in core science subjects[3] the Government will struggle to recruit its target of around 5,000 new teachers in these subjects for 2011/12 in England.

A national rise in the numbers of young people opting to specialise in science and mathematics post-16 will only occur if the following are taken into consideration:

1. The numbers of specialist science and mathematics teachers in both the primary and secondary workforce must increase.

2. Information, advice and guidance for young people must improve in quality.

3. Teachers should undertake subject-specific continuing professional development (CPD) as part of their overall CPD entitlement.

4. The number of qualified laboratory technicians in secondary schools must increase.

5. Physical resources (laboratories, lab equipment and computing hardware) need to be available and of sufficient quality to fully support science and mathematics teaching.

6. The revised 5–16 National Curriculum must provide a solid, inspirational and progressive grounding in science and mathematics for students.

7. The assessment regime must not focus on narrowly constructed measures of school performance.

8. Qualifications must be appropriate, available to all students and support progression in post-16 science and mathematics.

9. Understanding of how children learn should inform teaching practices.

'The UK has great scientific strengths, which underpin our society, culture and economy: we must build on these and continue to aspire to be the best country in the world in which to do science.'[4] Our future success in science depends on the current generation of students.

The Royal Society's four 'state of the nation' reports have produced extensive data on science and mathematics education from 5-19 and the teaching profession, across all four nations of the UK; the full reports are available on our website. If you have any views on the Royal Society's educational work, or would like further information, please contact the education team at education@royalsociety.org.

(1) Core sciences includes biological sciences, chemistry and physics.

(2) *Preparing for the transfer from school and college science and mathematics education to UK STEM higher education. A 'state of the nation' report.* Royal Society, February 2011. http://royalsociety.org/education/policy/state-of-nation/higher-education/

(3) Based on the total numbers of first degree graduates in biology (biology, botany, zoology, genetics and microbiology), chemistry and physics and astronomy in 2009/10.

(4) *The Scientific Century: securing our future prosperity.* Royal Society, March 2010. http://royalsociety.org/education/policy/reports/

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HOW HEFCE AND THE RESEARCH COUNCILS ARE UNDERMINING SCIENCE AND THE NATIONAL INTEREST

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Until recently the system of dual support for scientific research was predicated on the principle that researchers should be free to follow the scholarly agenda set by themselves and their international peers. Dual support is based on the division of labour; the research councils provide grants for specific projects and programmes, while *HEFCE* and the other funding councils provide block grant funding to support the research infrastructure, and to provide the capacity to undertake research commissioned by the private sector, government departments, charities, the European Union and other international bodies. Individual academics could rely on the fact that they could carry out a certain amount of their own research without having to apply for funding from a research council. This makes sense because some work is so exploratory in nature that no detailed research proposal is available. On the other hand, universities expected researchers to teach and carry out administrative duties, and so extended amounts of research leave still required funding. Dual support has a clear rationale that is rarely mentioned these days, namely that research council funding is based on a prospective assessment of a plan for future work, while the funding councils award resources based on a retrospective assessment of the work done in the years prior to

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the assessment exercise (the RAE, now replaced by the REF). This has been incredibly successful; the UK has around twenty of the best one hundred universities in the world by any reckoning and the latter have the status of national treasures, albeit ones that are taken for granted.

Despite their different roles both the funding councils and the research councils have embraced the impact agenda. In so doing they are distorting the incentives of researchers and universities. Pure intellectual inquiry has borne fruit that could never have been imagined in advance. When Bertrand Russell began his logical investigations into the meaning of sentences with empty names, such as famously 'the present King of France is bald', he was pursuing an intellectual agenda that had been set by the great Austrian philosopher of mathematics Gottlob Frege some years earlier, who had in turn wished to properly understand the meaning of simple arithmetical statements such as '7+5=12'. No research could seem more idle from a practical point of view, yet Russell's work gave us the artificial languages of mathematical logic without which contemporary computing would be impossible.

The American sociologist Robert Merton is credited with the phrase 'unintended consequences' (he also founded the study of the sociology of science of which more below). It is now widely acknowledged that the *Research Assessment Exercise* had unintended consequences. There is no question that in the immediate aftermath of the introduction of the *RAE* the top research universities had a very strong interest in prioritising research at the expense of teaching. This was directly or indirectly communicated to staff who realised that their own careers would not be enhanced, and might even be threatened, by allowing their research productivity to be compromised by extensive preparations for teaching new courses, or by time spent working on textbooks or pedagogy.

When people are given very clear incentives they often over-respond to them. This certainly happened with the *RAE*. While only four items per academic per seven years were required, universities and academics themselves reacted by making publication in top journals an overwhelming priority. One consequence of this has been the marginalisation and gradual elimination of academics who devoted themselves at least as much to understanding their subjects broadly and deeply, as they did to innovation. While of course we would like to have new results in science, there is a lot to be said for the importance and the difficulty of the rediscovery and transmission of what is known already. It is easily forgotten that science is not a dead body of work stored in books and journals, but a culture that is only kept alive by the individuals capable of fully grasping and communicating that knowledge. Often profound advances eventually follow when individual scientists seek to clarify and properly to understand fundamentals, and one of the ways they used to routinely do that was by teaching undergraduate or graduate courses. In the contemporary academy there is so much pressure to publish, and to win grants, that there is a positive disincentive for academics to devote much time and intellectual energy to teaching.

The impact agenda is now changing the incentive structure again by making all researchers think about the applications of hitherto unknown science. The absurdity of this is obvious to anyone with a passing knowledge of the history of science and technology. The laser, once successfully developed after much effort, was described as a solution in search of a problem. Lasers were built only because it was realised that they could exist, and the idea that its inventors should have contemplated the now ubiquitous use of lasers in supermarket checkouts, eye-surgery and information technology is preposterous. New science in one field (say lasers) often leads to technology by interacting with new science in a completely different one (say the digitisation of music, hence cd players). It is ridiculous to expect a researcher interested in, say optics, to anticipate possible applications of research they have not yet carried out, that will only be possible because of the results of other research in completely different fields that has also not yet been carried out. When researchers are encouraged to think about applications of their research they will almost always only be able to envisage them in the short-term. It is salutary to note that the great mathematician G H Hardy in his *Mathematician's Apology* explicitly claimed never to have done anything useful in his life. Little did he know that advanced number theory would become essential to cryptography in the computing age, nor that the law of population genetics to which his name is given would become a centrepiece of biology. More telling still is that this great Cambridge academic cited quantum mechanics as another area of study that was obviously completely useless, whereas it in fact is central to all of electronics and the aforementioned laser.

Those who introduced and advocated the impact agenda have never produced any evidence that researchers who identify applications at the outset produce more valuable research. In fact, many studies have shown the opposite, namely that so-called 'blue skies' research produces a better return on investment. Public critics of the impact agenda led by Don Braben include a good number of Nobel prize winners. Their public and private campaigning has been met with sophistry and spin and their evidence and arguments have never been intellectually addressed. Are we to believe that Treasury civil servants and research council bureaucrats know more about how science works than our elite scientists thousands of whom have signed petitions against the impact agenda?

It may be objected that there is no harm in encouraging researchers to think about applications even if they may not be able to foresee them all, however, the research councils are now asking all researchers even in the most pure and theoretical fields to do so at the earliest stages of research and to include an impact statement with their funding applications. The problem with this is that it fundamentally distorts scientific thought and creativity in so far as it is at least sometimes based on pure intellectual curiosity. The impact agenda incentivises scientists to neglect puzzling but seemingly irrelevant problems, and instead to work directly towards practical goals. This weakens our scientific and intellectual culture and undermines the values essential to education. As Merton pointed out, one of the key features of science is disinterestedness and a culture in which apparently selfless behaviour is rewarded.

The universities have immediately responded to the impact agenda by creating impact infrastructures and bureaucracies. In the *REF* two impact case studies will be worth as much as all the research of about two whole members of staff. One of the most obvious ways of having impact is to enjoy media attention. Universities are falling over themselves to publicise their research and to encourage their academics to court relationships with media professionals. Given the media's tendency to distort the truth in order to make it seem more interesting, it is astonishing how little critical thought is being applied to the consideration of the likely negative effects of this forced marriage.

It may be that tax-payers and policy makers only value science in so far as it produces tangible material benefits for society. However, it does not follow that all scientists should be encouraged to aim to produce those benefits. There are many goals such that aiming directly at achieving them is not the best way actually to achieve them. For example, the best way of impressing people is usually not to try to impress them. Shareholders may only value footballers in so far as they bring them a return on their investment, but encouraging individual footballers to aim at making money for the club would distract them from the goal of playing football well which is how they actually make money. Some scientists are directly motivated by practical problems, and nobody is arguing that the Government cannot set strategic priorities and goals for scientific research such as renewable energy or reducing heart disease. However, there is a great deal of science, even in relatively applied domains, that is driven by puzzlement and the desire to know for its own sake. The policies of the funding and research councils are undermining scientific culture by emphasising the pursuit of foreseeable and short-term application over the quest for knowledge and understanding. They are creating wasteful bureaucracies and encouraging scientists to engage in hype and to court media attention. The best predictor of impact is academic excellence.

The situation in UK academic research is dangerously close to disastrous for the future of education, the science base and ultimately for the economy. Academics are now increasingly only regarded as research active if they bring in grant income no matter how good their work. Researchers are spending huge amounts of time writing grant proposals and completing the baroque forms and processes of the research councils. They are being paid to compete with each other to have time to think, and since most grant applications are unsuccessful huge amounts of time is being wasted. Universities employ teams of people needed to help with these applications, and to sift research council websites and announcements for lists of funding opportunities to compile and send around the academic staff who are then encouraged to think of ways to exploit them. The research councils are increasingly abandoning responsive-mode funding in favour of launching fashionable strategies despite the lack of evidence that they are effective. They attempt top-down control of science, and employ people to travel around promoting their schemes and to court links with researchers and the growing infrastructures of research directors, research development teams and so on. There are ever growing numbers of people involved with research management and administration who do no research themselves whatsoever.

The research councils' enthusiasm for managerialism and wasteful bureaucracy has found its latest expression in their insistence that doctoral research be concentrated in a small number of doctoral training centres. This will lead to many universities having no doctoral students in subjects in which they carry out the highest rated research. Indeed, the research councils seem to be brazenly admitting that basic scientific research will not be found in every region. Doctoral training centres will promote a monoculture, whereas a certain amount of diversity is necessary for a critical culture and for innovation. The alleged need for interdisciplinarity will be used to promote spurious compulsory training modules and taught units at the expense of the kind of advanced doctoral research from which we have benefited so much as a nation. It is completely erroneous to suggest the nation cannot afford its science base. Our existing university system had produced world-beating results from a lower proportion of national income than our rivals. The radical changes in the way science is funded and organised that we are now witnessing are not a response to identified problems or inadequacies of the current system. No evidence has been produced to show that they are necessary. They all involve increasing the amount of bureaucracy, administration, and management associated with scientific research, and they all involve larger and more important roles for the research councils and their service organisations in our universities. Unless this trend is reversed, it will combine with budget cuts to create a perfect storm for UK science.

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