by peer review.

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?

The all-pervasive role of IT means that many areas of government, for example the NHS or defence, are involved in R&D, and in significant procurement exercises, which have the potential, through investment in the research base, to stimulate significant innovation. Government provides a market, which mitigates the risk to business of investing in R&D. We support the extension of the Small Business Research Initiative, which promotes access to procurement contracts by requiring government departments ring-fence funds for small businesses.

In particular, smart procurement of ICT systems should require greater use of scientific methods: see for recent example recent reports from the Royal Academy of Engineering[7]. This will both promote UK R&D, giving UK companies a world lead, and produce more dependable ICT systems, saving costs as a result. More generally, smart procurement can include the purchase of IP, which will directly promote UK high-tech industries.

[7] Engineering values in IT, a report from the Royal Academy of Engineering, July 2009
http://www.raeng.org.uk/news/publications/list/reports/Engineering_values_in_IT.pdf

University of Cambridge

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

Response to the Royal Society's Call for Evidence

Ian Leslie, Pro-Vice-Chancellor for Research
University of Cambridge

I have not had the opportunity to consult internally on the response I have provided below, nor have I attempted to provide a comprehensive response to all questions. I have made a number of points and observations (not always consistent, but then it is a complex landscape) which I hope will be helpful to you in your deliberations.
You will note that I have not held up the Research Assessment Exercise as an evil influence on science or the exploitation of science. I suspect others will. If anything the RAE has engendered an improvement in the basic research of the UK HE sector and is one of the few instruments that provides financial incentives to institutions to support basic research.

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 most transformational innovation comes either from novel discovery or from making novel links between existing pieces of knowledge. It is a simple matter to point to discoveries from curiosity-driven research that have led on to notable impacts, and no doubt your call will elicit many such examples. Coincidentally, we have recently produced a brochure examining two such discovery/impact pathways (organic semiconductors and CamPath) over a twenty year period which is appended.
The notion that the role of curiosity-driven research changes over time is flawed. It will always be the research that keeps the pipeline full of potentially transformative ideas and people who can question conventional wisdom and imagine beyond commercial time scales. However, one can point to particular opportunities at any given time: the current challenge might be expressed as the acceptance that mankind is pushing up against the limits of global resource; virtually all human activity must now be treated in the context of a closed system of resources rather than an open system in which resources are always available. Enterprise and innovation will be required as always, but the ground rules underlying them will be profoundly different.
A key problem in understanding the role of curiosity-driven research is tracing causality of impact. We can (and do) trace paths from discovery to impact of well over twenty years, but this is usually where the relationship between the two is direct and where the discovery provides the primary element of the innovation having the impact. Most surveys of industry which seek the sources of innovation will rather understandably find that the inspiring events are in the recent past, because that is the time scale on which most industry operates, and industry is not concerned whether their access to knowledge is through a primary or secondary source.
There is often a call in the UK for our research to concentrate on our strengths. We have a competitive edge in fundamental research in a very broad sense. We should from time to time evaluate where investments in downstream research – that is, research closer to market – might be made to reflect national strengths and opportunities. However, it would be folly to destroy a competitive advantage we have built up over decades which will enable us to move into new areas and abandon old ones when other economies, through efficiency of scale, out-perform us.
That competitive edge in basic research is demonstrated by the inward investment of global corporations who choose to place their research laboratories in the UK. (It is worth getting the global comparators on this.) This is despite a perverse regional strategy which denies funds to encourage inward investment from the regions of the UK with the bulk of its basic research.
In short, curiosity-driven research will give rise to unplanned opportunities which will spawn, if supported by downstream research, new industries which for a time will give the UK competitive advantage in those particular industries. (Note that if the outcomes were planned with well defined industrial application, we would have no advantage over our international competitors.) With globalisation, this will have to be a constant process, but globalisation also allows us to attract the best and brightest of the UK to be part of this process.
Moreover, the people that are exposed to basic research are by definition asked to explore new areas – often at a formative age. It is no coincidence that many entrepreneurs have PhDs; although few start

businesses related to their PhD studies. There is a tangible short term benefit from basic research – talented people.
A comprehensive framework that encompasses a spectrum of activity from basic research to impact (of any kind) requires stability. The time scales are large and unpredictable, but usually longer than political time scales. Curiosity-driven research, opportunity-driven research, problem-oriented research, roadmap driven research, proof of concept funding, seed capital, venture capital, and absorptive capacity of industry and the public sectors are all required. While one has to be selective in some areas, curiosity-driven research is arguably not one.
(To be over simplistic, parts of this process work extremely well: research. The fact that other parts are not working as well as they might is hardly a reason to dismantle the parts that are.)

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 investment and, even more importantly, the stability of investment over the past ten years has allowed an increase in quality of infrastructure and has enabled us to attract researchers from around the world.
Competitive research funding, both through the RAE and peer reviewed research grants, has provided the most efficient research environment in the world. It is also a very attractive environment for young researchers with confidence to compete.
These two elements might appear to be in tension: the certainty that comes from stable funding and the uncertainty that comes from competition. But in fact the combination is a powerful one, laying out medium term incentives which induce (on the whole) desired behaviour which is (on the whole) rewarded. It allows institutions and individuals to plan strategically.
Another positive aspect of the previous ten years has been a healthy balance of curiosity-driven and problem-oriented research with no administrative distinction being made between them.
Any discussion about moving forward must take account of the squeeze on resources that is inevitable. It will remain that case that stability of the competitive funding regime is essential, even if this is at a lower level. It is also vital that there is not an increase in directed programmes at the expense of responsive mode – that is, where the funder responds to bottom-up ideas from researchers – whether curiosity-driven or problem-oriented. Directed programmes have a tendency to reflect conventional wisdom, which, unsurprisingly, is shared by our international competitors.

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?
There is no doubt that researchers will follow funding opportunities. Indeed this has been a strength of the UK system over the past ten years. The rapid increase in science funding in the US is the greatest concern given mobility and academic culture, but it will take time to for established individuals to be confident that the current shift in US science policy and funding is indeed stable. China on the other hand more clearly represents opportunity since there is a lack of support for the unconventional: we have something they need. Both must be addressed through scientific collaboration to ensure that the UK remains a key player in global research.
It is the most able that are likely to move and will be the hardest to bring to an under-resourced system. A choice will have to be made between the size of the research base and the quality of the research base in the UK. This is related to issues of critical mass and research concentration; a diffuse research base in which resources are spread thinly will not be an attractive one.

4. How should science be governed to maximise benefits to society while acknowledging public questions, uncertainties and concerns?
There is a long recognised problem that the value of science is not well communicated to society. There is the additional problem that in the public's eye, science is associated with certainty. Providing sensible governance ultimately depends upon a well informed public – one that understands time scales and uncertainties. This linkage needs to be better understood by researchers.
The current arrangements of dual funding and the Haldane Principle should not be changed.
Consideration of impact is vital, but it has to be recognised that this relevant only at an aggregated level. The public is concerned with the benefit of the overall public investment in science, not in the benefit of individual research grants.
Greater obligations should be placed on institutions to communicate and enable impact. Resource which is directed via Research Councils for this purpose should either be provided directly to institutions, or,

perhaps more practically, Research Councils could be steered away from focussing on the impact of individual grants to the aggregate impact of the research they fund.

5. How should we assess the long-term social and cultural impacts of scientific research?
We need to continue to explore impact (in general) through studies which take different approaches. Up until now, this has necessarily been done without any groundwork having been laid in the past. This makes the provision of evidence to provide rigorous traceability extremely difficult. This can now change, but current attempts to raise the importance of impact that focus on the individual researcher, rather than the institution, are unlikely to lay this groundwork.
In the case of social and cultural impacts, the need to pursue multiple approaches is particularly pronounced. It is not just a case of determining in an intellectual sense what the impacts are, it is about having results which can be communicated in a meaningful way to a wide audience. (We are midway through a study of the impact of arts and humanities research of the University both to enable us to communicate them and to contribute to impact study methodology.)
One can understand the government's desire to raise the importance of impact but the headlong plunge in the REF when the understanding of impact is at such a nascent stage is misguided. (Solving this is as simple as decreasing the proposed weight to be placed on impact. The sector will still respond.)

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?

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

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)?

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?
Compared to other countries, the UK is an attractive place for a research career in academia. This is largely because of our competitive funding system in which a talented researcher can advance simply on merit. In comparison with options within the UK, universities do suffer from a lack of flexibility in mobility and remit – particular with respect to promotions. This is an institutional responsibility, but one in which the institution sees little external incentive to address.

10. What sorts of incentives can we develop to keep talented students and postgraduates in science?
We should not be too depressed about people choosing to be scientifically trained before embarking on a career outside science. Student debt seems to have had little impact on undergraduate applications, but the drop (until now) of UK students choosing to stay on to pursue postgraduate studies is likely to be partly related to debt. An obvious answer is to provide higher stipends to those carrying on postgraduate study.

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 would be wrong to entirely throw out the standard academic model, but we do need to provide more flexibility. A relatively small amount of movement could have a major impact on the exchange of knowledge. It is curious that this problem is regarded as intractable when research funders provide substantial and prestigious awards for, for example, Research Professorships which lie outside universities' usual structures. While academic institutions can be conservative in their operations, they nevertheless do respond to incentives. The career-track issues are perhaps not as large an impediment as ensuring that the skills and knowledge being offered are viewed as valuable by both sides of the exchange.

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?

The lack of a pervasive small business procurement requirement scheme on the part of government remains a mystery. All evidence points to its success in the US in stimulating innovation in small companies. What is lacking in the UK, with a number of extremely important exceptions, is absorptive capacity of the private sector. It would be wrong to suggest that the private sector should strengthen its science base as an end in itself; this is only sensible in the context of sector need. A more innovative sector will have this need and look widely for knowledge and ideas; some of this will make demands on research, whether in the private or public sector. A more comprehensive small business procurement scheme is probably the most cost effective intervention that can be made to enhance private and public use of research, by enhancing absorptive capacity for innovation.
Note that innovation in small companies will drive innovation in large companies as well.

13. How can we improve the scale and contribution of private sector R&D?
As above.

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?
As above

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?
We must start with a clear statement that both are necessary, and recognise that they should have different rates of successful outcome and different time scales for impact. On the whole leaving this to Research Councils has worked in the past; there will always be concerns when resources are tight that Research Councils will be asked to justify the investment in research and will "cash in" their portfolio by shifting emphasis to downstream funding to produce near term impact.
One way balance could be maintained if there could be consensus in research councils that new programmes would only be allowed to be created when others completed. (There is clearly a problem here relating to the time scale of impact. Targeted programmes are invariably downstream programmes in which the time scale to impact is shorter and highly traceable. Those running targeted programmes will devote energy to demonstrating impact; this is less so for the response-mode research – unless this is laid at the door of research institutions and comparisons are done with an understanding of the context.)

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 impact of the dual funding on the excellence and efficiency of the UK science base is under-recognised. It allows institutions and individuals to plan with incentives in the world's most competitive research environment. It must be preserved if we are to retain the efficiency of the system.
It is less important how the Research Councils are organised. Drives towards greater consistency in policy and practice are welcome. There is little to be gained in reducing the number of research councils, unless that reduced number is one.
The distinction between role of the Research Councils and the TSB needs to be more clearly articulated – in particular while selectivity is clearly a strong consideration for the TSB, it should be less so for the Research Councils.

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?
Government department use of science should be again driven by need. The problem is one of culture and practice: on the one hand government departments should be producing policy on the basis of rigorous evidence and should be questioned on that basis; on the other, researchers, particularly in universities, need to understand the policy generation process and how to interact with government departments. This is again a responsibility that should be laid at the door of universities: to build this capacity amongst its academics, but needs to be resourced.
Government departments are conservative in their procurement – read the MoD framework agreement given to suppliers and ask yourself, if you were a university supplying research, would you sign it!

There have been instances where departments "co-fund" with Research Councils to procure research to the department which one might consider crosses the ring fence. As a loss-leader this is acceptable, but should be watched.

University of Exeter

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

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?

We believe that curiosity-driven research plays a crucial role for the UK science base. Not only does the highest quality science often result from curiosity-driven research, but, it also attracts and retains talented individual scientists. Allowing for curiosity-driven research is extremely important for the future of the UK science base. That said curiosity is not valuable in, and of, itself. Curiosity needs to be balanced by theoretical and scientific rigour. Without integration with existing knowledge bases and theoretical work, research driven by curiosity alone may miss important links and thus contribute to fragmentation.

However, the role of curiosity driven research needs to be viewed within the context of key research issues, identified, for example, within RCUK's Grand Challenges. There needs to be a balance between 'pure' curiosity-driven research where ideas are pursued for their own sake, and 'targeted' research which is intended to meet the scientific and societal challenges which we know need addressing. Without allowing for a broad-base of research questions to be developed and pursued (curiosity, theory-driven, and problem-driven), the sciences will lose their capacity to be responsive to unforseen problems and will limit the potential for novel and exciting theory development.

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?

We believe that peer review and responsive mode programmes are successful schemes. They encourage creativity and collaboration with partners. The current emphasis on "managed programmes", on "central organisation" and concentration in a limited number of universities should cease as it stifles innovation, and constrains imaginative science. However, the current academic funding model encourages deep specialization. There is awareness that this in itself creates an inflexible and unresponsive structure which cannot easily adapt to the changing needs of society, particularly when inter-disciplinary work is needed. It is also essential that science policy ensures that broad scientific capability is retained within the UK, even when there is no apparent immediate need for them.

Initiatives to encourage collaboration between the research base and users have been very helpful in changing the culture in universities but the general over emphasis on SMEs is not always helpful in a research context. Future programmes need to take account of the absorptive capacity of the user base and should help organizations develop the ability to build lasting collaborations with academe through exchange schemes etc. Innovation networks and KTNs have been useful in helping to establish collaborations but need very active management to be successful.

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 increase in activity and support for science elsewhere will inevitably impact on the UK research community and will result in a more competitive research environment globally. If there is more funding, better opportunities, and more support offered elsewhere, the best researchers will go where the grass is greener - leading to problems of brain drain, in addition to increased competition. This is bound to have a negative impact on UK research, its international reputation and its competitiveness unless we are seen to match these initiatives.

It is difficult to see how any major changes in the effectiveness of UK research can be achieved without additional funding. However, to maintain competitiveness in this environment, the UK needs to play to its strengths. It should be noted that increased funding abroad has not occurred across all the sciences. In the social sciences, for example, funding in the US has become more competitive, leading many high quality researchers to come to the UK, further contributing to the strength in social science that is already present here. Collaborative activities which link the UK to other national activities could increase the value

of UK research, but there is a significant risk that the UK agenda will be driven by other nations if the UK is the minor partner.

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

It is evident that research in the UK has been successful in providing innovation and opportunities for the UK economy. To maximise benefit, science needs to be governed well - but what this means remains unclear. At a minimum, it is important that management of science does not mean micro-management of scientific research. Science, by its very nature is driven by novelty of ideas, our naturally inquisitive spirit, and the talent of individual scientists. It is imperative that the UK's government role is to nurture, support, and encourage our highly talented research community rather than adopt an overly-managed, top-down 'governed' approach.

5. How should we assess the long-term social and cultural impacts of scientific research?

We believe that it is important to assess the long term social and cultural impacts of research. The key to achieve this is to provide accurate scrutiny of the long term effects of funded research, with at least five and ten year perspectives on the outcomes after the funding has been received. It is important that social, economic, political, and cultural impacts are assessed. But quantifying these kinds of impact directly is often hard.

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?

The reintroduction of separate GCSEs in Physics, Biology and Chemistry has been a welcome improvement. There has also been a marked improvement in mathematics in schools which is encouraging.

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

A crucial challenge is to address the gender imbalance in particular areas of STEM education.

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)?

The key to attracting highly talented staff is to convince them that a structured and rewarding career path lies before them. The combination of an appropriate salary and employment conditions are clearly important - we should value what they do both socially and financially. Paying salaries that attract the very best into these professions (and especially senior scientists from industry who elect to make a mid-career change) is likely to have a beneficial effect.

Additionally, within the school system it is imperative that teachers have the freedom to innovate and engage their students with captivating science rather than be constrained by an overly prescriptive curriculum. This would benefit both the teachers and school students (who would be more likely to choose the sciences as a career).

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?

The crucial issue is to encourage, by financial incentives, more UK students to do PhDs. We need to offer them a clear career path with job security, and to value their work. Also, a major challenge for all research funders is to resolve the tension between the grant-supported research cycle, and the expectation and aspirations of PhD and postdoctoral scientists who wish to see a secure, and fulfilling career path in front of them.

10. What sorts of incentives can we develop to keep talented students and postgraduates in science?

Financial incentives (starting salaries for junior researchers are very unattractive), well defined career paths, and truly valuing their work.

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?

No, but see 9. The provision of 'conversion' training courses for highly trained staff that wish to develop their careers outside research could be considered. These could be offered at the end of a PhD or postdoctoral grant and ensure that highly trained staff have the best skills set to exploit their expertise. An appraisal scheme that recognizes that a range of career paths are open to highly trained staff would be helpful, allow informed decision-making, and maximize funding available for scientists genuinely planning a long term research career.

The current career models generally involve graduates or junior post-doctoral scientists making career choices between academia, industry, government laboratories and business. Movement between employers after this point is difficult and may slow career progression. Movement between academia, public and private sector is important for knowledge transfer and for consolidating the links across these sectors. However, it should be noted that this movement typically goes in one direction only: from academia to the private or public sector. That is informative with respect to the question above: people often feel more valued outside academia.

This creates barriers to technology transfer and the exchange of ideas between these sectors. Movement of scientists at all levels between these sectors needs to be encouraged.

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?

Movement of scientists between the academic and private sectors is the key to strengthen science and innovation. A scheme should be implemented that actively encourages scientists to move from one employer to another. Clearly, to be effective, this requires stability in that the individual's original position is guaranteed in some way (e.g. for a 3 year period). Provision of forums where scientists, industry and public sector representatives can meet and interact around issues of common interest and concern (and do so as equal partners) would be very helpful.

It is time that the engineering professional bodies came together to form one, united voice, to more effectively champion the importance of engineering in society.

13. How can we improve the scale and contribution of private sector R&D?

Play to our strengths. In the social sciences a lot of good, practical work is being done. Making people aware of this (e.g. by providing for interaction as above) would be the first step. Practical actions such as tax incentives could also be considered.

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?

The Knowledge Transfer Partnership scheme and the Technology Strategy Board appear to have been successful, when companies are prepared to make the necessary financial commitment. Other schemes, particularly for small businesses, seem to have had little impact.
In England, the regional development agencies have, at best, demonstrated a very patchy level of support for research from region to region and, at worst have failed to fully appreciate the importance of strategic, long term, internationally competitive research for the well-being of the regions.

The R&D tax credit scheme has not been able to be harnessed effectively by suppliers of research capacity to industry and has been disproportionately taken up by large R&D users.

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?

More involvement of practicing (and younger) scientists in the policy making processes. The direct allocation of budgets to these different types of activity (curiosity-led, response-mode research, and more targeted or programmatic funding) would also maintain a balance. Ensure that these activities are given equal footing and value. Curiosity-led research should not replace basic theory-driven research.

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?

More peer review, more responsive mode, less targeted and managed. Clear identification of major scientific and societal issues that need addressing as a priority, without overly managed research programmes.

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?

It should be more actively involved in engaging with business. Government Department spending on research must fill capability gaps which do not exist in other organizations, rather than attempt to duplicate academic or industrial activities. There must be much greater open competition for Government Department funded research and much better co-ordination of Government Department funded research with research in other sectors.

Ensuring a variable funding base for science is important for it to maintain the breadth that is necessary for continued success. Therefore, public sector R&D should be encouraged, especially where it can facilitate communication from academia to policy and create social and cultural impact. But public sector R&D should not become a substitute for ring-fenced science funding. As stated previously, a balance of basic theory driven work and responsive problem/ issue driven research needs to be maintained for the future viability of the sciences.

University of Glasgow

The Fruits of Curiosity: Call for Evidence

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?

Curiosity–driven research must be central to the UK science base at all times, not just in the next 15-25 years.

We seek to uncover and understand the fundamental principles that govern the physical and natural world and our interactions with it. Whether research is identified as basic, applied or translational, the main driver for real scientific advance is this curiosity-inspired desire for explanation and predictive power. Hypothesis-driven, peer-reviewed research led by individual investigators and teams should continue to form the major element of the science base in UK Universities. This clearly cannot take place in technological/infrastructural vacuums which thus need constant refreshment through capital investment programmes in emerging areas and technologies.

Funding should continue to reflect this by a high reliance and investment in responsive mode funding. The primary purpose of Universities should remain as intellectual powerhouses of curiosity-driven innovation rather than commercially driven research and development centres.

The need to ensure the translation of research into tangible economic or other benefits for society is, of course, also important, but should be the second and not the primary role for the Universities. To focus research entirely on topics with already obvious translational value will stifle innovation. The research agenda will become focused too narrowly, on low risk 'safe' research – on the 'known unknowns', rather than on the undiscovered and possibly unimagined.

In recent years, Government and Research Council policies have stressed, and continue to stress, the need for the translation of research and the requirement for the research they support to have an impact on human and animal welfare, on health and on the economy. As a result, scientists are required to write sections of grant applications with comments on potential impacts that they consider to be at best improbable and at worst entirely fictional. Such impact statements should come after, but not before, the research is carried out. We suggest that those researchers who obtain grants be asked to write such impact statements as part of the final reporting, rather than the application, process.

Furthermore, the over-emphasis on economic benefits is worrying. While Universities, where much of the research is done in the UK, can and should contribute to the county's economy, this is not done by generating simple monetary gain. The position of Higher Education and the strength of the research base in Universities in the UK stems from the ability to train future generations and to prepare them for the challenges ahead. The essential role of the Universities is to train the next generation of scientists including future research leaders and this is in danger of being overlooked.

Academic staff are not resourced or rewarded to conduct short-term applied research for immediate industrial use.

Governments and Research Councils should not shift responsibility for the economic wellbeing and development of the Nation away from industry and commerce, who are at the same time reducing their R&D investment and their support for the Universities.

Judgments of the efficacy and quality of universities and the science they produce must not be based on their capacity to generate short term economic profit. There is a danger that in a few years time the Universities will be penalized for failing in a role that they should not have.

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?

It is extremely important that responsive mode research is the main funding stream for Universities. This should be where the majority of research council funding is directed. Policies that have eroded this central core have de-motivated researchers, stifled their innovation, and been unsuccessful.

However, certain partnership project schemes are very successful. These are often, however, too narrowly focused on industry and financial gain. Such schemes should be expanded to include more partnership with government agencies and NGOs.

Major capital programmes such as the human genome project have been successful and investments in genome sequencing have been important. Large scale epidemiological/population projects that engage the public have also been successful and should be maintained. Generation Scotland is a prime example of this.

Support for Integrated Mammalian Biology (*'in vivo'* research) is proving beneficial, though the costs of doing research on animals are increasingly driving people away from the increasingly important areas of whole organism effects.
Capital investment programmes in new buildings/infrastructure have been successful. The major investment from the Wellcome Trust and Research Councils through Joint Infrastructure Funds has made a major difference in many areas. Demand for support from JIF demonstrated the chronic under-funding of estates and facilities.
To some extent, scientists in medical research are still dealing with the many negative effects of the MRC's cooperative awards system that virtually excluded many scientists from being able to exploit MRC's resources. The co-op system was particularly damaging to researchers are the early stages of their career.
In Scotland the SFCs 'Pooling' initiative has injected much-needed additional funds into a number of areas (Physics, Chemistry, Life Sciences etc). There have been some immediate benefits from Pooling, particularly in attracting leading international scientists to Scotland. It will be some time before there is any clear evidence of any sustained structural change in how science is done across the Scottish Universities, however. In the life sciences, the focus has been entirely on cellular-based research and no initiatives have been aimed at environmental areas despite the recognition that it is here we face societies' most challenging problems.
There remain concerns about links with industry and with the advent of FEC, the risk that big Pharma will relocate their efforts to India and Japan to exploit the cheaper labour costs in those countries.
It cannot be emphasised too strongly that there is no substitute for investigator-led responsive-mode funding. This has served the UK well over many years. It is important that this mechanism is retained and that researchers, not bureaucrats, set funding policies.

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?
US, China and India potentially present major threats to the international standing of UK research, since it will become increasingly likely that new discoveries are made in these countries. Talented researchers, frustrated at the lack of funding for innovative research, will increasingly move elsewhere. Partnership and international exchange arrangements may help reduce the impact but this will be a major issue for some years to come.
The developing science base in the US, China and India will be also synergistic, however, provided the investment foundations in people and infrastructure are maintained. UK-USA and UK-China co-operativity has yet to be fully developed through shared research opportunities/investment at grass roots level. We must remain financially competitive at the same time as being ethically and technically sound.

4. How should science be governed to maximise benefits to society while acknowledging public questions, uncertainties and concerns?
It is important to maximize the public's interest in and understanding of science by adopting transparent approaches and to engage the public in dialogue, science communication activities and decision making. Lay forums within Universities and Research Institutions should be developed.
More work is required towards synergising the public perception of science and the expert view. This is currently discordant in major areas (for example evolution, GM food, reproductive genetics etc). Animal research has to be understood as fundamentally integrated with medical research. It is expensive and raises major welfare issues that need to be publicized. Government has been shy about coming forward in support of controversial subjects like animal research, however political expediency should be secondary in this context. Most scientists are not motivated by a desire for financial reward, and seek to be independent and impartial in their endeavors for understanding. The public trust and value this important role in our society. More reliance on industrial funding will erode this impartiality.
Peer review and reproducibility of new findings rapidly weeds out the unethical in basic science. It takes a global financial crisis, however, to identify unethical behaviour in the financial services industry.

5. How should we assess the long-term social and cultural impacts of scientific research?
By whether or not we have a better understanding of the world, and more predictive power. Development and expansion of existing academic, public and government forums has a role to play in this process.
There is a need for more research linking science and technology with studies of likely impact. Retrospection, implied by assessment, is too late: the damage may be done or the opportunity lost. This may be a difficult challenge for the social sciences but not the creative disciplines.

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?
This remains controversial. It is still not clear that the changes that are now being proposed and in some cases introduced will lead to genuine improvements in delivery, content and assessment. Various reports have concluded that science subjects in schools are overloaded and there is a belief that the amount of material to be covered leads to very superficial learning. Decluttering the content of school courses must be encouraged and will be warmly welcomed by the Universities so long as pupils can gain the skills and techniques of science combined with a knowledge of fundamental principles. Applying the methods and the principles of the sciences also offers an ideal platform to develop numerical, mathematical, literacy and problem solving skills as well as analytical skills. School courses need to have an inbuilt mechanism for rolling change to avoid growing obsolescence and a need for major review every decade or so. Teachers should not be driven by the assessment process but should be given scope and space to enthuse pupils about the subjects studied. Extended practical work and good demonstrations can enthuse pupils, whilst adding their own distinctive educational value

7. What are the future challenges for STEM education at primary, secondary and tertiary levels? How should these challenges be addressed?
There is an urgent need to raise the "science literacy and confidence" of primary teachers. This is the best stage to stimulate an interest in the STEM subjects. It is vital that existing primary teachers are given the opportunity for CPD to raise their science skills. Even more importantly, more science graduates need to be recruited into primary teaching.
In secondary schools there is an overemphasis on learning by rote and insufficient exposure to problem solving and project work. Talented pupils are not given the opportunity to excel. Specialist provision is provided in the state sector for talented musicians, but not for talented mathematicians and scientists. The threat to hands-on experience of science because of health and safety concerns and costs deprives young scientists of much of the excitement of doing science that would encourage them to pursue a career in STEM. Young people also need to have the opportunity to interact with young scientists and engineers from industry and the public sector so that they are made aware of the attractive career pathways and salaries available to science and engineering graduates.

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)?
Good salaries are essential and in some cases salary enhancements may be necessary to recruit high quality individuals. Potential candidates must also be reassured that they will receive support in relation to pupil discipline where required.
Regular training and ongoing CPD is essential to keep teachers abreast of developments in their subjects. Well equipped laboratories and technical support should be available to allow students to get hands on practical experience. Local Universities will be able to help in these areas.

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?
Issues related to the early development of scientists are covered in the responses to questions 7 and 8 above.
Currently, there is a risk that young researchers see science as too competitive and too difficult to get sustained funding.
To improve the attractiveness of research careers, an improved public image of scientists is needed, as are improved career opportunities for women who are currently underrepresented in science. It is essential for research positions to offer salary parity with equivalent professions and contract improvements and the availability of tenure-track positions are important. All researchers should have access to continued professional development programmes and greater opportunities are needed in particular for clinical (including veterinary) academic development.
Restructuring of the career path is required to remove the currently entrenched 'intellectual ceiling' that blocks career progress at a critical age (30-35yrs) for all but the very able. This could be achieved, for

example, by creating middle-ground research support positions for competent researchers within larger research groups who would currently leave science for alternative training/labour markets (or not enter science at all due to perceived poor career prospects).

10. What sorts of incentives can we develop to keep talented students and postgraduates in science?
Greater opportunities are needed for PhD programmes, extending them to include post-doctoral training experience between institutions (UK and overseas). Initiatives that improve mobility are also important – e.g. short term (1-2year) exchange programmes for newly qualified post-docs.

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?
We would not change the basic career-track model which already provides for staff to be seconded into industry for substantial periods.

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?
By stimulating demand and encouraging companies and the civil service to employ more research-trained scientists in their management teams.

13. How can we improve the scale and contribution of private sector R&D?
By stimulating demand for R&D led innovation and reducing the cost of risky research in industry. For example, regulatory changes, encouraging development of clean technologies, better environmental monitoring etc create new markets. Back this up with a prototype procurement programme.

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?
We are advised by industry that government support schemes are littered with red tape and are more expensive to apply for/manage and report on than they are worth. Such disincentives must be eliminated.

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?
Targeted or programmatic funding would be at its best if it had elements of curiosity-led research. There is a danger now, of too much being directed to targeted 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?
During the next 20 years, interdisciplinary research will become increasingly important. It is vital that the Research Councils and the University Funding Councils develop effective mechanisms to support interdisciplinary research. The emerging interdisciplinary areas must not be handicapped because the research falls between the areas of current focus for the individual Research Councils

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?
Science budget funding should ensure a strong science base; departmental spending [there should be more of it] should fund 'Pasteur's quadrant' research i.e. research driven by consideration of use. This could protect the long term future of curiosity driven science, but also support essential targeted research for medium term application. Our systems were richer and healthier in the past when funding streams were more diverse.

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University of Nottingham

Institutional response to the Royal Society Call for Evidence

– The Fruits of Curiosity; science, innovation and future sources of wealth

General Statement

The University of Nottingham commissioned a wide-ranging review of its strategies, processes and investments in research and knowledge transfer. The resulting strategy is critical to the institution's future success and signals our determination to address global problems and our ambition and commitment to excellence, to impact and to sharing these benefits with stakeholders and the wider community. Our responses to this consultation result from a series of evidence based papers that informed the development of this strategy. We recognise pressures on policy and the economic drivers that will effect UK investments in science and research and consider that UK partnerships that leverage critical mass research with university's strategic investments will be the most effective route to maintaining UK international standing in world-class research.

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?
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?
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?
4. How should science be governed to maximise benefits to society while acknowledging public questions, uncertainties and concerns?
5. How should we assess the long-term social and cultural impacts of scientific research?

UK investment in core disciplines must continue, so that strong discipline led curiosity driven research on which interdisciplinary solutions and applications can be developed. It is right to focus most activity on priority research areas of strength where the UK is internationally competitive. These priority areas should be developed in consultation with leading universities, institutes and industry/ research users. However industrial and research user input should not dominate to the extent that blue skies research is downgraded. The majority of funding should be directed towards response mode proposals in these priority areas. Some work should be done on breaking the "template" of "1 post doc for 3 years" as a cultural norm for responsive mode research and promoting high quality applications that are larger, over a longer timeframe that will have increased impact.

Specific initiatives that focus resources on particular long term challenges such as: pressure on natural resources, an ageing population or the acceleration of innovation and technology transfer, have been successful in encouraging a more interdisciplinary and innovative research base. A gap still exists in translational funding, although this is closing with HEIF and FoF investments which have succeeded in encouraging and incentivising innovation that is more effectively embedded within the research community. There has been a substantive cultural shift across the research base to collaborate more with industry and transfer knowledge and technology for improved impact. However, this shift is not reflected across the industry and research user base. Universities have a greater understanding of the needs and objectives of industry and research users, there needs to be a complementary activity across industry to understand the needs and objectives of the research community.

The UK research community needs to collaborate proactively with the research base in America, China, India and EU to maintain its global position and remain attractive as a world-class science community. Although some progress has been made in breaking down the barriers to international collaboration, national funding restrictions and double jeopardy work against real international collaborations. Less restrictive funding regimes and expansion of UK supported international networks will aid direct international collaborations. Small travel and network grants are particularly important in initiating and developing international research partnerships.

Research governance and ethical codes need to be better co-ordinated at the national level, despite the establishment of UKRIO and recent RCUK publications there continues to be fragmentation and duplication of policy effort in this area. Public benefit and engagement needs greater incentivisation

packages perhaps along the lines of the successful HEIF initiative, with dedicated institutional investments. The research base is developing this area but partnership and leveraged investments from RC and other research sponsors will catalyse the activity and increase the momentum of any impact, mirroring the effect of embedding innovation/KT in the research base. The resulting impact measures need to reflect these broader aspects.

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

Initiatives such as the CETLs and Regional Science Learning Centres have done much to advance the delivery and promotion of STEM education across all levels (primary, secondary and tertiary), similar projects and interests from employers and professional institutes promote STEM as a career route. There is an argument that some of this work could be more effective if it were co-ordinated, although there is a counter argument that localised delivery has greater personal impact and individual effect. We suggest that there should be improved linkages across the various programmes to overcome duplication and maintain local delivery.

There continue to be challenges of engagement and currency for STEM education both in curriculum design and mode of delivery. This should be continuously addressed through the application of best practice in educational research that results in the design of improved methods of teaching STEM at all levels. Opportunities for researchers and practitioners to share issues and implement best practice should be encouraged.

Financial incentives to attract science and mathematics specialists to the teaching profession have had limited success thus far; however their long term effectiveness should be reviewed before any changes are made to the appropriate schemes. Outreach activities with HEIs do encourage and inspire young people to take up STEM subjects and careers. There should be continued support for the groups of actions that are aimed at encouraging engagement in STEM. These activities include: widening participation, student ambassadors, schools outreach, science clubs, public engagement and public understanding of science. To improve their effectiveness again there needs to be better linking of activities and significantly more use of digital media to attract young people.

There continues to be a major gender imbalance across STEM disciplines, at primary, secondary and tertiary levels. More proactive promotion of women in STEM, using role models and dedicated initiatives that enable women to overcome the career pinch points. Return to work fellowships, such as the successful University of Nottingham fully funded programme of Anne McLaren Fellowships (see Anne McLaren Fellowships for further details) are an excellent example of how we can go some way to re-balance this divide.

Similarly ATHENA SWAN Awards provide a process and guidelines for improving the development of women's careers in STEM. The expansion and take-up of this programme across the sector is important.

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?
10. What sorts of incentives can we develop to keep talented students and postgraduates in science?
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?

The major issue here is capacity rather than capability, we have very many high quality students who could progress to research careers either in academia or industry. The incentive package for research studentships are not comparable to salaried roles outside of research so can be less attractive to graduates. The position will be more of an issue in the current economic climate as the highest quality students will be most in demand.

To grow the volume and quality of the post-graduate research community there needs to be a mixed media that includes individual research studentships supporting blue skies research and substantive investments in collective or collaborative doctoral training centres, focused on UK priority research areas that include high quality integrative graduate training.

To encourage new academic talent here at Nottingham we are developing extended attractive fellowship packages that significantly supplement RC and major sponsor programmes and will create career paths for the most able researchers that enable independence and progression to academic posts.

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?
13. How can we improve the scale and contribution of private sector R&D?
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?

As referred to in the earlier response the HEIF initiative in universities has contributed to improving academic engagement with industry and research users, but this is primarily technology push. Routes for technology pull from the private sector are less mature. Similarly intermediary business support organisations do not seem to be solving this but act as barrier and often duplicate effort and activity.

We would recommend focused investment that will help in mining technologies from previous research that could have specific industrial application but resides in reports, PhD thesis, or has niche applications in research labs. At Nottingham we have employed industry specialists acting as a technology 'miners'. Based within the university they gain both an understanding of the research and objectives of the research organisation and can clearly see if research could have an application in a given sector.

Where appropriate the identification and detection of IP needs to be explicitly stated as an aim of STEM based research grants. The existence of a well drafted patent is essential to initiating meaningful discussions with industry. Continued training for students and researchers in IP should be encouraged.

There is a significant lag between the end of a research grant and subsequent economic and social impact. This impact is normally measured in years. The Royal Society needs to reiterate this argument with government as there continues to be a naive view that impact will follow immediately from completed research. To provide evidence of this, final reports should be requested 3 to 5 years after the end of the project to capture impacts. There could also be an assessment of the link between the impact of previously funded research and funding for future applications.

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?
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?

We believe that the peer review process should be maintained, whilst it is not a perfect system it is the best we have and admired by international research agencies. An issue of peer review is getting expert researchers to take part in the process to spread workload. Some Research Councils have tried to increase the input and turnaround by having a paid college of experts; others have an unpaid college where numbers of applications to be reviewed are restricted to 6 per person year. In practice some college members review high numbers of applications, others don't. Research Councils should send the proposals to fewer referees, but establish measures that ensure that the referees do actually referee the proposal.
The sector does need to be more targeted if we are to compete internationally. Spreading expertise too widely and thinly across all Universities will undermine quality. Conversely however in some disciplines there is a concentration in too few Universities. The challenge is to achieve an optimum balance that achieves highest quality research outputs. Discipline reviews provide a valuable opportunity to open

dialogue with institutions on what constitutes critical mass research at an institutional and national level in terms of maintaining and developing the health of research disciplines.
It is important that the dual funding system is maintained so that institutions can make local decisions on investment in research priorities and nurture basic research.

University of Sunderland

Response from the University of Sunderland to The Royal Society's Fruits of Curiosity Call for Evidence, deadline 11th September 2009

In general the University in Sunder supports the notion of curiosity driven research, in balance with applied research. Below we have given brief answers to the specific questions raised.

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?

It should play a large role, not only to counter the short-termism inherent in the current financial climate, but to address the unknown future needs of society.

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?

Knowledge Transfer Partnerships (formerly TCS) have been successful in underpinning long term relationships between industry and academia. There is however still a dearth of industrial and commercial research in the UK.

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?

This will undoubtedly challenge the position of the UK as top provider of research. In order to address this the science base must be better resourced and should include specific schemes for international collaborative research both on the large scale and on the small developmental front.

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

Public Understanding (and crucially, appreciation) of Science is a key issue. In terms of uncertainties and concerns it is appropriate that informed lay-persons are represented on groups and committees at all levels.

5. How should we assess the long-term social and cultural impacts of scientific research?

This is non-trivial question and we believe that much work is required in this area.

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?

Progress has been slower that desirable, and perhaps even retrograde in certain aspects. Much needs to be done in this area.

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

Raising the profile of STEM in society is key, STEM professionals in some other countries are seen in a much higher regard by society than they are in the UK. It is important to improve the quality of the learning experience in schools and colleges, which could perhaps be addressed by better links between teachers and researchers. The enthusiasm and knowledge of teachers is key.

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)?

Better pay, and crucially better conditions. Teachers should be able to teach as they see fit as long as the curriculum is covered, they will be judged by their results in any case.

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?

Better pay and working conditions; being able to conduct the research that interests them as well as undertaking research with more obvious direct benefits.

10. What sorts of incentives can we develop to keep talented students and postgraduates in science?

Better resources (pay, conditions, facilities, attitudes) and more professional support for research, allowing researchers to conduct research rather than getting bogged down in bureaucracy that others are better equipped to address.

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! There are fewer opportunities for researchers to become academic staff, it is crucial that this seen as not the only option, but even, not necessarily the most desirable career option.

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?
The private sector needs to be better rewarded (to be better able to make use of research) for doing their own research and interacting with academia. There should be more incentives to increase the private spend on R&D

13. How can we improve the scale and contribution of private sector R&D?
Again, it must be easier for the private sector to reap the benefits of research.

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?
Tax credits have had only limited success. As well as supporting businesses to succeed they must be able to fail without stigma.

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?
This should be reviewed regularly, perhaps as part of the Comprehensive Spending Review, but there should always be a reasonable amount ring-fenced for non-directed curiosity driven research.

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 Dual Support system should be retained, but brought into balance with additional QR funding to allow HEIs to follow their individual missions. Charity funding could be better managed in HEIs; perhaps CRSF could be allocated (to approximately the level of research council funding) at the time of award, so that HEIs can better manage their portfolios. RC funding levels (80% fEC) are about right, as long as QR is increased to balance this. If 100% fEC were allocated as a matter of course then this could reduce the ability of HEIs to be strategic in their approach to research planning. However the success rates currently achieved in RC funding in general are too low to be efficient, unless research funding overall is dramatically increased (eg from the private sector) then HEIs must better manage their research enterprise.

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?
The level of private R&D funding is currently far too low (perhaps by a factor of 3), it is imperative that for the UK that this is increased. This could be addressed in part by more funding for collaborative schemes (eg KTP) where private sector income is multiplied by public funds, however in an ideal world this would not be needed as the private sector would be better able to reap the benefits from and hence more willing to participate in and fund research. This must of course be balanced with discretionary (QR) funds for curiosity driven research and RC (and other) funders having schemes to support curiosity driven research.

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Vitae/Career Development Organisation (CRAC)

Vitae/CRAC response to 'Fruits of curiosity' consultation
October 2009

About Vitae

Vitae is the national organisation which promotes and enhances the career and personal development of researchers in UK higher education. Its mission is for the UK to be world class in its support and development of researchers. Managed by CRAC in partnership with eight regional Hub universities, Vitae enhances the support available within higher education, champions the development and implementation of effective policy and provides research and intelligence to support the researcher development agenda. Vitae is funded by Research Councils UK but most of its activities are available to the spectrum of researchers in the UK, irrespective of their funding source.

About CRAC: The Career Development Organisation

CRAC created and has managed Vitae since its launch and managed the UK GRAD programme which preceded it. For 45 years CRAC has played an independent but expert role in supporting the career development of young people and adults, providing R&D and developing programmes and interventions for all those who support career development, including careers professionals, employers and education professionals. A registered charity, CRAC now focuses on innovation and intelligence work to inspire and inform career development and management.

Response to Royal Society consultation issues

Our response covers the perspectives of both Vitae and CRAC.

Long-term policy direction

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

One of the most positive aspects about the policy landscape in the last few years has been the 'Science and Innovation Investment framework' and the articulation of a long term commitment and strategy to increase investment and place science and research as a key function of the UK economy.

Alongside this, we have seen a cohesive and sustained policy commitment to developing PEOPLE alongside research which has enabled the professional development of researchers and the impact of researcher careers to be a strategic rather than piecemeal agenda. Over the last few years, building on the 1996 Concordat, there has been the Roberts Review highlighting the need for transferable skills and career development, and the recent Concordat to Support the Career Development of Researchers[8] which brings up to date a renewed commitment to the good management of research staff in HEIs. Also importantly, alongside these policy drivers, the Research Councils' investment in Vitae has ensured that there is an implementation channel for many of the people initiatives for researchers to be coordinated on a national basis.

As the focus on economic and wider impact has become a dominant theme in response to reports such as they Warry report [9] 'Increasing the economic impact of the Research Councils', Vitae and the HE sector have responded by developing an 'impact framework' to apply specifically to the training,

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8 www.vitae.ac.uk/policy
9 www.vitae.ac.uk/1684/Initiatives.html#warry

development and careers of researchers10. This framework also aims to enable HEIs and the sector as a whole to demonstrate the outcomes that have been achieved as a result of the investment (approx £22m per year) via the Research Councils in researcher careers.

The importance of continuing this stream of funding has been well recognised at policy level, through the HE debate and the Thrift11 and Wellings reports, and a specific 1994 Group report12 published earlier this year which stated: '… the study shows that, as a result of Roberts' funding, skills training and related support for early career researchers are now firmly embedded within institutions, and that the amount, range, and quality of training and other support has improved considerably. Maintaining the progress that has been made is a critical area for ensuring that researcher career development and our capacity to be a leading nation in science and research continue to develop over the next few years.

Alongside this the close alignment of UK and European policy objectives has also been helpful in ensuring a coherent strategy in relation to professional development for researchers. The European Charter and Code for researchers has been incorporated in the UK through the QAA Code of Practice for Research Degree programmes and the new Concordat and links with the European Commission and other member states are strong. The UK is recognised as being a leader in the field of training, development and management of researchers and we could do more at policy/high level to promote this aspect of UK research.

More broadly, the consistent emphasis in Government education and business policy to promote the study of science and technology (now STEM) subjects has been welcome and appears to be starting to have impact. As a result of a series of reviews and policy documents, there is now almost universal recognition that an increase in the number of young adults entering the workforce with STEM qualifications is both necessary for the future health of the UK economy and potentially beneficial to the individuals in terms of their careers and wellbeing. This 'alignment' of policies and adoption of a campaign-like strategy with a common mission has been effective. This should now be embedded further by a clear and strategic joining up of DCSF and BIS policies and focus.

Investing in tomorrow's talent

6. How much progress has there been in the past decade in the delivery, content and assessment of education in STEM subjects?

Our response to this is focused on STEM education in relation to career-related learning, rather than content or pedagogy within the STEM subjects themselves. We believe that career-related learning is a critical aspect in long term strategy.

Two of the main areas of emphasis within the DCSF STEM Programme (or Agenda) are the improvement of subject teaching and making STEM curricula more relevant and appealing to young people. We see that there is additional, and achievable, potential in integrating aspects of career-related learning within both of these imperatives. We welcome the strong investment in the support for development of STEM teachers (such as Project Enthuse) in particular, but would like to see an increase in the careers awareness of teachers within that, as teachers have strong influence on students' career decision-making.

Successful subject teachers have both sophisticated disciplinary knowledge and also the ability to inspire and connect with young people. Not all young people respond to the inherent excitement or intellectual stimulus of a science or technology subject. Some will study it for its relevance to the world, and efforts to adjust curricula to enhance this relevance to the real world, and the young person, should be

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10 www.vitae.ac.uk/rugbyteam

11 vitae.ac.uk/policy-practice/375-14461/The-Thrift-report-now-available-online---Have-your-say-on-the-future-of-Higher-Education-and-research-careers.html

12 vitae.ac.uk/policy-practice/375-64101/Feature-article-from-the-1994-Group-The-impact-of-Roberts-Funding-.html

beneficial. A curriculum such as '21st century science', or an approach such as an Engineering Diploma, should appeal to many, provided that they carry respect within the educational community and especially are recognised positively as sufficient entry requirements for higher education.

Other young people will study a technical subject, like physics, not because they like it but because it is useful to them, in their future. There is untapped potential during STEM teaching to emphasise this aspect, in particular by making more overt reference to examples of real people who have studied the subject and the benefits they have derived in career and personal life (ie relevant role models). It would be beneficial if all teachers had a few key stories, ideally even of their own acquaintances, to deploy to inspire the more "pragmatic" learners, to broaden and reinforce the benefit of studying STEM subjects. CRAC have developed a nationally available free online resource **icould** [www.icould.com] which is a collection of 1,000 career stories on film to inspire young people in the range of career possibilities.

In terms of the supply chain of young people into research, more study is needed as to how well STEM teaching is preparing and inspiring people to pursue longer term careers in these areas. CRAC is currently studying the transitions and associated career decisions of graduates into STEM jobs (or not), in a project for BIS, but study of the transition into doctoral programmes could usefully be explored further.

7. What are the future challenges for STEM education? How should they be addressed?

There is acceptance of benefit to the UK and to individuals that more young people should study STEM qualifications and for longer. Increasing and sustaining the flow in the pipeline of people with STEM qualifications, who may eventually enter the workforce, is critical. The benefits to a wide range of professions and work forces of those with some STEM education may need to be evidenced more closely to enable us to combat the idea that those who do not pursue STEM to higher levels are 'lost' or 'wasted'. However, the highest priority issue is to increase and sustain the number of young people studying STEM beyond compulsion at 16.

A vast array of activities to encourage young people's interest in science and technology has grown up in and around education, supported by Government and industry and delivered by a myriad of charities and other bodies. The launch of the (national) STEM Programme by DfES, now DCSF, in 2006 was instrumental in identifying and promoting the national 'cause' that those activities support.

From a careers perspective, Lord Sainsbury's review (Race to the Top, 2006) was particularly effective in suggesting that improved careers education/information/advice would support this agenda, and especially that it should be embedded more broadly within activities to support study of STEM subjects, rather than as an isolated activity. This new notion of integrating careers within other activities has been articulated within the DCSF STEM agenda progressively since 2007.

We believe that career-related learning should be embedded within the extension and enrichment activities available to young people and in the improvement of STEM subject teaching and curricula, the two main strands of the DCSF STEM agenda. Essentially this recognises that there are multiple contexts for learning and different 'hooks' for different young people, rather than assuming that all will be excited by science or technology for its own sake. We therefore welcome the recognition of the potential benefit of integration, by DCSF in particular, of better careers awareness in relation to STEM, and believe that the effectiveness of all STEM support programmes will be enhanced as a result.

Challenges:

- The array of activities offered to young people and schools, as extension and enrichment, remains Byzantine in its complexity, with providers competing to "get into schools". While all have aims that roughly align, the value and benefits of different programmes vary wildly and schools, let alone young people or parents, have little idea of how to choose between them. More strenuous efforts to rationalise this array of provision are needed, based on more sophisticated measurement of the impact of the interventions, which is rarely attempted to any degree now

- Careers education, although statutory at secondary level, has never been integrated into the national curriculum. Current provision of careers advice and guidance focuses on the elite and those at the bottom (i.e. those at risk of becoming 'NEET' – not in education, employment or training). The 70% in the middle get little or no personal or informed support for their subject choices and ultimately career choices. The incorporation of careers guidance within integrated IAG (information, advice and guidance) provision does not benefit the majority of young people studying STEM subjects. While efforts to professionalise the careers workforce are welcome, a wholesale underlying shift within education and its management is needed to recognise that careers support is fundamental to the future of the young people that the education system serves, and to the UK's employers (including higher education and research)

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 abroad?

An enormous amount of work has been undertaken over the last few years to address both the career development within research careers in higher education, and some of the more systemic structural challenges which are often cited by those making career decisions as barriers to undertaking research careers. This includes the Concordat to Support the Career Development of Researchers13, availability of research fellowships, increases in stipends as a result of the Roberts review and HEIs addressing issues relating to the fixed-term employee legislation14.

The debate around the future of the doctorate sparked by an initial paper by Professor Chris Park15 has brought together some of the national conversations about what the doctorate is for, and why we are training people in research. What is clear is that the wider application of the skills of researchers is increasingly well documented and there is beginning to be a wider acknowledgement of the benefits to the economy, society and culture of doctoral training whether or not the individuals continue their careers in research. The Vitae publication 'What do researchers do?16 demonstrates that doctoral graduates are employed in a wide range of sectors and occupations. Vitae collections of career stories17 highlight the influence of their doctorate on employability and on their career journeys, whether these are within or outside HE, and research or non-research. So the value of research training in the career context is becoming more evident.

The national aggregate of the CROS survey data18, which includes surveys in 51 HEIs during 2009 and published in September, in fact suggests that most research staff feel valued, are satisfied with their work-life balance, have discussed career development with their manager or principal investigator and believe their employer is committed to equality and diversity.

However, the report also encourages research staff to be realistic in their career aspirations. According to the survey results, over half hope for a career in a 'combined' role (teaching and research) in HE in the long-term, a proportion which is likely to exceed the number of such jobs available for them in HEIs.

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13 www.vitae.ac.uk/concordat ; www.researchconcordat.ac.uk

14 http://vitae.ac.uk/policy-practice/375-117821/Researchers-fixed-term-contracts-and-universities-Understanding-law-in-context.html

15 http://vitae.ac.uk/policy-practice/1693/Redefining-the-Doctorate.html and the recent UUK/Vitae report http://vitae.ac.uk/policy-practice/375-117811/Feature-UK-report-sets-out-the-challenges-and-future-vision-for-the-UK-Doctorate--.html

16 www.vitae.ac.uk/wdrd

17 http://vitae.ac.uk/researchers/105653/Link-to-Vitae-projects.html Collection of 40 Career profiles of researchers, and www.vitae.ac.uk/careerstoriesonfilm a collection of 20 career stories on film

18 www.vitae.ac.uk/cros

So, it is time to re-phrase this question about the attractiveness of research careers. Should the question be, 'we know research careers are attractive to those who are already in the field of research; are we attracting the 'right' people in at doctoral/masters level?'. Are young people making choices at school which limit their ability to pursue STEM research at a later date? Are these choices explicit?

There is evidence that for many people who undertake a doctoral degree, their primary interest is in their research field19. Their levels of satisfaction with their doctoral degree experiences are high20.

We also know that people's perceptions of their preferred career direction often change during the process of undertaking research. What we know much less about is whether we are attracting the RIGHT people into higher-level research. It is the people who are not even considering undertaking a doctoral programme who perhaps should become our focus.

As with all careers and jobs, the key challenge for research careers is how they are perceived. Increasingly with the focus on economic and societal impact of research and public engagement activities, there is more targeted information available in the public domain about what research is delivering. However, there still often seems to be a 'perceptions gap' between the trend at graduate level for interest in ethical careers, and the idea that a research career may in fact make a demonstrable difference to a range of ethically important issues.

Despite all this, we also know that there is often a trade off between the highly valued independence of following an academic research career and what can be perceived as the instability of short term funding and contracts.

Vitae is working with UK HEIs to explore the collection on a national level of exit interview data to gain a richer picture of why postdoctoral researchers and research staff move outside HE research careers.

The future landscape could usefully see a more open transition culture between academia and industry. The implementation of the recent Concordat's principles at HEIs should build on recent development to enhance further career support and build on training programmes and their demonstrable impact in areas like successful application for fellowships, gaining grant funding etc21.

Given the investment that has been made in improving the 'lot' of UK researchers in HE, (approx £100m of Roberts funding over the last 5 years) the focus should now be on embedding and sustaining that work and promoting the benefits to both young people in the UK and to international researchers about the benefits of the UK research environment.

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 important to remember that all individuals have individual careers. There really never is 'one size fits all'; every individual has a complex mix of personal circumstances, social/cultural and personal motivations, self perceptions, and perceived opportunities that shape their decisions. As careers theory moves away from the notion of creating a long term career goal and a structured plan to achieve it, to acknowledgement of the role of serendipity and a focus instead on people's ability to create and respond to opportunities and 'luck', we need to ensure that cultures as well as structures are enabling people to pursue careers across sector and other boundaries.

That said, there is still a case for looking more closely at the enabling factors in successful transitions, particularly between business and HE. There is a growing interest in the role of work experience and placements and this is an area that could be explored further; this was a key theme in the CROS survey

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19 Career motivations report, UK GRAD Programme

20 Postgraduate Researcher Experience Survey (PRES) 2007-2009 www.heacademy.ac.uk/pres

21 Evidence collected in the 'Rugby Team Impact Framework: one year on' report on the evaluation of training and development for researchers www.vitae.ac.uk/rugby team and http://www.vitae.ac.uk/CMS/files/upload/RTIF_update_Sept09.pdf

results. In most disciplines there remains a route 'out' but a not so well acknowledged 'route in' to academic research from industry. Given the average age of someone starting a doctoral programme is over 27 for full time study and 38 for part time study22 it may be that we need to change perceptions to a greater degree than reality.

There is also a case to explore (particularly during the consultation phase) the proposed REF and what this means for research staff in terms of recognition, progression and career development [these issues will be covered in our national research staff conference on 5 November]. It remains the case that the perceived and real opportunities for a 'successful academic career' remain narrow. More attention could be paid to recognising and valuing research staff in HE and the various roles which are critical to producing successful research, but which are often seen as mere a stepping stone on the path to professorship rather than a career choice in their own right.

22 Trends and profiles, 1996-97 to 2004-05, 2009, HEFCE www.hefce.ac.uk/pubs/hefce/2009/09_04/

Wellcome Trust

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

Response by the Wellcome Trust

September 2009

1. The Wellcome Trust is the largest charity in the UK. It funds innovative biomedical research, in the UK and internationally, spending over £600 million each year to support the brightest scientists with the best ideas. The Wellcome Trust supports public debate about biomedical research and its impact on health and wellbeing.
2. We appreciate the opportunity to contribute to the Royal Society's Fruits of Curiosity inquiry. We recognise that this is an ambitious undertaking with the potential to have a significant impact on the direction of UK science policy.

General comments

3. We consider that the Fruits of Curiosity project will have most impact if it can articulate a compelling vision for the future direction of UK science, and then place the various actions and recommendations in that context. For example, we suggest that such a vision will need to include:
   - the changing global landscape for science, and the need for the UK to respond;
   - the need for new roles and relationships between the various players – government, delivery agents, universities, and businesses;
   - the opportunity to embed science as a major contributor to our economy and society.
4. As part of the vision, it will be important to emphasise the UK's existing strengths, one of which is our enormously strong medical research charity sector, which works in close partnership with government and HEIs. The strength and contribution of this sector places us in a unique position within Europe, and internationally.
5. The Call for Evidence identifies a number of questions and challenges in relation to UK science policy, science education, research careers, innovation policy and funding. While the questions are interesting and thought-provoking, we consider that something may be lost in the reductionist approach – many of the questions are inter-connected and it will be difficult to answer or develop actions to respond to them in isolation. The report will need to be structured in a way that acknowledges the interconnections between the various areas – perhaps by linking back to the over-arching vision discussed above.
6. We note the comment in the Call for Evidence that the list of issues is long, and will need to be prioritised. We agree that prioritisation will be important, and suggest that one of the factors that the Royal Society should consider is which areas have significant existing activity which can be built on, and which require substantially new thinking. In some areas there is already substantial evidence about what types of initiatives are likely to be effective, and the greater challenge may be implementing existing strategies. In these areas, the Royal Society could consider using the Fruits of Curiosity project to support the further implementation of existing strategies and recommendations, rather than seeking to develop new, and potentially competing initiatives. For example, the area of building and sustaining research careers, with the recent 'Concordat to Support the Career Development of Researchers', may be one of these areas.
7. By comparison, some of the areas identified in the Call for Evidence have had minimal policy focus and in these areas the Fruits of Curiosity project presents an opportunity to pose questions and propose a direction that others can follow. Such areas might include the role of public sector R&D outside the ring-fenced science budget, and the interface between secondary and tertiary education.
8. Policy statements that seek to shape the long term direction of UK science and education policy, such as the Fruits of Curiosity project, will be most effective if they provide clear statements regarding best practice going forward, including how best to implement recommendations. They should include follow up reports and evaluation as a way of monitoring success. Partner organisations must commit to relevant recommendations and actively build these into their own strategic plans.

The long-term direction of policy for science

9. The Wellcome Trust supports the Royal Society's desire to challenge the artificial distinction between pure and applied research. We suggest that the recent study *'Medical Research: what is it worth'*[23], which was partly funded by the Wellcome Trust, may be a useful source of evidence. This study illustrates the time lag between research expenditure and the realisation of benefits, and the presence of significant 'spillover' benefits from basic research. It may also be useful to obtain information from the research councils on any differences in research application trends following the introduction of 'impact statements.'

10. The Government's ten-year Science and Innovation Investment Framework has been successful in raising the political profile for science, setting out a blueprint for public investment that allows long-term commitments outside the spending review cycle, and recognising the contribution of other sectors, including medical research charities. The approach has allowed other funders, including the Wellcome Trust, to develop long term partnership activities with government. Although constrained economic circumstances are likely to require hard choices, and greater focus and selectivity of investment, it is important that a long-term, strategic approach to Government investment in science be maintained. The Wellcome Trust therefore supports the development of a further ten year framework.

11. From the Trust's perspective, the introduction of full economic costing has also been positive in enabling university research to be placed on a more sustainable footing, and allowing greater transparency around the real costs of research. The Charity Research Support Fund forms an essential part of this model, recognising the important role that charities play in supporting UK university research.

12. The US and China are specifically mentioned as important geographical considerations. We suggest that emphasis should also be given to the European context. For example, the report could emphasise the need for early input of science advice into EU decision-making. Each year more that 100 European Directives have to be implemented into UK legislation, and if these are not informed by the best available advice there is a risk that they could inhibit research. The EU animal directive is a good example – while the goal of improving and harmonising animal welfare standards across Europe is laudable, early drafts would have significantly limited important types of fundamental research that can only be undertaken using animals, and dramatically increased bureaucracy and costs with minimal benefit for animal welfare. It has taken the submission of more than 400 amendments, and many hours of work by researchers, funding organisations, industry representatives, medical charities and patient groups, to begin to reach a workable balance.

13. As this example demonstrates, it is crucial that Europe develops mechanisms to embed high-quality scientific advice within decision-making, and develops a regulatory environment which is able to preserve public confidence while striking the right balance between risk and opportunity. The example of stem cell research, where the UK has taken a facilitative position compared to other nations (in particular the United States), shows how an effective regulatory environment can present a competitive advantage to the UK. We must ensure that the impact of EU regulations do not jeopardise this. The forthcoming review of the EU Clinical Trials Directive is an important test – since the Directive was implemented the UK's participation in global clinical trials has dropped from 6 per cent to 2 per cent.

Investing in tomorrow's talent in schools, universities and in the FE sector

14. The Wellcome Trust is currently conducting a review of science education for the future, informed by experts in the field of science education, policy and strategy. The first phase will be to produce a policy 'road map' report which addresses the overarching question:

    "What should the future of science education up to the age of 19 years look like in order to inspire young people, ensure they understand the role of science and ensure that science and technology underpin our future prosperity and well-being?"

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[23] Health Economics Research Group, Office of Health Economics, RAND Europe (2008) http://www.brunel.ac.uk/385/other/TAP825EconomicBenefitsReportFULLWeb.pdf

15. Phase 2 of the road map project will be to consider implementation of the recommendations through development of the Wellcome Trust's commitment and contribution and fostering partnerships with key players in the sector to address areas that need further development.

16. As the roadmap will address a number of the same topics listed in the Call for Evidence, we suggest that both organisations should work closely over the common areas, to consolidate agreement around the aims, with the view to strengthening the overall voice of both reports.

17. One area of focus of the Wellcome Trust road map will be testing and assessment methods. While there have been significant improvements in curriculum design in recent years, 2007 research commissioned by the Trust in and carried out by the Institute of Education revealed concern from teachers that statutory testing was leading to a narrowing of the science curriculum, and making it difficult for pupils to develop positive attitudes to science.

18. High quality and inspiring teaching from well-trained teachers is vital to ensure effective student engagement. The Wellcome Trust is active in the area of continuing professional development (CPD) for teachers, in particular through Project Enthuse - a £30 million partnership with Government and Industry to remove barriers to CPD. The most frequently cited barrier to participation in CPD is cost, and Project Enthuse will help address this by providing bursaries for travel and lesson cover to enable teachers to attend residential courses at the National Science Learning Centre.

19. We suggest that in addition to any specific recommendations around STEM education at primary, secondary and tertiary levels, the Fruits of Curiosity inquiry should consider the interface between these levels. In particular, we would like to see some attention given to the transition between secondary and tertiary education, including the question of how we can attract more promising secondary students into science studies at tertiary level. The project might also consider the implications of the evidence that suggests an increasing number of students are turning to medicine and the biological sciences, rather than engineering and the physical sciences. Inter-disciplinary research is becoming increasingly crucial to answer the challenges of today's society, and we need to ensure that students understand the important contributions all disciplines can make to scientific and technological advancement.

Building and sustaining research careers

20. A significant trend in science policy over the last decade has been the increased focus on research careers and the role of the individual researcher. The Trust sees this as a very positive development, which the Fruits of Curiosity project could highlight, while noting the significant challenges that still remain in this area. As the area of research careers has been a topic of intense focus in recent years, it is important that any recommendations and initiatives in this area build on and complement the existing body of work. In particular, we suggest that the 'Concordat to Support the Career Development of Researchers' is a useful point of reference.

21. A key message emerging from the recent initiatives in the careers area has been that, while financial rewards are undoubtedly one factor contributing to the attractiveness of science careers, they are not the main motivator. We suggest that actions to improve the attractiveness of science careers will also need to target the broader issues of recognition, career security, and opportunities for mentoring and personal development. These challenges are summarised well in the Concordat. The Careers in Research online survey also provides a useful source of evidence on the experiences of researchers.

22. In relation to the 'standard career track model', we question whether such a model actually exists. The need to support people with less conventional career paths (which includes mobility, but also other issues such as the retention of women in science) have long been recognised and the Wellcome Trust has developed mechanisms (e.g. Career Re-Entry Fellowships), to respond to them, as have other funders. There is a large body of evidence on the importance of mobility which the report could draw on, such as the work of the Organisation for Economic Co-operation and Development (OECD) Committee for Science and Technology Policy.

23. In addition to considering the role of individuals with research skills within industry and business, the report should also note the need for skills to support public sector innovation. In particular, we need to maintain and grow research capacity within the NHS. The Government should continue to support initiatives which promote an effective interface between clinical and basic research, speeding up the process of taking research breakthroughs into NHS patient care. Academic Health Science

Centres (AHSCs) are one such mechanism, although there is an opportunity for greater industry involvement. There is a need to address barriers to clinician-led research within the NHS, through providing greater support and recognition for research career paths, and reviewing incentives and cultural barriers to research within NHS Trusts and other structures.

Science, innovation and wealth creation

24. The questions in the Call for Evidence are very broad and we suggest that in this area the project would benefit from greater focus. There is a huge volume of existing policy work the science and innovation area, including key reports such as the 'Innovation Nation' white paper, the Sainsbury Review of government science and innovation policies, and recent work by NESTA, such as the report on the role of public investment in financing growth. These reports contain a large number of recommendations, many of which are still in the implementation phase. The Fruits of Curiosity project could be used to support and give further impetus to existing recommendations which support its overall vision for UK science.

25. One potential area of focus might be the evolving relationship between universities and industry. The trend towards 'open innovation' is changing the way industry sources research and development and intellectual property. For universities, this may require a radically new approach to industry partnerships, and a new set of skills needed in our next generation of researchers.

26. The Higher Education Business Community Interaction survey[24] indicates that collaborative interactions between universities and industry are increasing, but a number of barriers remain. These include cultural barriers, such as the tendency by the academic community to undervalue time spent in industry; financial barriers, including a relative lack of funding for industry-academic collaborations compared to competitor countries, and the difficulty accounting for intangible industry contributions under the full economic cost model; and practical barriers, such as an absence of metrics to identify collaborative excellence in research. it is important that future policy initiatives, such as the Research Excellence Framework, act to reduce, and not further exacerbate, these barriers. The UK should also consider policy models adopted in other nations, such as Ireland and the Netherlands, which have been successful in facilitating industry-academic collaboration.

27. Taxation policy also plays an important role in enabling partnerships between research organisations and industry. The Trust is experiencing challenges as we work towards the establishment of the UK Centre for Medical Research and Innovation (UKCMRI) at St Pancras, which will be a world-class research centre tackling some of the most important medical challenges of the 21st century. The impact of Value Added Tax (VAT) threatens to limit the viability and success of UKCMRI, as new buildings can only be zero-VAT rated for construction costs if they are used predominantly for non-business charitable purposes. This would impose major constraints on technology transfer, external collaborations, and industry investment at the UKCMRI. The Trust is continuing discussions with government to resolve this issue.

The ecology of research funding

28. The Wellcome Trust considers that there is a role for both response-mode and targeted funding in the UK science portfolio. Government strategy must recognise the importance of pursuing research for the advantage of expanding knowledge as well as for potential economic and social benefit. Where funding is targeted at particular socio-economic outcomes, it will be important to give researchers sufficient flexibility to put forward the best ideas to address a identified problem or opportunity.

29. The Government's decision to ring-fence the budget for science, and for research within the Department of Health, has been successful in achieving greater profile, awareness and investment in science. Going forward, there may be trade-offs associated with such a siloed approach to science investment. There is an increasing need for science to be integrated into policy on macro-level issues, such as climate change, obesity and the implications of an ageing population. The inquiry could consider whether new arrangements are required to respond to this, such as structural links between government departments, or a thematic approach to Budget development. A number of the actions in the Government's recent 'Life Sciences Blueprint' relate to the need for better coordination of activity across government.

[24] http://www.hefce.ac.uk/reachout/hebci/

30. The report should also comment on the future of the dual support system for university research, following the implementation of full economic costing, and the creation of a single department for higher education and science. The dual support system has been effective in allowing a diversity of funding sources to support excellent research, and we strongly support its continuation. Universities UK has also conducted work relating to the benefits of dual support, which the Fruits of Curiosity project could usefully draw on.

31. For charitable funders, the Charity Research Support Fund (CRSF) is a key element of the existing university funding model – retaining the integrity of the full cost model while providing certainty to public donors that their contributions will be spent directly on research. Recent evidence has underlined the importance of the CRSF, while suggesting that more needs to be done to raise its profile, and that the level of funding needs to be revisited. For example, a recent report by Breast Cancer Campaign[25] revealed low awareness of the role of the CRSF amongst academics, and a perception that the current level of funding is too low to enable charity-funded research to stand on an equal footing with research funded by Research Councils. These findings are consistent with those from the recent Research Councils UK and Universities UK report 'Review of the Impact of Full Economic Costing on the UK Higher Education Sector,' The Wellcome Trust considers that the CRSF has a crucial role to play in the university funding ecosystem, and Government and the devolved administrations should make a clear commitment to its future. Charities and Government should work together to determine the appropriate level of funding for the CRSF.

32. In relation to question 17, we note that the issue of full economic costs is a potential barrier to the expansion of research funded through other government departments, as currently other departments are not meeting 100 per cent of costs. This issue is explored in the RCUK/UUK report referred to above. We support the report's recommendation that government departments funding research at HEIs should fund on the basis of paying 100% full economic costs, unless funding through competitive tender.

33. In addition to research funding, the Fruits of Curiosity project should also consider the questions around sustainable funding for research resources and infrastructure. Government investment in large research infrastructure must occur in a coordinated and strategic manner, and opportunities for a more coordinated approach to infrastructure investment across Europe should be explored. Bioinformatics and data management infrastructure is a good example. New, more powerful informatics resources and platforms are crucial to enable researchers to share, analyse and interpret the growing volumes of bioinformatics data. For Europe to remain internationally competitive, key data resources, such as European Life Sciences Infrastructure for Biological Information (ELIXIR), must have sustained, long-term support. The UK government and funding agencies must provide long-term commitments, and take a leadership role in securing sustainable European Union funding. It is important that investment in European-wide infrastructure initiatives does not occur at the expense of investment in the UK's national infrastructure.

[25] http://www.breastcancercampaign.org/files/fecreport.pdf

White Rose University Consortium

10 September 2009

Dear Dr Wilsdon

Re: Evidence for the Fruits of Curiosity inquiry

I am writing to provide evidence from the White Rose University Consortium for the Fruits of Curiosity inquiry. The White Rose University Consortium is a strategic partnership between the Universities of Leeds, Sheffield and York. This collaboration has established major research, teaching and enterprise initiatives that benefit the Universities, economy and society. The evidence we provide is based on our experience of collaborative initiatives and working with regional, national and international partners.

The key messages from the White Rose University Consortium:

- Great benefits can be achieved by bringing together research intensive universities for strategic partnership. The White Rose University Consortium combines the strengths of Leeds, Sheffield and York, enabling these Universities to establish and deliver major initiatives that would be difficult for a single institution to undertake. White Rose has brought in over £80 million into the Universities since it was created in 1997.
- Regional collaboration of universities enables strong engagement with the Regional Development Agency (RDA) – bringing benefits to the universities and region. Yorkshire Forward (Yorkshire's RDA) is a key partner on many White Rose initiatives and has invested many millions in these. Working in partnership with Yorkshire Forward has greatly helped the enterprise and commercialisation activities of the Universities.
- Successful strategic collaboration between universities requires creating a strong reputation and brand, as well as engagement of senior university management. This has enabled the White Rose University Consortium to achieve strong academic engagement, has given funders confidence in our ability to deliver major initiatives, and has meant that White Rose has been in demand to develop initiatives on behalf of the region.

The following examples describe major collaborative initiatives that would have been difficult for a single institution to undertake. The White Rose University Consortium has played a key role in all of these initiatives.

Science, innovation and wealth creation

The **White Rose Technology Seedcorn Fund** (WRTSF) is a key investor in technology spin-out companies from the Universities of Leeds, Sheffield and York. This Fund has received investments from Government (£4.5m), Yorkshire Forward (£3M) and the Universities themselves (£1.5M). This provides a clear route for commercialisation of promising technology and has led to successful spin-out companies from the Universities. We feel that Yorkshire Forward should be commended for their investment in this Fund. We believe that RDAs should have a key role in exploiting the world class research strengths of the Universities – this will benefit the region by creating jobs and wealth. We would encourage further regional funding to help with university enterprise activities.

The **White Rose Health Innovation Partnership** (WRHIP) aims to dramatically accelerate the rate at which new and innovative technologies, methodologies and practices reach the medical and healthcare sectors. This initiative brings together academia from the UK and USA, the NHS and industry to provide a platform through which all those involved in the health sector can innovate together. This project (which also includes the University of Bradford) received an investment of £4.7 million from the Higher Education Innovation Fund in 2006. This novel initiative has already been highly successful and demonstrates that innovative collaborations can benefit industry as well as society. Examples of success include:

- Continuing Professional Development 4 Health Innovation. This training is innovative in design, being relevant for industry, academia and NHS. A key feature is to include the end users in the design of the training. Yorkshire Forward has backed this with further investment to further the reach into the region's healthcare businesses.

- The model of accelerated healthcare and partnerships formed in this initiative has provided a platform to develop further links – including organisations in China and Singapore.
- Bringing together academia, industry and the NHS has accelerated commercialisation through patents, new company formation and licensing deals. Proof of Concept funding has accelerated the development of new innovations.

The **White Rose Centre for Excellence in Teaching and Learning (CETL) of Enterprise** is a £4.5M initiative funded by the Higher Education Funding Council for England (HEFCE). The CETL Enterprise enables students to develop enterprise skills so that they are equipped to make an impact in the future as social entrepreneurs, enterprising employees and successful business owners. The collaboration enables co-ordinated activities and the sharing of experience and knowledge.

The White Rose University Consortium has played a key role in the design and development of the **Centre for Low Carbon Futures** - an innovative new £50 million research centre established to help build a competitive, sustainable and carbon efficient regional economy, while providing climate change solutions of national and international significance. This is a flagship initiative of the Yorkshire Universities-Yorkshire Forward Strategic Alliance Activity Framework. The Centre is being developed on behalf of the region by the White Rose Universities and the University of Hull to help meet the global challenge of climate change by harnessing the expertise and research power of Yorkshire universities The Centre will integrate the themes of climate change impact and adaptation and life cycle carbon management to understand the impact of climate change at a local level and therefore design appropriate technology and carbon foresight capabilities that will be critical in identifying implementation pathways for a low carbon future.

Investing in tomorrow's talent in schools, universities and in the FE sector

The White Rose University Consortium, together with Sheffield Hallam University was appointed to run the prestigious **National Science Learning Centre (NSLC)** – a major Government/Wellcome Trust initiative to invigorate science teaching across the UK. This centre, based at the University of York, opened in 2005 and is playing a key role in the professional development of science teachers. The NSLC is submitting more detailed evidence to the enquiry.

I hope that this information is useful for the inquiry and I am happy to provide further information if appropriate.

Yours sincerely

Dr Julian White
Chief Executive

The British Psychological Society

The British Psychological Society Memorandum of Response to the Royal Society's project 'The Fruits of Curiosity: Science, Innovation and future sources of Wealth'

The British Psychological Society thanks the Royal Society for the opportunity to respond to this consultation. The British Psychological Society ("the Society") is the learned and professional body, incorporated by Royal Charter, for psychologists in the United Kingdom. The Society is a registered charity with a total membership of almost 50,000.

Under its Royal Charter, the key objective of the Society is "to promote the advancement and diffusion of the knowledge of psychology pure and applied and especially to promote the efficiency and usefulness of members by setting up a high standard of professional education and knowledge". The Society is committed to providing and disseminating evidence-based expertise and advice, engaging with policy and decision makers, and promoting the highest standards in learning and teaching, professional practice and research. The Society is an examining body granting certificates and diplomas in specialist areas of professional applied psychology.

We are content for our response, as well as our name and address, to be made public. We are also content for the Royal Society to contact us in the future in relation to this consultation response. Please direct all queries to:-

Dr Ana Padilla, Parliamentary Officer, The British Psychological Society,
30 Tabernacle Street, London, EC2A 4UE
Email: ana.Padilla@bps.org.uk Tel: 020 733 00 893 Fax: 020 733 00 896

We hope you find our comments useful.

Dr Judi Ellis and Dr. Richard Latto, M.A, Ph.D. F.B.Ps.S
Chair, Research Board Chair, Psychology Education Board

The Royal Society's 'The Fruits of Curiosity: science, innovation and future sources of wealth' Project

Broader Comments from The British Psychological Society

Psychology is one of the fastest growing science subjects in the UK and is currently the largest scientific discipline being chosen by students (for example, 52872 students completed A Level Psychology in 2009 and there are around 42,000 undergraduate students). It not only has a very strong scientific basis but also shares many similarities with other long established quantitative social and biological sciences. Its diversity is one of its core strengths and as such it has much to contribute to the future development and strengthening of the UK research and science base. Nevertheless, there is a tendency to exclude Psychology (and other sciences) from the STEM family. It is recognised as a science by Joint Qualifications Council and to continue to not include psychology as a STEM subject is wholly inconsistent with the classification of the discipline by the major examination bodies in the UK.

The science of psychology is central to the development of the knowledge-based economy, underpinning a number of science-based industries, such as information technology and some pharmaceutical industry enterprises, amongst others. Moreover, psychological research provides an alternative evidence base for addressing some of the key societal problems that we are currently facing. For example, the UK public tends to believe that health can be ameliorated by biomedical means rather than recognising the potential for behavioural change. The human genome project indicates the potential for health gain not only in direct biomedical intervention but also in identifying people who might gain from simpler solutions related to behaviour change, such as individuals genetically predisposed to heart disease may prevent the condition by altering other risk factors such as diet and activity levels. Other key contributions concern advances in understanding the importance of identifying and developing effective intervention techniques that change risky health behaviour and patient behaviour in response to illness; as well as the behaviour of health

professionals. This evidence-base has far reaching implications for tackling the rise in obesity, smoking, binge drinking, as well as other addictive behaviours outside the remit of 'pure' Public Health policy (such as gambling).
Psychological research related to changing social and personal priorities (these for example may affect population growth and dispersion, working patterns, availability of women, older people and others for various forms of work and training) will continue to provide important information about how society will be able to capitalise on scientific and economic opportunities. For example, demographic changes in the national age profile have huge implications for the social and economic structure of UK society. Key research from social psychology in relation to attitudes to age and ageing (and specifically age prejudice and discrimination) is currently under way with the Department for Work and Pensions to establish a time-series analysis from these data which will provide a long term benchmark against which future trends and changes will be assessed (see work by Abrams, D. et al.at the University of Kent).
Research on the use of new technologies (such as human-computer interaction) and communication processes; issues surrounding population and structure; the nature of skills and resource sharing (and ensuring equal access to opportunities and resources); and on cooperative teams and decision making networks also have important contributions to make. Indeed, knowledge stemming from organisations psychology is been extensively implemented as a way to promote effective working patterns, which are already being tested in the context of industry.
The Society believes that multi-level approaches to focused problems will be a hallmark of research excellence in years to come (examples of which include – the assessment, treatment, and care of people with brain damage or injury which is best approached using neurological, medical, cognitive and behavioural interventions that are properly integrated; motivating a sceptical population to use vaccinations (e.g. MMR) is likely to require a combination of medical and social research as well as engineering better population delivery strategies).

Responses to Specific Questions:

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?
Curiosity driven research will have a significant role to play in the development of the UK science base in the next 15-25 years. An important aspect of this will be greater interdisciplinary – and in particular between the natural and behavioural sciences. This would allow for new advances in research on the social and behavioural factors that affect science development, implementation and diffusion; organisational effectiveness and innovation; motivation and creativity; understanding learning; the interface of individual and social development; managing risk, threat and opportunity arising from co-operation and conflict between social groups **.**

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?
There is a tendency for relatively short-term economic criteria to dominate policy but there are other long-term considerations that should be reflected in commitment and priorities for research. For example, health, wellbeing, long term stability and societal cohesion, reduction of disadvantage and inequality, fuller social and political participation and environmental preservation.
The existing framework does not support an appropriate level of risk taking for the advancement of science. Funding tends to be overly conservative. Innovation needs to be targeted by funding bodies in ways which facilitate creative projects.

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?
4. How should science be governed to maximise benefits to society while acknowledging public questions, uncertainties and concerns?
There is a need to ensure a careful balance between support for curiosity-driven, blue-sky research and targeted resources. There is also a need to be aware of the public uncertainty and distrust of science.
We believe that an evidence-based approach to policy making is entirely appropriate and necessary – so ensuring that science is governed by a mechanism that is flexible enough to allow research in areas of societal concern and need to be funded in a timely manner enable informed policy

development is crucial.
Science has a fundamental role in informing both the development of policy as well as the way in which such evidence is used in policy making (i.e. the mechanisms through which it is obtained and evaluated). However, government must be minded of the publics' perception (trust/distrust) of both science and scientists, and the importance of ensuring that the information provided is in a transparent and accessible form.
Policy work is often driven by high priority issues with considerable time pressure. As a result it is rarely possible to evaluate the potential positive and negative outcomes of policy strategies ahead of time. Nevertheless, an excellent example of the benefits of committing to such an approach comes from the Department for Communities and Local Government which decided to conduct such an evaluation ahead of launching its REACH role model campaign to raise the aspirations and achievements of black men. This research (conducted at the Centre for the Study of Group Processes at the University of Kent) directly informs the REACH campaign and involves close liaison with the policy and research advisors at the DCLG.

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?
The delivery, content and assessment of education in STEM subjects has tended to concentrate on the three traditional sciences (physics, chemistry & biology) and mathematics, to the detriment of the scientific community. The lack of willingness to embrace 'other' sciences within the STEM agenda has meant that we have missed opportunities to welcome those who perhaps would not normally be attracted to these traditional sciences, into the scientific community.

7. What are the future challenges for STEM education at primary, secondary and tertiary levels? How should these challenges be addressed?
Future challenges for STEM are to incorporate the 'other' sciences within the STEM family and to ascertain how their inclusion can be of benefit to the whole science community, rather than be viewed as in 'competition' for students. Often people who are not attracted to physics and chemistry are interested in subjects such a psychology (e.g. high proportion of female psychologists and women and ethnic minority students on psychology courses) and thus can be welcomed into the STEM community while valuing their scientific knowledge and firm grounding in scientific methods. Increased collaboration between psychology and the other sciences (such as psychobiology, psychophysics, neuroscience, psychopharmacology) may be one of the most straightforward developments to encourage more people (regardless of age, gender and ethnic background) to pursue careers in and from science.

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)?
The challenges for STEM education are likely to be the need for knowledge from a variety of STEM subjects (interdisciplinary) and the skill to integrate STEM advances with existing knowledge. Consideration should also be given to the most appropriate teaching methodologies, such as enquiry based learning, designed to develop the appropriate skill-set to address the challenges
For psychology, the most important factor in ensuring the supply of subject specialists is to increase the number of funded PGCE places. There is no shortage of psychology graduates wanting enter the teaching profession, but the difficulty in gaining QTS is a deterrent.
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?
It is important to sustain the broader research culture. UK research suffers from insufficient longterm support and restricting research funding to a decreasing number of institutions narrows research focus and reduces diversity of thinking. Concentrating funding towards a decreasing number of "centres of excellence" reduces the attractiveness of employment outside of those centres for both UK trained individuals and those from overseas. A consequence of the RAE has been aggressive recruitment and movement between institutions of research leaders and research role models. By strongly encouraging this movement of high quality staff, the RAE has resulted in a situation in which research funding is dissociated from the work of the individual researcher. This acts as a disincentive for young people considering a research career in which only a few

departments with large concentrations of well-established researchers receive sufficient research grant income. A system that is more sensitive to high calibre research spread across a wider range of institutions would be a welcome development. We hope that the REF will allow for this.

10. What sorts of incentives can we develop to keep talented students and postgraduates in science?
Continue to develop funded bursaries for undergraduate students to undertake research projects during their vacations and increase the number of postdoctoral and early career research fellowships.

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?
Consider including the opportunity for postgraduate and postdoctoral researchers to undertake research placements in industry.

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 response to Q.11; a similar schemes could be adapted to fulfil this aim.
Many good research ideas are not translated and developed into practice and production. Mechanisms for greater co-ordination and support for such translational research, perhaps with cofounding from HEIs or industry are needed.
Building up a stronger research culture and openness to inquiry within business is essential. Business investment could be more successful if supported through local authority initiatives, as well as through ad hoc individual negotiation and direct collaboration with single HEIs and business

13. How can we improve the scale and contribution of private sector R&D?
It is in practice difficult to secure funding for high calibre collaboration (and applied) work. The logistics and timing required to gain co-funding from different sources are often complex. Mechanisms to facilitate this collaboration and encourage funding from business R&D into universities would be very welcome.

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?
Tax incentives have encouraged greater collaboration between academia and commerce/industry, and have provided much needed funding for more applied/practitioner based research. Such investments can provide sponsorship for research studentships, funding for specific projects, and participation in research through the provision of in-house data or access to research participants or technical facilities

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?
There is a need to ensure a careful balance between support for curiosity-driven, blue-sky research and targeted resources. The role of the Research Councils as the key mechanism through which funding allocations can best be made should not be forgotten. Whilst targeting funding by government departments does provide a means of supporting research leading directly into immediate policy development; the contributions of the applied research that is being conducted across the UK should not be underestimated or forgotten.
Ensuring that the Councils receive sufficient funding to support research and research development in the UK is one of our key concerns (particularly in relation to the ESRC).

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 Society is supportive of the maintenance (and indeed strengthening) of the dual support system for the public funding for research in English higher education. Such a system allows for the provision of block grant funding, via HEFCE, to support the research infrastructure, and enable s institutions to undertake ground-breaking research in keeping with their own mission. Research Councils, charities,

the European Union and Government Departments follow on by providing specific grants for key projects and programmes. However, we are concerned that scientific research in the UK has suffered from long-term insufficient funding by HEFCE, and the current allocations do not properly support and enhance the science base in the UK. In addition, The Society believes it is important to recognise the key roles that the Research Councils have played and will continue to play in supporting high calibre research in the UK. The best means of ensuring the development of breakthrough, next generation science research is to use a peer-reviewed, open-competition, responsive-mode funding model.

Ensuring that the remit of the Councils remains broad enough to cover the ever-evolving research landscape in the UK will be essential. Opportunities for collaborative, multi-disciplinary research must also be fostered to ensure that key societal problems and concerns can be addressed in a timely manner to inform current and future policy development. More advanced cross-Council liaison needs to encouraged and strengthened; to ensure that high calibre research is appropriately funded wherever it is being carried out.