SET for success

The supply of people with science, technology, engineering and mathematics skills

The report of Sir Gareth Roberts' Review

April 2002

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FOREWORD

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Dear Chancellor

Scientists, mathematicians and engineers contribute greatly to the economic health and wealth of a nation. The UK has a long tradition of producing brilliant people in these areas, from Isaac Newton and Isambard Kingdom Brunel, to Dorothy Hodgkin and Neville Mott last century, and most recently to Andrew Wiles who proved Fermat's Last Theorem. The challenge we face is to continue to attract the brightest and most creative minds to become scientists and engineers.

The Government, in partnership with the Wellcome Trust, has done much in recent years to increase investment in scientific research in UK universities. There are already signs that this and the measures taken to stimulate the commercialisation of research are yielding fruit. Much has also been done to stimulate UK industry to invest more in research and development through the introduction of tax breaks and special partnership schemes linking universities and industry. The purpose of this Review has been to establish whether we have sufficient people to exploit these new facilities and technologies.

The Review has identified a number of serious problems in the supply of people with the requisite high quality skills. They are not equally spread across science and engineering; indeed, the aggregate numbers of students with broadly scientific and technical degrees has risen in the last decade. However, there have been significant falls in the numbers taking physics, mathematics, chemistry and engineering qualifications. These downward trends, combined with deficiencies in transferable skills among graduates, could undermine the Government's attempts to improve the UK's productivity and competitiveness. Furthermore, these discipline-related problems will have negative implications for research in key areas such as the biological and medical sciences, which are increasingly reliant on people who are highly numerate and who have a background in physical sciences. It should also be acknowledged that there are other shortage areas, such as modern languages, outside the scope of this Review.

EXECUTIVE SUMMARY

Purpose of the Review

0.1 This Review was commissioned at the time of Budget 2001 as part of the Government's strategy for improving the UK's productivity and innovation performance. It stemmed from the Government's concern that the supply of high quality scientists and engineers should not constrain the UK's future research and development (R&D) and innovation performance.

0.2 Continuous innovation is key to the future survival and growth of businesses operating in what are increasingly competitive global markets. Although not all innovation is based on scientific R&D, the need for human ingenuity in making discoveries and creating new products, services or processes means that the success of R&D is critically dependent upon the availability and talent of scientists and engineers.

0.3 The Review considered the supply of science and engineering skills in the UK and the difficulties employers face in recruiting highly skilled scientists and engineers. A number of problems were identified in the development of science and engineering skills in school, further and higher education, and the Review makes a number of specific recommendations to the Government and the education sector to address these problems.

0.4 The Review also identified the need for further action by businesses and others seeking to employ scientists and engineers to work in R&D. Scientists and engineers are in increasing demand right across the economy and employers cannot expect to attract the best scientists and engineers without offering competitive conditions of employment. The challenge for R&D employers, therefore, is to improve the attractiveness of the jobs they offer, improve the coherence of their skills planning, and increase dialogue and research collaboration with the education sector, all of which are crucial in ensuring an adequate supply of scientists and engineers to work in R&D.

Scope of the Review

0.5 The report focuses on biological sciences, physical sciences, engineering, mathematics and computer science. Graduates and postgraduates in these subjects are referred to as 'scientists and engineers'.[1] The Review recognises, however, the powerful influence of multidisciplinary and interdisciplinary activities in innovation, where related subjects (for example, medicine and information studies) are increasingly important, and that consumer-led demand is a powerful motivator in the production and development of novel products and services.[2]

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[1] In order to concentrate on the labour market for scientists and engineers in R&D, the Review notes but does not examine explicitly, the supply of graduates and postgraduates from areas such as medicine, agriculture, social sciences, and psychology. The labour markets for most researchers in these areas are significantly different to those for science and engineering graduates.

[2] The Review recognises that subjects in other areas - for example, arts and humanities - are important in the supply of innovative and creative employees. The Review also acknowledges that a limited number of these subjects, which lie outside the scope of this Review, may face one or more of the same problems as science and engineering.

0.6 This Review was commissioned by the UK Government and it therefore focuses its recommendations on the Government's areas of responsibility. It is hoped, however, that elements of the report will be of use to the Devolved Administrations and add to their understanding of differences in the supply of, and demand for, science and engineering skills in different parts of the UK. Most of the data used by the Review therefore refer to the UK as a whole (although England-only data have been used for school qualifications and English regional comparisons).

Overview of the Review's findings

0.7 Compared to other countries, the UK has a relatively large, and growing, number of students studying for scientific and technical qualifications. However, this growth is primarily due to increases in the numbers studying IT and the biological sciences, with the overall increase masking downward trends in the numbers studying mathematics, engineering and the physical sciences. For example, the number of entrants to chemistry degrees dropped by 16 per cent between 1995 and 2000.

0.8 However, graduates and postgraduates in these strongly numerical subjects are in increasing demand in the economy – to work in R&D, but also to work in other sectors (such as financial services or ICT) where there is strong demand for their skills. Many areas of biological science research also increasingly rely on the supply of these skills. Furthermore, there are mismatches between the skills of graduates and postgraduates and the skills required by employers (for example, many have difficulty in applying their technical knowledge in a practical environment and are seen to lack strong transferable skills).

0.9 The 'disconnect' between this strengthening demand for graduates (particularly in highly numerate subjects) on the one hand, and the declining numbers of mathematics, engineering and physical science graduates on the other, is starting to result in skills shortages. This is evident in higher employment rates and salaries for graduates and postgraduates in these disciplines, and in surveys of employers' recruitment difficulties. The Review identifies a number of issues that lie behind this 'disconnect':

- a shortage of women choosing to study these subjects at A-level and in higher education;
- poor experiences of science and engineering education among students generally, coupled with a negative image of, and inadequate information about, careers arising from the study of science and engineering;
- insufficiently attractive career opportunities in research for highly qualified scientists and engineers, particularly in the context of increasingly strong demand from other sectors for their skills; and
- science and engineering graduates' and postgraduates' education does not lead them to develop the transferable skills and knowledge required by R&D employers.

0.10 Addressing these issues requires action in school, further and higher education. However, improving the supply of scientists and engineers to R&D cannot be tackled through the education system alone. Ultimately, those wishing to employ scientists and engineers to work in R&D must offer attractive career packages that are competitive with the full range of other opportunities open to scientists and engineers. The action taken by employers in responding to this challenge will be crucial in securing a strong supply of highly skilled scientists and engineers who want to work in R&D.

0.11 This report follows the development of science and engineering skills through school, further and higher education, before considering the issues surrounding careers for scientists and engineers in academia and in the labour market more generally. The main issues and the thrust of the key recommendations in each area are set out below. A full list of all recommendations is provided at Annex A.

School and further education

0.12 The experiences of pupils in school and further education are crucial to their subsequent education, training and careers. Although standards in schools and colleges are rising overall, it is concerning that significantly fewer pupils are choosing to study mathematics and the physical sciences at A-levels in a period when total A-level entries have risen by more than 6 per cent. The decline has been most marked in physics, where between 1991 and 1999 numbers taking A-level physics in England fell by 21 per cent. During the same period, the numbers taking A-level mathematics in England fell by 9 per cent, and those taking A-level chemistry by 3 per cent.

0.13 There are a number of deep-seated issues particular to these subjects that need to be addressed in order to improve the UK's future supply of high level science and engineering skills. These issues, which are common to both school and further education, include:

- shortages in the supply of physical science and mathematics teachers / lecturers;
- poor environments in which science, and design and technology practicals are taught;
- the ability of these subjects' courses to inspire and interest pupils, particularly girls; and
- other factors such as careers advice which affect pupils' desire to study science, technology, engineering or mathematics at higher levels.

Teachers

0.14 Secondary schools and further education colleges find it increasingly difficult to recruit science, mathematics ICT and design & technology (D&T) teachers and lecturers, since graduates in these subjects often have other more attractive and better paid opportunities open to them. This is evident in the consistent failure to recruit sufficient numbers specialising in these subjects onto Initial Teacher Training courses and in the higher teacher vacancy rates in these subjects.

0.15 This is in part due to the increasing demand for science, mathematics and engineering graduates from other sectors combined with static or falling numbers of graduates in a number of science and engineering disciplines.[3] Linked to this, a significant stumbling block to recruiting more science and mathematics teachers is their relative remuneration. The Government has taken steps to target financial rewards to teachers of subjects in which there are teacher shortages – for example, through the introduction of golden hellos and the flexibility for schools to target additional allowances on particular recruitment and retention problems. These have had an effect, although serious shortages and recruitment difficulties remain and are damaging pupils' attainment. For example, the most recent OFSTED[4] subject teaching reports revealed that:

> "[In mathematics] there are insufficient teachers to match the demands of the curriculum in one school in eight, a situation that has deteriorated from the previous year."

0.16 **The Review concludes that the Government should tackle such recruitment and retention problems through increasing the remuneration offered to teachers of these shortage subjects – and also that head teachers and governing bodies use all the pay flexibility at their disposal.**[5]

0.17 Particularly in science there are also concerns over the level of initial training that teachers receive. This is important both in primary schools, where very few teachers have a strong scientific background, and in secondary schools and further education colleges, where science teachers are often required to teach areas of science that they did not study at degree level (nor, in many cases, at A-level).

0.18 **To address these issues, the Review makes recommendations that trainee teachers receive significantly more training aimed at improving their teaching of areas of science in which they have not specialised**. This is particularly important in addressing the declining numbers of pupils choosing to study the physical sciences, since primary school teachers and many secondary school science teachers (who often come from a biological science background) are in general least confident in teaching the physical science elements of the National Curriculum.[6]

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[3] The Review's recommendations aimed at increasing the number of graduates in these subjects will therefore be of help.

[4] Office for Standards in Education.

[5] The Review acknowledges that similar measures may be necessary for a limited number of other subjects outside the scope of this review - for example, modern foreign languages.

[6] Science Teachers: a report on supporting and developing the profession of science teaching in primary and secondary schools, CST, February 2000.

0.19 In a similar vein, the Review also concludes that the Government must act to improve the take up of science-related continuing professional development (CPD) by science teachers. CPD is vital in improving science teachers' understanding of, and ability to teach, all areas of science – particularly those related to contemporary issues discussed in society and the media that are most likely to capture pupils' interest. CPD also allows science teachers to stay in touch with the latest developments in their specialist subjects, which can be an important retention mechanism. Yet only around 15 per cent of science teachers at secondary school take up subject-related CPD a year.[5] **The Review therefore, makes recommendations aimed at improving science teachers' take up of science-related CPD – in particular, supporting the Government's commitment to a National Centre for Excellence in Science Teaching and urging the Government to work closely with others (notably the Wellcome Trust) with an interest in delivering this.**

The teaching environment

0.20 The environment in which science and D&T are taught is also an important influence on the achievements of pupils, and on their desire to pursue further study and careers in science and engineering. At their best, science and D&T laboratories and equipment can inspire pupils. However, only just over a third of school science and D&T laboratories in secondary schools are estimated to be of a good standard or better; in general they are in a worse condition than the overall school estate. **The Review therefore, recommends that the Government and Local Education Authorities prioritise school science and D&T laboratories, and ensure that investment is made available to bring all such laboratories up to a good or excellent standard, as measured by OFSTED.**

0.21 A further factor that influences the environment in which science and D&T are taught is the pupil-to-staff ratio in practical classes, which is higher in England than in Scotland and many other countries. The Review believes that skilled teaching assistants can be important in lowering pupil-to-staff ratios, thereby improving the learning experience for the pupils, as well as assisting the teacher and the other support staff (e.g. technicians). **The Review therefore, recommends that the Government establish a major new programme to pay undergraduates and postgraduates to support the teaching of science and D&T in schools**. The Review believes that mathematics and IT (and possibly other subjects outside the scope of this review such as modern foreign languages) would also benefit from such a programme, and recommends that the Government should set an ambitious target for the number of science and engineering university students who should be participating in such a scheme by 2005. This initiative would also bring benefits to the university students, through developing their transferable skills.

Subject curricula

0.22 The content and difficulty of the subject curricula, as well as pupils' access to initiatives that can enhance their learning (for example, trips to science centres), significantly affect the desire of pupils to study particular subjects. However, pupils' views of the physical science elements of the science curriculum are poor and pupils can be put off studying the physical sciences and mathematics due to the perceived difficulty of these courses. **The Review makes a number of recommendations, across the spectrum of academic and vocational courses, aimed at:**

- **improving the relevance of the science curriculum to pupils in order to capture the interest of pupils (especially girls) and to better enthuse and equip them to study science (particularly the physical sciences) at higher levels;**
- **ensuring that pupils stand a broadly equal chance of achieving high grades in all subjects (in particular, ensuring that it is not more difficult to achieve high marks in science and mathematics, as currently appears to be the case);**
- **ensuring that pupils are able to make the transition smoothly from GCSE to AS- and A-level and in turn to further and higher education in science and mathematics; and**
- **providing easier access for teachers, schools and colleges to the many independently organised initiatives (for example, the Crest Awards and the Industrial Trust) to enhance the science, D&T, mathematics and ICT curricula.**

Other factors influencing students' choices to study science and engineering

0.23 The views of parents, teachers, careers advisors and society in general towards study and careers in science and engineering can play a significant role in shaping pupils' choices as to whether to study these subjects at higher levels. Regrettably, and incorrectly, pupils often view the study of science, mathematics and engineering as narrowing their options, rather than broadening them. A contributing factor is that careers advisers often have little or no background in the sciences, and that science teachers are often unwilling to advise pupils on future career options. **The Review recommends that the Government establish a small central team of advisers – possibly within the new Connexions service – to support existing advisers, teachers and parents in making pupils aware of the full range of opportunities and rewards opened up by studying science, mathematics and engineering subjects.**

0.24 Improving the public perception of SET more generally is also important. The Review noted extensive activity and interest in this area and therefore does not make an explicit recommendation on this issue. Instead, the Review focuses its recommendations on improving the reality of science and engineering study and careers, which it believes will in turn have a positive effect on the public perception of SET.

0.25 The Review also calls for improving participation from groups currently under-represented in science and engineering, particularly women and those from certain ethnic minority groups. Although this is important at all levels of education, it is particularly vital in schools. The Review welcomes initiatives such as Baroness Greenfield's study on improving the participation of women in science and engineering and urges the Government to take forward the actions that will in due course be identified.

0.26 Through the recommendations relating to school and further education, the Review also sets out a vision for science, technology and mathematics education that it believes will lead to exciting, challenging and rewarding learning experiences for all pupils, and thereby strengthen the UK's supply of science and engineering skills.

Undergraduate education

0.27 Undergraduate education is the springboard from which science and engineering graduates either enter employment or continue their studies through postgraduate courses. Compared to its competitors, the UK has a relatively high proportion of graduates in scientific and technical disciplines. However, the trends seen in students' subject choices at A-level (with fewer choosing to study engineering and the physical sciences) are repeated in their choice of undergraduate course. Between 1995 and 2000, although overall graduate numbers rose by 12 per cent, the number of entrants to chemistry degrees fell by 16 per cent and the number of entrants to physics and engineering degrees by 7 per cent.

0.28 These declines are partly due to pupils' subject choices at A-level. However, the Review identified a number of issues specific to higher education that reduce the attractiveness of undergraduate education in mathematics, engineering and the physical sciences:

- students can experience difficulty in making the transition from studying at A-level to degree level in these subjects;
- the teaching environment for these courses often gives rise to poor learning experiences;
- the course content can be out-dated and not as relevant as it could be to either the student or to future employers; and
- issues arising from the student funding system may cause added difficulty in studying science and engineering subjects.

The transition to degree level study

0.29 Students can sometimes struggle to make the transition from A-level to degree level study in science, engineering and mathematics, since undergraduate courses often do not pick up where students' A-level courses end. Furthermore, the increasing modularisation of A-level courses has led to students entering higher education with wider varieties of subject knowledge; differences in students' mathematical knowledge are perceived to cause particular problems for mathematics, engineering and physical science degree courses. **The Review makes recommendations to address this issue, including the promotion of special 'entry support courses' to bridge gaps between A-levels and degree courses, and encouraging higher education institutions and A-level awarding bodies to manage this transition better.**

Undergraduate course content

0.30 Improving the relevance and excitement of science and engineering courses to students is linked closely to improving the relevance of these courses – in terms of skills and knowledge taught – to employers. Updating the nature and content of the course to reflect the latest developments in science and engineering can be achieved both through having lecturers who can draw on recent experience of work environments other than Higher Education Institutions (HEIs), and through explicit changes in course content. The Review believes that both are important in improving the attractiveness of science and engineering study.

0.31 **Accordingly, the Review makes recommendations to both employers and HEIs aimed at increasing the interchange of staff between academia and business, and encouraging universities to be more innovative in course design in science and engineering – thereby improving the attractiveness of courses to both students and employers.** These actions by HEIs and employers must be supported by those professional bodies that accredit science and engineering courses – for example, members of the Science Council and the Engineering and Technology Board – who must work with HEIs to drive forward innovation in course design and not allow the accrediting processes to inhibit this.

0.32 The Review's recommendation that undergraduate and postgraduate students should be paid to support the teaching of science, mathematics, IT and D&T in schools will also help students develop good communication and other highly sought-after transferable skills.

Undergraduate teaching environment

0.33 Outdated science and engineering laboratories and equipment inhibits a potentially vital way of enthusing students about science and engineering, as well as reducing their knowledge and expertise in areas of cutting-edge research. Although the Government – in partnership with the Wellcome Trust – has invested heavily in research laboratories, outdated science and engineering teaching laboratories are a major problem. The Higher Education Funding Council for England (HEFCE) estimates that about half of all teaching laboratories are in urgent need of refurbishment.

0.34 **The Review, therefore, recommends that the Government should introduce a major new stream of additional capital expenditure to tackle the backlog in the equipping and refurbishment of university teaching laboratories. In particular, the priority should be to ensure the availability of up to date equipment and that then, by 2010, all science and engineering laboratories should be classed as at a good standard or better, as measured by HEFCE.**[7]

0.35 **Furthermore, in order to ensure that in future higher education institutions can and do invest properly in science and engineering teaching laboratories, the Review recommends that HEFCE should formally review, and revise appropriately, its subject teaching premia for science and engineering subjects.** The revisions should ensure that the funding of undergraduate study accurately reflects the costs – including the market rate for staff, as well as the capital costs – involved in teaching science and engineering subjects.

Student funding and debt

0.36 The Review considered whether the length of engineering and physical science degrees (most are now four years, compared to three years for many other courses) is a further factor behind the declining number of students taking these courses (since students would be aware that they would be likely to build up more student debt during four years than three). Little firm evidence exists to prove that this is having an impact, although the Review believes that the Government should monitor the situation closely.

0.37 However, there are more widespread concerns that students' longer scheduled hours of study on science and engineering courses – in the laboratory, as well as in lectures – inhibits their ability to take part-time work to support themselves through university. Given the growing reliance of students on part-time work, and bearing in mind the Government's agenda to widen access, the Review believes that access and hardship funds are particularly important for those students who cannot take up part-time work due to these long hours of scheduled study. **The Review makes recommendations to ensure that such students are able to access these funds effectively.**

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[7] In delivering this recommendation, the Review believes it is important that the teaching infrastructure capital stream complements research infrastructure funding to facilitate the building or refurbishment of joint research and teaching facilities, where appropriate.

Postgraduate education

0.38 Postgraduate study is fundamental to the development of the highest level of science and engineering skills. It develops specialist knowledge and, particularly at the PhD level, trains students in the techniques and methods of scientific research. However, the number of doctorates awarded to UK-domiciled students in the physical sciences, for example, fell by 9 per cent between 1995/96 and 1999/00.

0.39 The declining attractiveness of PhD study has given rise to concern about the quality of postgraduate students – illustrated by declining proportions of PhD students with 2:1 or first class degrees in some subjects.

0.40 There are a range of factors that act to reduce the attractiveness of a PhD, including:

- low stipends, when seen against the option of entering employment and reducing the substantial debt that many students will have built up during their first degree;
- concern from students that they are likely to take more than three years to complete their PhD, while generally, funding is only available for three years; and
- inadequate training – particularly in the more transferable skills – available during the PhD programme. As a consequence, many employers do not initially pay those with PhDs any more than they would a new graduate, viewing the training (particularly in transferable skills) that PhD students receive as inadequate preparation for careers in business R&D.

PhD Stipends

0.41 To improve the attractiveness of studying for a PhD it is vital that PhD stipends keep pace with graduate salary expectations, particularly given the increasing importance of student debt on graduates' career choices. It is also important that stipends better reflect the market demand for graduates in different disciplines. **The Review therefore recommends that the Government and the Research Councils raise the average stipend over time to the tax-free equivalent of the average graduate starting salary (currently equivalent to just over £12,000), with variations in PhD stipends to encourage recruitment in subjects where this is a problem.**

Length of funding

0.42 Although students have traditionally been funded for three years by the Research Councils, the average PhD takes considerably longer – nearer to $3^1/_2$ years. This can deter students from taking a PhD, and the time pressure can also lead to the students being given 'safe', rather than innovative, projects to complete. **To address these issues, and to allow time for the greater training referred to below, the Review recommends that the Government and the Research Councils should fund their present numbers of PhD students on the basis that full-time students need funding for an average of $3^1/_2$ years.** The Review makes further recommendations to enable this principle to be applied in flexible ways.

PhD training

0.43 Current moves to improve the quality of PhD training are welcome but institutions are not adapting quickly enough to the needs of industry or the expectations of potential students. The Review therefore believes that the training elements of a PhD, particularly training in transferable skills, need to be improved considerably.

0.44 **In particular, the Review recommends that HEFCE and the Research Councils, as major funders of PhD students, should make all funding related to PhD students conditional upon students' training meeting stringent minimum standards. These minimum standards should include the provision of at least two weeks of dedicated training a year, principally in transferable skills, for which additional funding should be provided and over which the student should be given some control.**

0.45 There should be no requirement on the student to choose training at their host institution. The minimum standards should also include the requirement that HEIs – and other organisations in which PhD students work – reward good supervision of PhD students, and ensure that these principles are reflected in their human resources strategies and staff appraisal processes. The Review also believes that institutions should introduce or tighten their procedures for the registration of students to the PhD as part of these standards to ensure, for example, that all PhD projects test and develop the creativity prized by employers.

Employment in higher education

0.46 Upon graduating, over one-third of PhD students become postdoctoral researchers in HEIs,[8] which for nearly all PhD graduates is a necessary step before becoming a permanent member of the academic staff. Postdoctoral researchers work in the research teams of permanent academic staff, who may have received funding for the project from the Research Councils, businesses, charities or elsewhere (including self-finance by the HEI). Those in receipt of prestigious fellowships have more influence over the nature of their projects.

Postdoctoral Researchers

0.47 Postdoctoral research is a crucial phase in researchers' careers, for it is here that researchers can make a name for themselves through ground-breaking, innovative research. It is also an important phase in which they can develop the skills to lead research projects, which in turn is vital in making the transition to becoming a permanent member of academic staff (or to leading research work elsewhere).

0.48 However, entering the environment of postdoctoral research work is an uncertain and, for many, unattractive prospect. Postdoctoral researchers receive pay that compares unfavourably with that which comparably qualified people could expect to earn outside academe; receive few opportunities to undertake training and development; and are faced with uncertain futures since employment beyond the current project contract – commonly around two years – is not guaranteed. Furthermore, there is little structure to their career, and little advice as to how to make the jump to becoming a permanent member of the academic staff. Although a large proportion remain intent on pursuing academic research careers, it is estimated that fewer than 20 per cent reach a permanent academic job.[9]

0.49 The Research Careers Initiative (RCI) has made considerable progress in analysing the problems surrounding postdoctoral 'contract' research. The Review endorses the work of the RCI and builds on this work through making a number of recommendations to improve the attractiveness of postdoctoral research, and thereby improve the supply of skilled scientists and engineers to both academia and beyond.

[8] Or similar organisations such as public sector research establishments.

[9] Source: Career Paths of Physics Postdoctoral Research Staff, Institute of Physics, London, 1999.

0.50 Foremost, it is important that postdoctoral researchers are able to develop individual career paths, reflecting the different career destinations – industrial, academic and research associate – open to them, and that funding arrangements reflect the development of these career paths. **The Review believes that enabling the individual to establish a clear career path and a development plan to take them along it are critical to improving the attractiveness of postdoctoral research. The Review therefore recommends that HEIs take responsibility for ensuring that all their contract researchers have a clear career development plan and have access to appropriate training opportunities – for example, of at least two weeks per year. The Review further recommends that all relevant funding from HEFCE and the Research Councils be made conditional on HEIs' implementing these recommendations.** Funders of postdoctoral researchers need to take this requirement fully on board in providing resources for research projects.

0.51 **In addition to establishing clearer career progression, the Review recommends that Research Councils should significantly increase salaries – particularly starting salaries – for the science and engineering postdoctoral researchers they fund, and sponsors of research in HEIs and Public Sector Research Establishments should expect to follow suit.** The Review considers that the starting salary for science and engineering postdoctoral researchers should move in the near future to at least £20,000 and that there should be increases above this aimed at encouraging recruitment and retention in disciplines where there are shortages due to high market demand (for example, mathematics).

0.52 The Review makes further recommendations to improve the interchange of postdoctoral researchers between academia and industry, in order to assist their accumulation of a broad range of skills and experiences.

0.53 As well as recommending an increase in postdoctoral researchers' salaries and industrial secondment schemes, the Review believes that there should be a clearer path for postdoctoral researchers into academic lectureships. This should be achieved through creating prestigious fellowships which allow those involved to move from principally research-based work towards the role of lecturer, with the added roles of supporting reach-out to schools and widening access to Higher Education. **The Review therefore, recommends that the Government provide funds to establish a significant number (the Review believes 200 a year) of academic fellowships to be administered by the Research Councils.** The fellowships should last for five years and should be designed to prepare people explicitly for an academic career, to be distributed and awarded on the basis of academic (not only research) excellence across the range of subjects considered in this Review.

Academic Staff

0.54 Academic staff contribute to the UK's R&D and innovation performance both directly, through innovative research and knowledge transfer activities, and through training the next generation of researchers. There is widespread concern that HEIs are increasingly finding it difficult to recruit and retain their top academic researchers, with universities in other countries and businesses both in the UK and abroad offering better pay and conditions. These problems in recruitment and retention tend to be in particular subjects rather than across the board, and can be seen in the response of universities (namely, earlier promotion of academic staff in these subjects).

0.55 There are also concerns over the demographic profile of academic staff in the mathematical and physical sciences, with over 25 per cent of academic staff in these disciplines over the age of 55, compared to an average across all subjects of 16 per cent.

0.56 **The Review concludes that in order to attract academic staff, universities must use all the flexibility at their disposal differentially to increase the salaries – particularly starting salaries – of some scientists and engineers, especially those engaged in research of international quality, where market conditions make it necessary for recruitment and retention purposes.**[10]

0.57 The Government should assist by providing additional funding to permit universities to respond to market pressures. The additional funding, which must be permanent, may initially have to be part of a separate stream to institutions. However, the Review believes that it should be incorporated into core funding for research and also into revised subject teaching premia once more market-based salary systems have been established.

Scientists and engineers in R&D

0.58 Ultimately, those wishing to employ scientists and engineers to work in R&D must offer attractive career packages that are competitive with other opportunities open to scientists and engineers. This applies not only to businesses but also to public sector organisations such as the NHS, Public Sector Research Establishments and Government departments.

0.59 However, other sectors from which there is strong, and growing, demand for the skills and knowledge of science and engineering graduates (for example, financial services) tend to offer more generous pay and more attractive career structures. For example, salaries offered to science and engineering graduates in these other sectors can often be 20 per cent or more than those offered by many R&D businesses. As a result, they have taken increasing proportions of the best science and engineering students.

[10] The Review notes that these conditions are likely to affect a number of other subjects outside the scope of this review, such as economics.

0.60 Responding to the challenge of improving the attractiveness of jobs in research and development, to match or surpass other opportunities open to the best science and engineering graduates and postgraduates, is crucial to individual businesses' future success, since their R&D underpins their future products, services and, ultimately, their future sales and profits.

Attractiveness of work in R&D

0.61 The Review identifies a number of issues that act to reduce the attractiveness of working in R&D, and makes recommendations to employers for addressing these issues. **In particular, the Review is clear that the continued supply of scientists and engineers to R&D requires more R&D employers to:**

- **compete directly on pay with private sector employers, both through an attractive starting package and through competitive salary progression;**
- **provide time and resources to allow their scientists and engineers to stay in touch with the latest developments in their field (for example, by registering for a part-time PhD programme or having an association with a research intensive university), since those working in research are often motivated by an interest in their subject area; and**
- **more generally, ensure that from entry their scientists and engineers have professional development plans, structured and attractive career paths, and adequate training and development opportunities.**

0.62 The Review is clear that the response of employers to the challenge of improving the opportunities for working on research and development activities will be a deciding factor in the future supply of scientists and engineers to R&D and, therefore, also the UK's innovation and R&D performance.

0.63 **The Review therefore, recommends that the Government should establish a group of R&D employers to support and monitor employers' responses to the challenge of improving the pay, career structures and working experiences for scientists and engineers in R&D**. The group should include representatives from businesses (large, medium and small) and others that employ scientists and engineers in an R&D capacity.

0.64 The Review believes the group must drive the recommendations in this report forward, and thereby ensure that the supply of scientists and engineers acts as a stimulus to innovation and R&D, not a constraint. **Furthermore, the Review believes that the group should publish a report, before the next public spending review, setting out the response of employers to the challenges identified in this report.**

Skills planning and dialogue

0.65 It is also clear that there are serious weaknesses in communication between R&D employers and HEIs and students. Although some large businesses have the resources to influence particular university courses directly, the evolving skills needs of most businesses are not known to students or HEIs and therefore, not planned for. The consequent delays in providing the skills required by employers contribute to the emerging skills shortages seen in the economy. Addressing these communication difficulties requires action, in particular, from both employers and universities.

0.66 First, it is important that R&D employers identify the skills they need to underpin their R&D activities. It is clear that although many employers plan R&D projects many years in advance, fewer employers consider the people and skills that are needed to underpin this research. Although there are difficulties in detailed skills planning, the Review believes that employers must do more to identify their evolving skills needs.

0.67 Secondly, through coherent dialogue with businesses HEIs can learn the extent to which, and how, skills needs are evolving. **The Review believes that the Regional Development Agencies (RDAs) should, through the new FRESAs (Frameworks for Regional Employment and Skills Action), take a leading role in the coordination of communication mechanisms between businesses and HEIs regionally, to ensure that demand for higher-level skills at a regional level can be met.** Other parties – in particular, trade associations, the Learning and Skills Council and Sector Skills Councils – should be involved in this dialogue, to ensure that cross regional and national trends relevant to particular sectors and clusters can be recognised and acted upon.

0.68 The Review also identified widespread concern over the level of research and training collaboration between universities and businesses. Although there are excellent examples of innovative and mutually beneficial collaborative research, the Review feels that there is both the scope and need for the levels of research collaboration to be increased significantly. This would both improve the flow of scientists and engineers into business R&D (through helping to bridge the gap between studying science and engineering and then working in R&D) and increase the UK's overall R&D and innovation performance.

0.69 There are a number of Government sponsored and/or funded schemes that exist (for example, Faraday Partnerships) that act to encourage this type of collaboration. However, the Review feels that the collective impact of these schemes is not as high as it should be. **The Review therefore recommends that the Government should develop stronger, more coherent and more substantial innovation partnerships to boost research collaboration between universities and businesses. The Review believes that these should incorporate the following principles:**

- **that the research be business led and focussed on commercially-oriented R&D;**
- **that the partnerships be based on clusters of businesses with particular research interests, either nationally or regionally;**
- **that the Government invest in each partnership alongside the primary funders (business, higher education and RDAs);**
- **that each partnership could be virtual or have a physical centre, depending on the nature of the research and the participants; and**
- **that each partnership should have an explicit aim of prioritising skills training for science and engineering students/graduates, building a critical mass of SET students/graduates with experience in commercial R&D, and encouraging the interchange of people and technology between business and academia.**

International migration

0.70 There is widespread concern that some of the best scientists and engineers are leaving the UK to work abroad – a trend that is commonly referred to as a ‘brain-drain’. Some evidence for this is found, although, in fact, more scientists and engineers locate to the UK than leave the UK. However, it is vital that universities and businesses compete with their counterparts abroad through offering attractive and well-paid career structures and working environments. Earlier recommendations are intended to help achieve this.

0.71 It is also important that universities, businesses and other employers in the UK are able to access scientific expertise from abroad. The Review therefore welcomes the Government’s campaign to raise HEIs’ and overseas students’ awareness of the recent improvements to the work permit system. **However, given the lack of knowledge of these changes shown by businesses during the consultation, the Review recommends that this campaign be extended to cover the business community, including smaller and medium-sized businesses engaged in R&D.** Through this, more UK businesses will be able to draw upon worldwide scientific expertise in driving forward their R&D.

Conclusion

0.72 The Review has identified a number of issues in school, further and higher education, as well as in the labour market for science and engineering skills, that need to be addressed in order to secure a strong future supply of scientists and engineers in the UK.

0.73 The recommendations set out in this report, which represent challenges for the Government, for employers and for the education system, are designed to help secure a strong supply of people with science and engineering skills. The Review believes that implementing these recommendations will be a crucial element in achieving the Government's agenda for raising the R&D and innovation performance of the UK to match the world's best.

0.74 The Review is clear that progress towards the goals set out in the report must be reviewed regularly in order to ensure that the UK's R&D and innovation performance can grow as intended. **In particular, the Review recommends that that the Government should review progress on improving the supply of scientists and engineers, encompassing all the areas identified by this Review, in three years' time, and take any further necessary action to continue the process of improvement.**

1 SCIENTISTS AND ENGINEERS IN THE UK

Summary of issues

The UK's innovation and research and development (R&D) performance is relatively weak, with the UK spending only 1.8 per cent of its Gross Domestic Product (GDP) on R&D, compared to the US and Japan which spend nearer 3 per cent of their GDP on R&D. Furthermore, the proportion of GDP spent on R&D in the UK fell between 1980 and 1997, whereas the proportion in nearly all other major industrialised countries increased.

More recently, however, there have been signs that the UK's R&D performance is improving, with increased public sector investment being accompanied by an apparent upturn in private sector R&D investment. This in turn is leading to a rising demand for scientists and engineers to work in R&D, while at the same time there is strong demand for graduates with highly numerate science and engineering degrees to work in other areas (notably the financial services sector).

Although the overall number of science and engineering students in the UK is relatively high, and growing, the numbers of students choosing to study the highly numerate scientific subjects of mathematics, physics, chemistry and many branches of engineering are falling significantly. For example, the number of students studying A-level physics in England fell by 21 per cent between 1991 and 2000. Unchecked, these trends could result in a serious shortage of scientists and engineers, both for R&D and for other areas of the economy. The first signs of this are starting to appear, with graduates in mathematics, engineering and the physical sciences commanding higher, and faster increasing, salaries than most other graduates (including biological science graduates). These difficulties were borne out in the Review's consultation and are also evident in surveys of employers' recruitment difficulties. Given the increasing importance of interdisciplinary and multidisciplinary research, these trends in engineering and the physical sciences could also affect research in other areas, for example, the biological sciences.

Alongside these subject-related skills shortages, there are also issues around the ability of students emerging from higher education to apply their scientific and technical knowledge in a practical and business environment.

There is, therefore, an emerging 'disconnect' between the demands of businesses and other employers for high-level science and engineering skills and the supply of suitably skilled scientists and engineers.

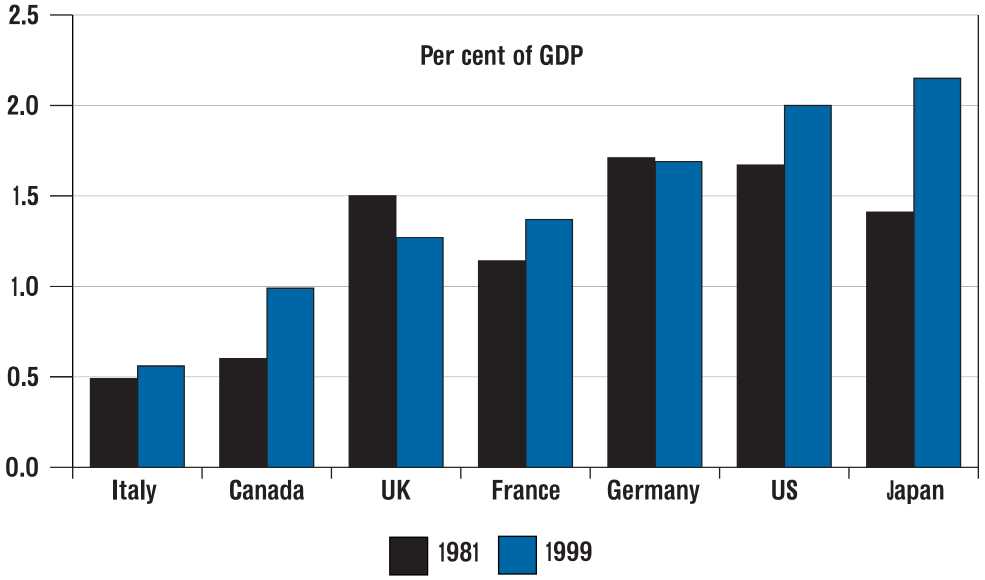
Innovation and R&D in the UK

1.1 Research and development (R&D) is widely recognised to be one of the most important factors in the innovation process. Numerous studies have shown a direct link between investment in R&D and future improvements in productivity.[11] The Government is therefore concerned that, for much of the last two decades, UK businesses have invested proportionately less in R&D

[11] The impact of R&D investment on productivity – New evidence using linked R&D – LRD data, Lichtenberg and Siegel, Economic Inquiry, Vol. 29 (2) (1991).

than their counterparts in other countries. This is illustrated in Figure 1.1, which also shows that between 1981 and 1999, investment in R&D as a percentage of GDP fell in the UK, although it rose in nearly all other G7 countries.[12]

Figure 1.1: Business enterprise expenditure on R&D (BERD), as a per cent of GDP, 1981 and 1999



Source: OECD Main Science and Technology Indicators.

1.2 The Government has sought to improve the UK's R&D and innovation performance through a number of measures, including promoting macroeconomic stability, seeking to encourage investment generally and introducing tax credits to stimulate investment in R&D. There are signs that businesses' commitment to innovation and R&D may be increasing, since between 1997 and 1999 expenditure by UK business as a proportion of GDP increased from 1.20 per cent to 1.27 per cent, although it fell back slightly in 2000.

1.3 Although not all innovation is based on scientific research and development, the need for human ingenuity in making discoveries and creating new products, services and processes means that the success of R&D and innovation is critically dependent on the availability and abilities of scientists and engineers. It is therefore vital that the supply of science and engineering graduates with appropriate skills keeps pace with greater investment in R&D and innovation, and with the demand for these skills from other sectors.

[12] The fall in Germany is due in part to an inconsistency in the time series – 1981 data relate to West Germany only, whereas 1999 data relate to the reunified Germany.

The UK's supply of scientists and engineers

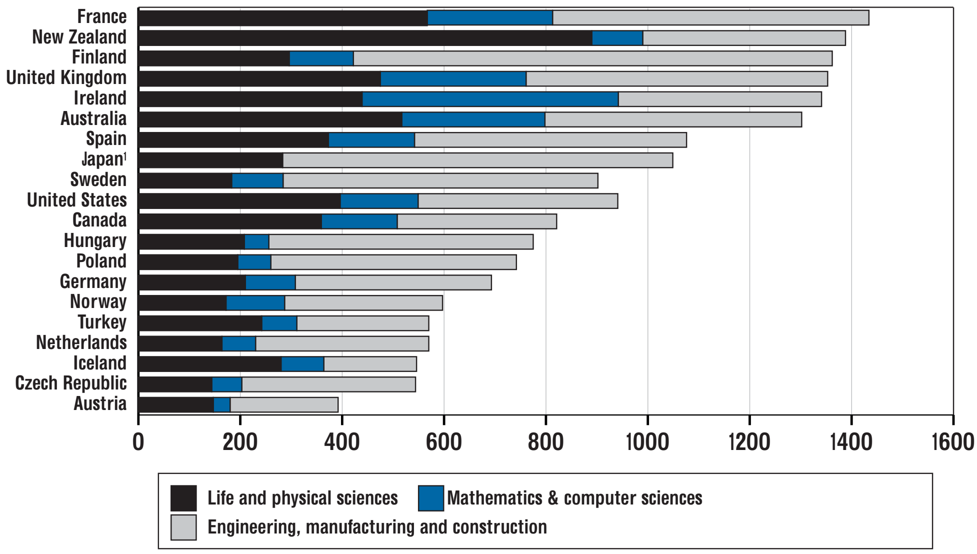
1.4 Students learn about science, technology, mathematics and IT in school, from where they can advance, either directly or via further education (FE), into higher education (HE) at a university or HE college. Some university and college graduates go on to postgraduate work, to study for Masters degrees or PhDs, before entering employment – which could be in higher education, in business R&D, in school or further education, or elsewhere in the economy.

1.5 This section focuses initially on the supply of graduates (and postgraduates) in scientific and technical disciplines, since they are most likely to be at the forefront of businesses' R&D activities.[13]

Science and engineering graduates

1.6 Overall, the UK's supply of science and engineering graduates is strong compared to that in many other industrialised countries (Figure 1.2), with the UK having more new science and engineering graduates as a percentage of 25-35 year olds than any other G7 country apart from France.

Figure 1.2: New science and engineering graduates per 10,000 in the labour force aged 25 to 35, 1999

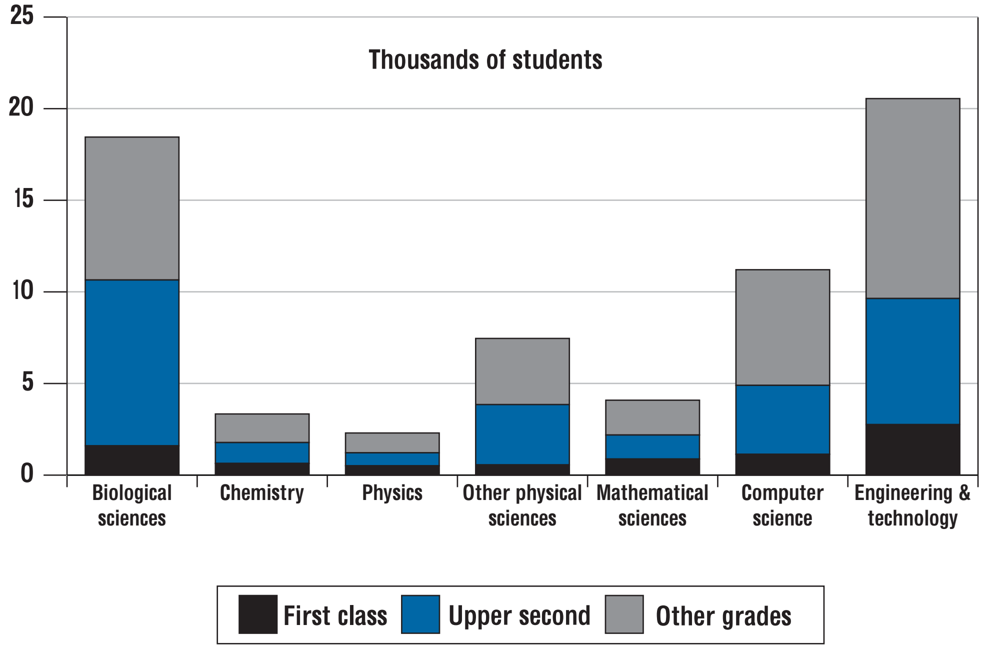


Source: OECD (2002) Education at a Glance 2001: Table C4.4.
[1] Mathematics & computer sciences included with Life & physical sciences.

[13] The Review acknowledges, of course, that progress and growth in the new cultural and creative arts industries will depend on the supply of high-quality and innovative graduates from other disciplines.

1.7 As Figure 1.3 shows, the majority of these graduates in the UK are in the biological sciences or in engineering & technology and computer science. Relatively few students study the mathematical sciences, or the physical sciences of chemistry and physics.[14] Indeed, more students study computer science than study all of these subjects combined, and the numbers studying the biological sciences, or engineering and technology, are around double the number of graduates in the mathematical sciences and the physical sciences of chemistry and physics combined.

Figure 1.3: Students graduating with first degrees in SET[15] subjects, 2000



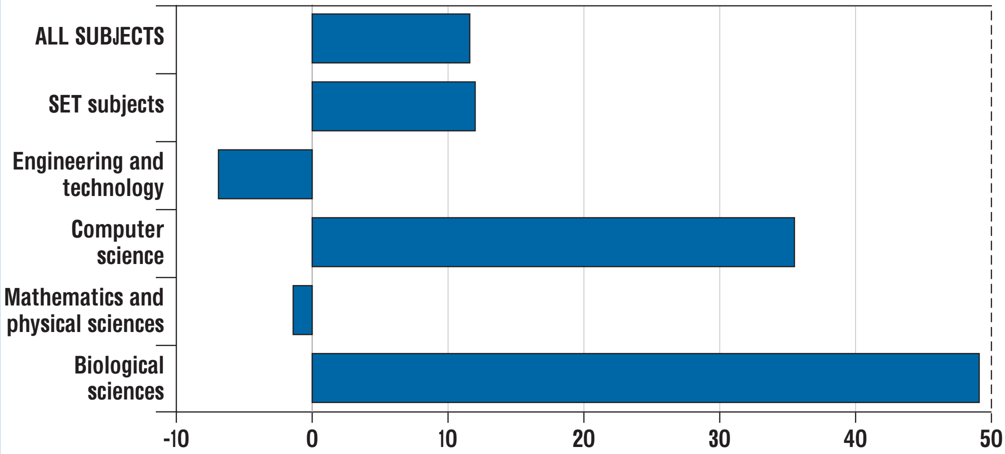
Source: HESA.

1.8 In recent years the number of science and engineering students in the UK has been increasing, mainly on the strength of growth in biosciences and computer science. However, this growth masks a steady weakening of demand for courses in physical sciences, engineering and mathematics. Figure 1.4 shows that whereas the numbers of students in the UK entering higher education rose by more than 10 per cent between 1995 and 2000, the numbers studying engineering & technology fell by 7 per cent, and those studying mathematics and the physical sciences by 1 per cent.

[14] The physical sciences additionally include earth and material sciences.

[15] Science, Engineering and Technology (including mathematics).

Figure 1.4: Students graduating with first degrees in SET subjects, percentage change 1994/95 to 1999/00



Source: HESA.

Development of science and engineering skills

1.9 The previous section showed that relatively few students take degrees in the physical and mathematical sciences, and that the number that do has fallen significantly in recent years. Table 1.1 takes this analysis one step further and summarises the proportions of students taking scientific and technical qualifications at different levels. It shows that at the stages when a positive decision to carry on studying mathematics or a physical science subject has to be made, such as from A-level to degree level, the number of individuals choosing SET subjects falls off significantly[16]. This is in contrast to business studies – and the biological sciences to a lesser extent – where the proportion taking the subject at degree level is closer to proportion taking the subject at A-level.

Table 1.1: Percentage of 'year group'[17] taking SET qualifications, 2000

	A-level	First Degree	PhD
Mathematics	7.8	0.6	0.05
Physics	4.1	0.3	0.07
Chemistry	5.1	0.5	0.13
Biology	6.6	2.5	0.25
Engineering & Technology[18]	2.2	2.8	0.24
Computer science	2.8	1.5	0.04
Business studies	4.7	4.4	0.05

Source: DfES, HESA and Government Actuaries Department.

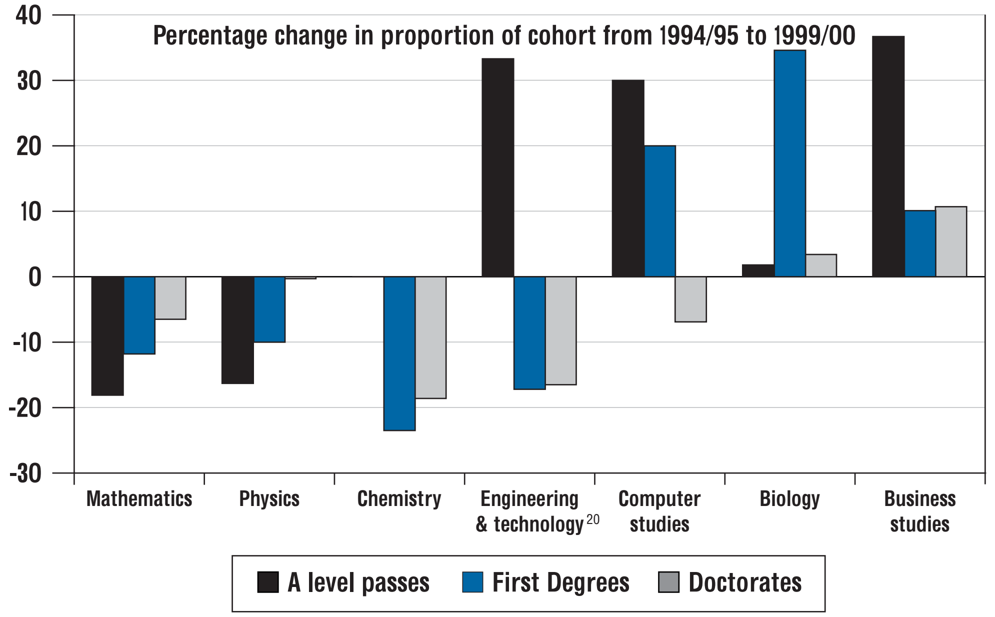
[16] This will, in part, be due to the fact that some students taking physics, mathematics (in particular) and chemistry at A-level will study engineering, computer science or 'other physical sciences' at degree level, rather than continue with these subjects directly.

[17] The base age group: for A-levels is the average of the numbers of 17 to 18 year olds; for first degrees is 21 year olds, and; for PhDs 27 year olds.

[18] A-level figure represents the proportion taking design & technology. It is smaller than the proportion taking engineering and technology degrees since the numbers taking engineering and technology degrees tend to be determined more by the numbers taking A-levels in mathematics and the physical sciences.

1.10 Figure 1.5 examines the change between 1994/95 and 1999/2000 in the proportion of students gaining qualifications in different scientific and technical subjects (and business studies) at A-level, first degree and doctorate level. It shows that the falls in the numbers of mathematics and physics students at A-level are larger than the falls seen for students in these subjects at degree level. This might suggest that issues in school and further education are the main cause of fewer students taking these subjects at degree level. However, there has been little change in the proportion of students taking chemistry at A-level although a significant fall at degree level, which suggests that issues specific to undergraduate education may also be having an effect (at least in this subject).

Figure 1.5: Students gaining scientific and technical qualifications[19], 1994/95 and 1999/00



Source: DfES, HESA and Government Actuary's Department.

1.11 Although the proportion taking design and technology at A-level has risen sharply, the numbers taking engineering and technology subjects at degree level and doctorate level have fallen significantly. This seeming disparity arises, in part, because other subjects such as mathematics and physics – which are in decline at A-level – are also very important in preparing students to study engineering in higher education.

1.12 Figure 1.5 also shows that proportion taking computer science and the biological sciences has increased at degree level and at A-level (particularly in computer science). However, a smaller proportion of computer science students go on to take a PhD, which is primarily because a PhD is not viewed as essential a qualification to work in cutting-edge IT development work, as a PhD in chemistry is to work in, for example, cutting-edge pharmaceutical R&D.

[19] Business studies is included as a comperator.

[20] Note that the Engineering & technology A-level figures are for Design and Technology.

Summary

1.13 The UK has a relatively high and growing overall number of students taking scientific and technical qualifications. However, relatively few study mathematical or physical sciences courses. Furthermore, the growing overall trend masks some significant reductions in the proportion (and numbers) taking mathematics and the physical sciences at A-level as well as engineering at first degree and doctorate level.

The demand for scientists and engineers

1.14 Scientists and engineers in the UK are in demand from a wide range of sectors, not just from higher education or from businesses looking for R&D workers. In particular, recent years have seen an increasing demand from the financial services sector for highly numerate graduates and postgraduates. Increasingly, scientists and engineers are also in demand from businesses and universities in other countries. Other research,[21] which included a survey of 23,000 employers across the economy, found that over one third of employers need more and higher levels of problem solving, communication and IT skills than they did 5 years ago – in addition to a continuing strong demand for specialist information and communication technology (ICT) skills.

1.15 Figure 1.6 illustrates that in many science and engineering subjects over half of all new graduates enter employment working in 'R&D manufacturing'.[22] The figure is noticeably lower for graduates in the biological sciences, who tend to work in a greater variety of areas. Two further points to note are:

- mathematics and physics graduates are more likely to enter the financial services sector (which is consistent with the highly numerical and problem solving nature of these degrees); and
- biological science graduates are more likely to work in education than physics or chemistry graduates (with many working as science teachers/lecturers in schools and further education colleges).

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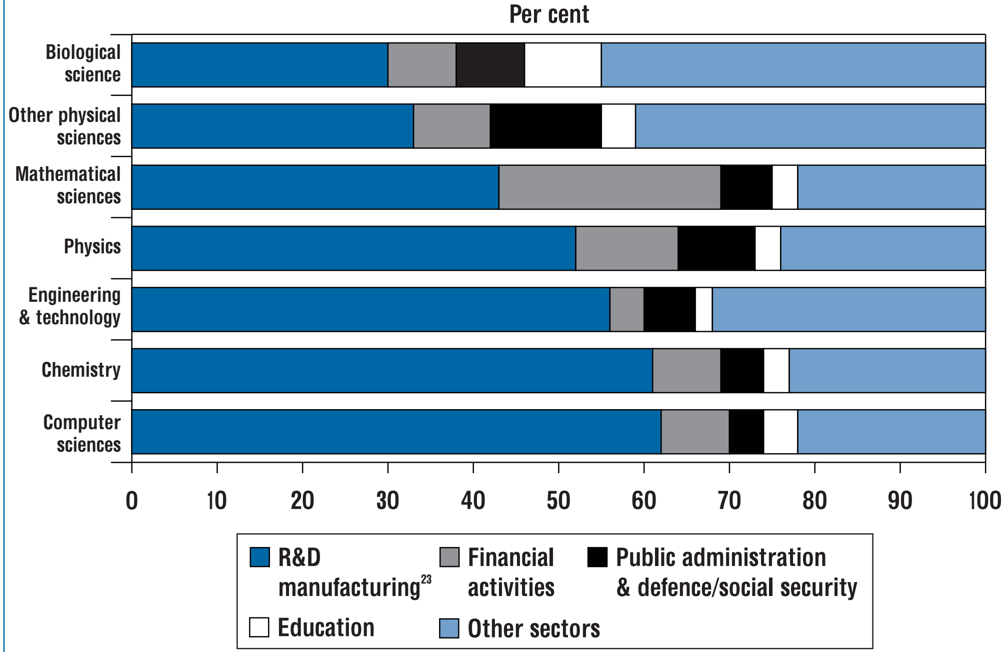
[21] Skills for all: Research Report from the National Skills Task Force, June 2000.

[22] This is defined as the Standard Industrial Classification (SIC) group for 'Manufacturing' and the SIC group for 'Real estate, renting and R&D' (which in this case is primarily R&D).

Figure 1.6: First destination for first degree graduates entering employment in 1999/00



Source: HESA.

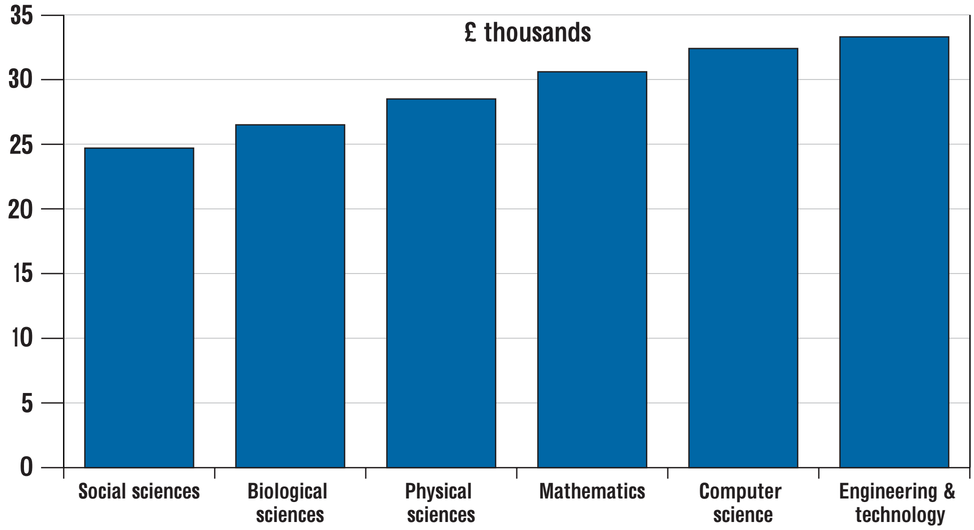
Shortages in the supply of scientists and engineers

1.16 Shortages resulting from the declining numbers of graduates in the mathematical and physical sciences might be expected to show up in increased salaries for these graduates, as employers find they must compete harder to attract the same calibre of employee. Figure 1.7 presents data from the Labour Force Survey, which shows that graduates with degrees in computer science, mathematics, engineering & technology, and the physical sciences do indeed attract higher salaries than graduates in the biological sciences or the social sciences.[24]

[23] This is defined as the Standard Industrial Classification (SIC) group for ‘Manufacturing’ and the SIC group for ‘Real estate, renting and R&D’ (which in this case is primarily R&D).

[24] These differentials are in part related to the higher proportions of men taking computer science, mathematics, engineering & technology and the physical sciences; men on average earn more than women. However, these subject-related salary differences still exist even after taking into account these gender issues.

Figure 1.7: Graduates' average gross salary in primary job, 2001



Source: Labour Force Survey, March 2001.

1.17 Emerging shortages in the supply of scientists and engineers, caused by strengthening demand for them to work in both R&D and elsewhere, would also be expected to show up in recent increases in scientists' and engineers' salaries. Table 1.2 shows that the annual salary increase in real terms has risen substantially in the last few years compared to the 1980s and early 1990s.

Table 1.2: Real-terms increases in median salary for technical and senior R&D specialists

	Annual percentage change (1980/81-1996/97)	Annual percentage change (1996/97-1999/00)
Senior specialist	1.0	3.8
Technical specialist	1.7	2.4

Source: Research & Development Rewards, Reward Group.

1.18 It is not possible directly to disaggregate these data to identify whether these increases have been more pronounced in the subjects in which graduate numbers have been falling (mathematics, engineering and the physical sciences). However, data from other sources appear to confirm that recent wage rises have been focussed more in these subjects (Table 1.3). While the average salary for biological scientists fell by 1.9 per cent in real terms between 1994 and 2000, the average salary for natural scientists overall rose by some 0.4 per cent (which implies that the salary growth for physical scientists rose by considerably more, in order to offset the fall in biological scientists' salaries). Salaries for engineers and technologists also rose in this period, by 4.1 per cent in real terms.[25] These figures support the views expressed by many employers that there are developing shortages in engineering, mathematics and the physical sciences.

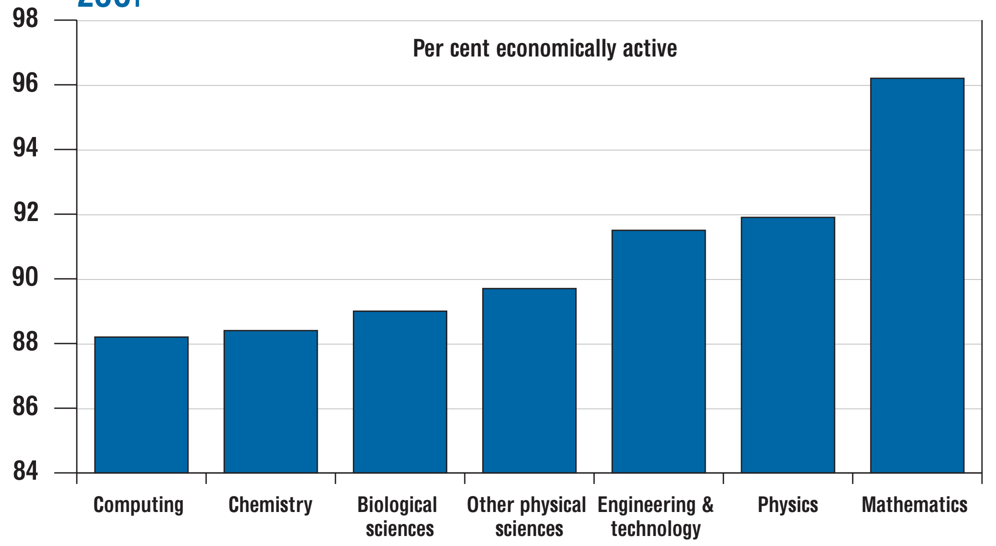
Table 1.3: Increase in average gross weekly pay in real terms, 1994 to 2000

Subject	Percentage change
Natural scientists	0.4
Of which: biological scientists	–1.9
Engineers and technologists	4.1

Source: New Earnings Survey (various years).

1.19 An alternative way of identifying emerging shortages is to compare employment rates (or 'economic activity' rates, i.e. the proportion of people of working age known to be working or seeking work) amongst science and engineering graduates and postgraduates. Figure 1.8 contrasts the economic activity rates for those with different postgraduate qualifications and presents a picture consistent with the salary data presented above. Engineering, physical science and particularly mathematics postgraduates are more likely to be economically active than those with postgraduate qualifications in the biological sciences, computer science and the social sciences.[26]

Figure 1.8: Economic activity rates for SET postgraduates, 2001



Source: Labour Force Survey, March 2001.

[25] These increases are lower than the figures presented in Table 1.2 since these new figures include public sector scientists and engineers as well as private sector scientists and engineers. They are also over a longer period of time, over part of which demand for R&D (and hence, for scientists and engineers) was not particularly strong.

[26] These differences are in part related to the higher proportion of women who take biological and social sciences degrees and PhDs, where issues such as career breaks to start a family may affect the figures. However, these differences in economic activity rates exist even after taking account of these greater issues.

Employers' recruitment and retention difficulties

1.20 The emerging shortages suggested by the previous analysis were supported by the Review's consultation. Many employers reported more difficulty in filling positions in or related to the physical sciences and engineering areas as opposed to the biological sciences. Employers often said their problems were with the quality of applicants, which they tended to define as the combination of general transferable skills and the required breadth in a relevant technical or scientific field. This criticism extended to biological scientists too. These views are supported by other studies of recruitment and skills needs.

- A report by Mason[27] found that 43 per cent of recent recruiters in R&D services had faced some difficulty in meeting recruitment targets. The report also found that the majority of mismatches between supply and demand for SET graduates ". . . appear to be attributable to quality shortcomings rather than any overall shortfall in quantity".

- Work by The Institute for Employment Studies[28] found that technical and generic skills deficits persisted in the ICT sector although this had eased more recently. The report also established that ICT employers' recruitment difficulties increasingly concentrated on the 'quality' of applicants. Interviews with employers suggested that the technical skills gaps were caused by difficulty in keeping pace with the fast changing nature of the ICT sector, as well as a failure by employers to provide adequate training and development for their staff.

- A study of the current and future skill needs of the electronics sector[29] found difficulties with both quantity and quality of recruits. Lack of experience was a common problem, particularly for recruitment to higher level posts, and recent graduates were criticised for their inability to apply their academic knowledge in a practical environment and their lack of important generic skills such as problem-solving, communication and commercial awareness.

- A report on skill needs in engineering[30] also found that a number of employers faced recruitment difficulties and identified skills gaps in specific technical as well as generic skills. It was estimated that one in six engineering employers had 'hard to fill' vacancies, particularly at the higher end of the skills spectrum and at

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[27] The labour market for engineering, science and IT graduates: are there mismatches between supply and demand?, G Mason, National Institute of Economic and Social Research, March 1999.

[28] An Assessment of Skill Needs in Information and Communication Technology, Report by The Institute for Employment Studies to the DfES, Helen Connor, Jim Hillage, Jane Millar, Rebecca Willison, 2001.

[29] Skill Needs in Electronics, A report by The Institute for Employment Studies commissioned by the National Training Organisation for Engineering Manufacture (EMTA), Jim Hillage, John Cummings, David Lane, Nick Jagger, January 2001.

[30] An Assessment of Skill Needs in Engineering, A report by The Institute for Employment Studies to the DfEE, Helen Connor, Peter Bates, Sally Dench, February 2001.

professional engineer level. These often involved the need for project management, commercial awareness and people management skills, together with up-to-date technical skills.[31] The national Employers Skills Survey (ESS), cited by the report, showed that the problems were with applicants' general skills, rather than their technical qualifications. Low numbers of applicants and a lack of experience were also factors.

- This shortage of engineers in the UK was mirrored by the findings of a survey carried out for the World Competitiveness Yearbook, 2001. In a survey of executives about the availability of qualified engineers, the UK ranked 45th of the 49 participating countries, significantly behind all other G7 countries.
- The British Chambers of Commerce Skills Survey[32] found that engineers and technologists were among the five most commonly cited occupations with hard to fill vacancies.
- In the R&D-intensive aerospace industry, one survey[33] established that the main reasons for recruitment problems were "not enough suitably skilled people, people lacking practical skills and a lack of people interested in the type of work", suggesting that both quality and quantity issues may be at the root of the problem.

1.21 There are also reports of shortages in supply and quality of academic staff, which are discussed in Chapter 5.

The quality of scientists and engineers

The definition of quality varies depending on the type of employer – for example, whether they are a university or a business, or even whether the business is large or small.

Generally, businesses seek quality applicants who have sound scientific knowledge but who also have the ability to apply their knowledge in a practical environment and have transferable skills – such as communication, business awareness and team working. In addition, R&D businesses stressed the importance of recruits needing to be innovative, and having a 'creative spark'. Skills needs vary according to the different natures and sizes of business; for example, smaller businesses place more emphasis on SET graduates possessing business awareness and other transferable skills and knowledge.

Universities have tended to stress the importance of scientific knowledge and an aptitude for leading scientific and technical research and less emphasis on transferable skills.

[31] Employers Skills Survey Case Study - Engineering, Tony Buckley, Colin Davis, Terence Hogarth, Ruth Shackleton - Institute for Employment Research/Warwick Manufacturing Group.

[32] The British Chambers of Commerce Skills Survey, January 1998 (last survey).

[33] People Management in Aerospace, The Competitiveness Challenge, Report Summary, The Society of British Aerospace Companies (SBAC), London.

1.22 On issues of quality and the mix of skills possessed by graduates and postgraduates, a study of postgraduate physicist employers for the Engineering and Physical Sciences Research Council (EPSRC) found that employers were generally content with the technical skills of physics postgraduates. However, they felt that softer skills such as communication, team working and business awareness were often not well-developed among these graduates.[34] This survey found that such employers therefore often recruited on the strength of the transferable skills possessed by a suitably qualified applicant.

Summary: Emerging shortages of scientists and engineers

The declining number of graduates in mathematics, engineering and the physical sciences, coupled with increasing demand for these highly numerate, highly skilled graduates, is leading to emerging shortages in the supply of these scientific and technical skills. However, instead of the resulting higher salaries acting to draw more students into these subjects to fill these shortages, the trend is that fewer students are choosing to enter these shortage areas. This suggests that there is a 'disconnect' between the demand for these skills and their supply.

There are also some shortages in the supply of IT skills, although students do appear to be responding to these shortages and pursuing IT-related courses. The trend of increasing student numbers, coupled with the slowing demand for IT skills (following the downturn in the dot.com market) suggest that the same 'disconnect' does not apply to IT skills generally. However, there are concerns that these positive trends mask shortages of graduates with specialist or high-level IT skills such as software engineering.

Skills shortages also appear to arise due to a limited pool of students emerging from higher education with both an excellent scientific and technical background, and an ability to apply these skills in a practical environment (e.g. in problem-solving), at a time when transferable skills are increasingly valued by businesses.

Addressing problems in the supply of science and engineering skills

1.23 The Review based its approach to addressing problems in the supply of science and engineering skills on analysis of responses to the Review's consultation carried out during the summer of 2001. A short summary of the issues raised in the consultation is provided in the box below.

[34] Employers' Views of Postgraduate Physicists, Report by The Institute for Employment Studies to the Engineering and Physical Sciences Research Council, N Jagger, S Davis, D Lain, T Sinclair, February 2001.

Addressing shortages in science and engineering skills – consultation responses

Respondents to the Review's consultation identified issues throughout the education system; from primary and secondary schools through to further education, undergraduate education and postgraduate education. These issues were believed to be contributing to the declining number of students in mathematics, engineering and the physical sciences. Concerns were also expressed that the jobs of scientists and engineers, whether in higher education or in business R&D research, were unattractive to science and engineering graduates and postgraduates.

Science and mathematics education in school and further education was the subject of many responses, with widespread concern about the supply and quality of teachers, particularly in mathematics, physics and chemistry. Further comments were made about the poor standard of school laboratories and the quality of pupils' learning experiences in practical classes. In addition, respondents were concerned that pupils found science and mathematics courses hard, that they were not enthused by the content of the science curriculum nor by the way it was taught, and that they could not relate the issues they studied in science to the world around them. All these issues, coupled with a lack of positive advice about careers arising from the study of science and engineering, were seen to result in declining numbers taking mathematics, physics and chemistry at A-level and beyond.

Concerns raised on issues related to university science and engineering education often focussed on a lack of modern and well resourced university laboratories, as well as the negative effect of student debt on postgraduate study. Respondents also mentioned the importance of employers' involvement to making study at university relevant to the student and employer.

On postgraduate education, many respondents thought that PhD stipends were uncompetitive compared to the employment opportunities available to science and engineering graduates. The amount of training – particularly in transferable skills – available to postgraduates was criticised as inadequate, contributing to many employers not valuing a postgraduate student significantly more than a first degree graduate.

Employment in higher education was believed by many respondents to be unattractive compared to other opportunities for the best science and engineering postgraduates, both in the UK and abroad. Particular issues raised included the uncertain nature of short-term postdoctoral research and the poor pay and limited training given to those in such posts. Low salaries available to junior academic staff were also seen to be causing difficulties for the recruitment and retention of academic staff in subjects such as physical, mathematical and computer sciences as well as engineering, where overall demand for their skills in the economy was particularly strong.

Looking at the role of employers more generally, many respondents felt that jobs in R&D needed to be more attractive (both financially and in terms of job design) so as to compete better with other employment prospects for scientists and engineers. Concern was also expressed that the communication mechanisms between R&D employers and HEIs regarding the skills needed by R&D employers were often incoherent and uncoordinated, and should be improved.

A number of respondents made it clear that action by government (in improving scientific, technical and mathematical education) needs to be matched by employers responding to the challenge of improving the attractiveness of careers in R&D.

2 SCHOOL AND FURTHER EDUCATION

Summary of issues

The experiences of pupils while in school and further education are crucial to their subsequent education and training, and to their careers. There is much concern that, during their time in school and further education, pupils are turning away from the study of science, technology, engineering and mathematics. This is a significant factor in explaining the difficulties experienced by employers in recruiting people with high level science and engineering skills.

This chapter explores these issues and finds that whereas standards in schools are rising overall, there are worrying trends in the subjects chosen by pupils, with significantly fewer choosing to study mathematics and the physical sciences at higher levels. For example, between 1991/92 and 1999/00 the numbers taking A-levels in physics and mathematics fell by 21 per cent and 9 per cent respectively. The Review's analysis suggests that there are a number of deep-seated issues that need to be addressed in order to improve the UK's future supply of high level science and engineering skills. These issues include:

- shortages in the supply of science and mathematics teachers;
- out of date scientific laboratories and equipment;
- the ability of courses to inspire and interest students; and
- a number of other factors affecting students' motivations to study science, technology, engineering and mathematics at higher levels (for example, careers advice).

The chapter considers the effect of steps already taken to address these issues, before going on to make recommendations for further improving pupils' learning experiences in science, mathematics, information and communication technology (ICT), and design and technology.[35] The majority of these recommendations fall to the Government to implement and will require additional resources. However, the Government will need to work closely with teachers and others in and outside schools and further education in order to deliver these improvements in a way that brings about the substantive change needed without disrupting pupils' education or adding unnecessarily to teachers' workloads.

These recommendations are intended to improve the supply of science and engineering skills to the economy while also widening access to higher education and increasing the ability and flexibility of schools to respond to the challenges facing them in the 21st century.[36]

[35] Although achievement in a range of subjects is important in developing science and engineering skills, particular emphasis is given to the study of science and mathematics, and also to design & technology (D&T) and ICT.

[36] Many of the recommendations made on issues relating to secondary schools also apply to further education. For ease of reading, the recommendations are phrased in terms of secondary schools, but the intention of the Review is that the further education sector should be covered, wherever appropriate, by these recommendations.

Education in England[37]

2.1 Subject-oriented education for most pupils in England starts at the age of five in primary school, and continues until the age of eleven, at which time they move on to secondary school.[38] Pupils are required, in nearly all cases, to attend school until the age of sixteen, at which time they take a number of GCSEs (commonly in around eight subjects).

2.2 The National Curriculum sets out the statutory framework for education in England up to the age of 16, and is structured around four 'Key Stages':[39]

- Key Stage 1 (5 to 7 year olds);
- Key Stage 2 (7 to 11 year olds);
- Key Stage 3 (11 to 14 year olds); and
- Key Stage 4 (14 to 16 year olds).

Primary school education

Under the National Curriculum, students are taught the 'core' subjects of mathematics, ICT, English and science from the age of five. The Government focuses its assessment of pupils' academic achievements in primary schools on their scores in 'Key Stage' tests at the ages of 7 and 11. Pupils also study a number of 'Foundation' subjects: geography, history, D&T, art, music and physical education as well as religious education, and personal, social and health education and citizenship. Key Stage 1 assessments (taken by 7 year-olds) focus on English and mathematics, whereas, attention in the Key Stage 2 assessments (taken by 11 year-olds) is on achievements in English, mathematics, and science.

2.3 Education is not compulsory after the age of 16, but around 60 per cent of pupils will study full time for AS-levels, A-levels and/or more vocational qualifications, such as GNVQs. This generally occurs in a school sixth form or a further education college.

[37] This report is for the UK Government and the chapter therefore focuses on school and further education in England. However, comparisons with particular aspects of education in Scotland, Wales and Northern Ireland are made where appropriate.

[38] An alternative route followed by a minority of students is to attend a 'middle' school between, for example, the ages of 7 and 14. However, this report focuses on the route described in the main text, which is followed by the vast majority of students.

[39] Key Stages and tests are not specifically age-related. Pupils can pass through them at a pace judged appropriate by their teachers. Most pass through at the ages set out above.

Secondary and further education

Between the ages of 11 and 16 assessment of students occurs at 14 with the Key Stage 3 tests and the GCSEs (Key Stage 4), generally at 16. The National Curriculum – which specifies the areas that must be studied – states that at both Key Stage 3 and Key Stage 4, pupils must study English, mathematics, science, design and technology (D&T), ICT, a foreign language, physical educataion, and citizenship. History, geography, art and music are also compulsory at Key Stage 3, although not at Key Stage 4. There are also a great many optional subjects (e.g. economics) that may be taken in addition to the compulsory subjects.

After taking their GCSEs at the age of 16, pupils can study a wide range of academic and vocational A-levels and AS-levels, as well as other vocational qualifications such as Vocational Certificates of Education (VCEs). Pupils now have much more choice over the range of subjects open to them, reflecting the Government's aim of increasing participation in post-16 education by (among other measures) helping students to find courses that appeal to them. Under the current arrangements students are encouraged to study combinations of academic and vocational courses – such as AS-level General Certificates of Education (GCEs) and VCEs (3 units), A-level GCEs and VCEs (6 units) and double award advanced level VCEs (12 units) to take them up to a total of around 21 units. There are also a range of other vocational courses that can be taken – for example, Advanced Modern Apprenticeships (AMAs).

Proposals aimed at reforming the 14-19 phase of education were recently announced in the Green Paper, 14-19: extending opportunities, raising standards. Under these proposals, which aim to increase flexibility, appeal, choice and participation in this phase of education, pupils would no longer have to take D&T (or a foreign language) past the age of 14. Pupils would also work towards gaining a "Matriculation Diploma" at the age of 19 – an overarching award incorporating their subject qualifications (e.g. A-levels) and also recognising activities like voluntary work.

Mathematics and science in the National Curriculum

2.4 The Review takes particular interest in mathematics and science education in schools and further education (since these courses are in many cases a prerequisite for higher study in mathematics, engineering and the physical sciences). Until Key Stage 4 nearly all pupils follow the same mathematics and sciences courses, which are aimed at providing a strong foundation of mathematical and scientific principles, while also relating these principles to pupils' experiences outside the classroom. At Key Stage 4, pupils face a number of course choices in both mathematics and science, as set out in the box below. These mathematics and science courses are based on the National Curriculum, which is set by the Qualifications and Curriculum Authority (QCA).

Science and mathematics education at Key Stage 4

Under the National Curriculum, science study in physics, chemistry and biology is compulsory up to the completion of Key Stage 4. Pupils in most schools comply with this through taking a 'double award' science GCSE course, which covers all the major sciences (biology, chemistry and physics).

The aim of the double award is to provide a broad and balanced education for all at GCSE level in less time than would be needed should the pupil study all three sciences. Schools can still allow their pupils to comply with the National Curriculum through taking all three single sciences at GCSE. However, the double award has become dominant for science at Key Stage 4. Schools that persist with three separate GCSEs in science tend to be in the independent sector, although pupils in some maintained schools (for example, some grammar schools) do take individual sciences.

As an alternative to taking the three separate science GCSEs or the double award, some students take a 'single award' in science, covering biology, physics and chemistry but in less breadth. However, these students tend to have reason to spend more time on other subjects.

For mathematics at Key Stage 4, there are three course options available to students: 'Foundation', 'Intermediate' and 'Higher'. Pupils intending to study mathematics at A-level take the Higher course, which is the course required in order to receive a grade A or A*.

2.5 After the age of 16, pupils have a wide range of subjects and course types available to them. These range from the more academic A-level and AS-level courses to the more vocational VCEs and Advanced Modern Apprenticeships. Historically, the main qualifications required by universities for science and engineering degree courses have been A-levels in subjects such as mathematics, further mathematics, physics, chemistry, biology and design and technology. This is likely to continue for some time, although the trend is for pupils entering higher education increasingly to have a wider range of qualifications, including AS-levels and more vocational qualifications.

Further and vocational education

2.6 It is important to consider the roles of both further education colleges and schools in the supply of students to higher education. Nearly one-third of those studying A-levels are doing so in further education colleges, and many of the same issues face both schools and further education colleges. The chapter does not, therefore, consider school education and further education separately, in line with the Government's wish to break down the barriers and the distinctions between school and further education. However, where problems specific to either school or further education exist, these are considered explicitly.

2.7 The Review consulted on whether vocational study is a recognised route for becoming a leading scientist or engineer. The consultation confirmed that although there are cases of individuals who do follow this path, it is not an established route. However, Advanced Modern Apprenticeships increasingly offer a route for young people to progress beyond 'Level 3' (A-level equivalent standard). Until the introduction of AMAs, pupils studying for vocational qualifications in science, technology, engineering and maths tended to fulfil what might traditionally be described as a technician function. For this reason, and given the Review's remit focused on the supply of high-level science and engineering skills, the data presented in this chapter tend to focus on those pupils studying for academic qualifications, such as A-levels.

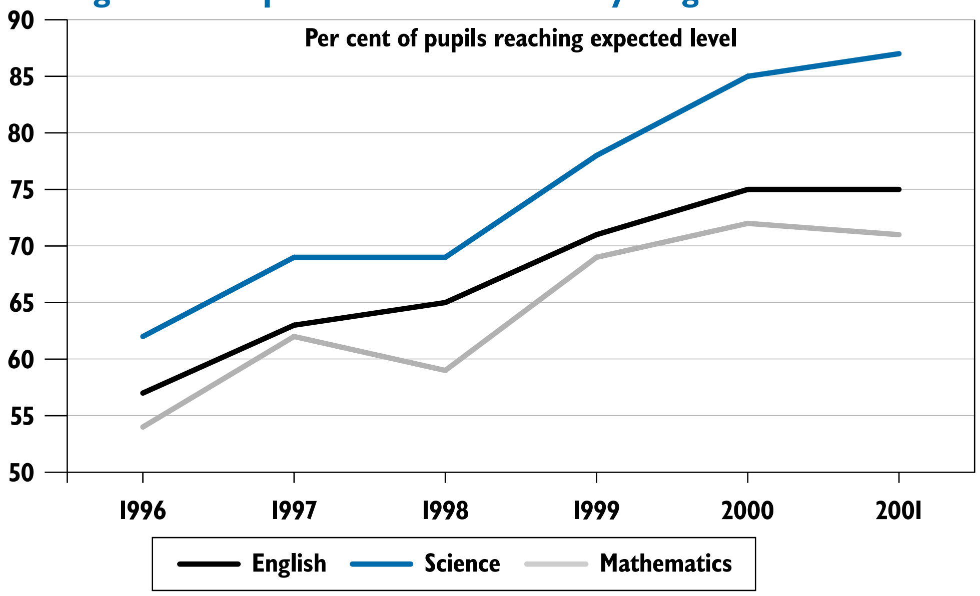
2.8 However, pupils are increasingly likely to take a mixture of academic and vocational qualifications; the current boundary between academic courses and vocational courses is also likely to become increasingly blurred; and vocational routes and courses are likely to become increasingly important if the Government is to meet its target of 50 per cent participation in higher education. The chapter's recommendations are therefore designed to apply, where relevant, to both academic and vocational education.

Pupils' achievements in science, mathematics, D&T and ICT

2.9 Recent years have seen steady improvements in pupil attainment at nearly every level and in nearly every subject. These improvements (see Figure 2.1 and Figure 2.2) reflect the impressive efforts of pupils and teachers, coupled with the new investment in schools in recent years, and the success of initiatives such as the Key Stage 2 literacy and numeracy strategies.

2.10 Figure 2.1 presents trends in the proportion of pupils reaching the required standard (Level 4) in Key Stage 2 assessments. It demonstrates that over the last five years there have been steady improvements in mathematics, English and science. The Government's target is that 85 per cent of all pupils should reach the expected level in mathematics and English by 2004.

Figure 2.1: Pupils' achievements in Key Stage 2 examinations



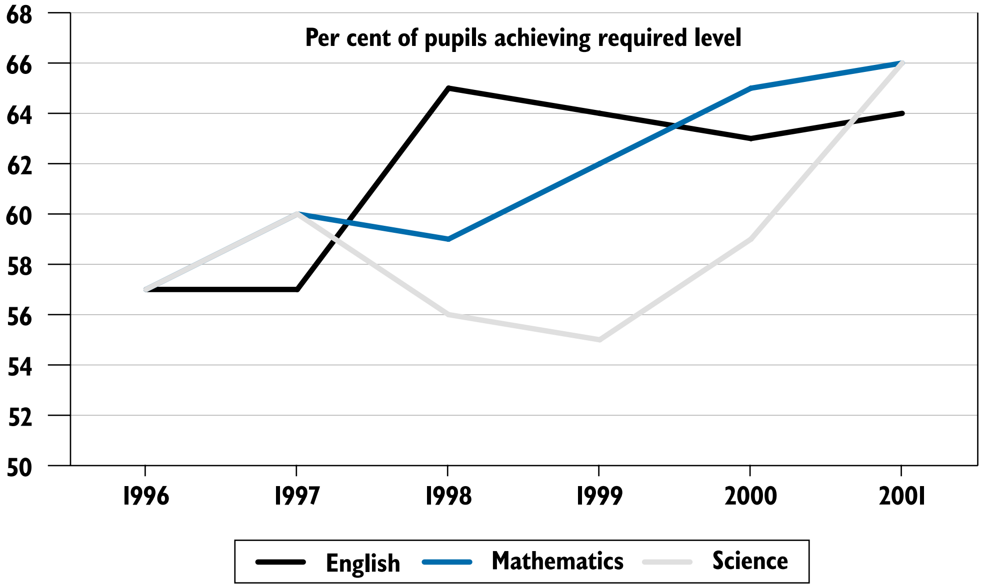
Source: DfES.

2.11 The Government has placed considerable emphasis on boosting pupils' achievements at Key Stage 2, through initiatives such as the national numeracy strategy[40] introduced in the autumn of 1999. However, more effort is needed both to bring pupil's achievements in mathematics up to the levels seen in English and to close the attainment gap between the lowest and highest performing pupils. For example, in over a third of all local education authorities in England, pupils' average attainment levels in the Key Stage 2 mathematics tests are more than ten percentage points below the minimum performance target for 2004. The Review encourages the Government to ensure that policy increasingly enables those pupils currently underperfoming to reach their full potential, so as not only to widen their lifetime opportunities but also to broaden the potential stock of candidates for science and maths at later stages of the education process.

2.12 Pupils' achievements in Key Stage 3 examinations are also encouraging, although the story is somewhat mixed, as shown in Figure 2.2.

2.13 Figure 2.2 shows that although the proportions of pupils reaching the required standard in English, mathematics or science at Key Stage 3 has risen over the last five years, the increases have not been as steady nor as impressive as at Key Stage 2. The Review therefore, welcomes the Government's national Key Stage 3 strategy, which aims to build on the progress that pupils have made at primary school in this critical phase of education.

Figure 2.2: Pupils' achievements in Key Stage 3 examinations



Source: DfES.

[40] The national numeracy strategy introduced a daily 45-60 minute mathematics lesson in primary schools, in which oral and mental work feature strongly, supported by regular mathematical activities for students to do at home. Teachers receive extensive training and guidance to support them in delivering the strategy.

Key Stage 3 National Strategy

The new Key Stage 3 strategy aims to raise expectations and ensure that pupil progress continues smoothly into secondary education. Evidence from OFSTED and other sources suggests that the Key Stage 3 results have been too variable. There is a perceived lack of pace in pupils' education between the ages of 11 and 14, causing some children to lose motivation. There is a strong need to strengthen the early years of secondary education so that the progress gained at Key Stage 2 is not lost. Key elements of the Key Stage 3 Strategy include:

- supporting pupils who start secondary school below the level expected for their age in English and mathematics with programmes to help them catch up with their peers early on. The strategy also caters for more able learners as well, and aims to promote higher standards for all pupils;
- professional development of teachers, with training and support materials which promote direct teaching, interactive learning and strategic management, as well as strengthening teachers' subject knowledge;
- strengthening transition this year from Key Stage 2 to 3, with initiatives starting in primary schools and school holiday initiatives such as summer schools or Saturday classes, as well as catch-up programmes;
- the extensions of the literacy and numeracy strategies into the early years of secondary education through improved teaching and learning of English, mathematics, literacy and numeracy across the curriculum;
- plans to raise standards in science, teaching and learning in the foundation subjects and in ICT, to be introduced nationally from 2002; and
- introduction of targets for Key Stage 3:
    - 75 per cent to achieve Level 5 in mathematics, English and ICT; 70 per cent in science by 2004;
    - 85 per cent to achieve Level 5 or above in English, mathematics and ICT; 80 per cent in science by 2007; and
    - as a minimum performance target, at least 65 per cent to achieve Level 5 and above in English and mathematics; 60 per cent in science in each Local Education Authority by 2004.

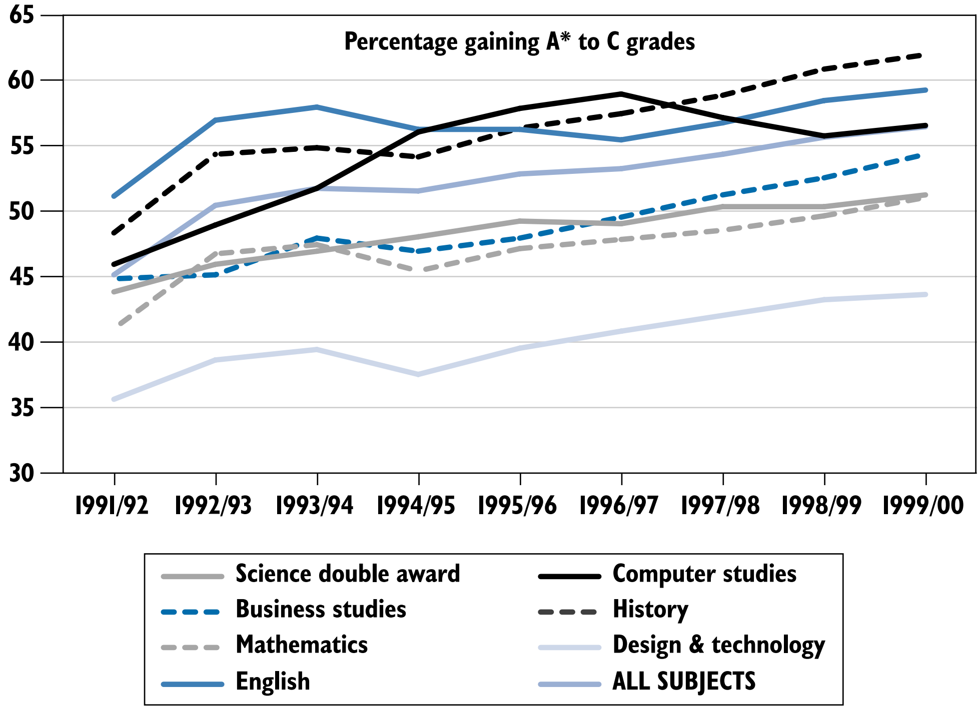
The Key Stage 3 strategy aims to raise standards of all 11 to 14 year olds so that by the time they move on to Key Stage 4 they have:

- reached acceptable standards of attainment (Level 5 or above in their Key Stage 3 National Curriculum tests) in the basics of English, mathematics, science and ICT;
- benefited from a broad curriculum, including studying each of the National Curriculum subjects; and
- learned how to reason, think logically and creatively and to take increasing responsibility for their own learning.

2.14 In line with the progress seen at Key Stages 2 and 3, pupils' achievements in GCSE examinations have also improved steadily in the second half of the 1990s (Figure 2.3). Computer studies is the only subject that does not show this steadily increasing profile.

2.15 It should be noted that there is an annual debate at the time the GCSE and A-level figures are released as to whether standards have indeed risen. The popularity of this annual debate reflects the difficulty in proving or disproving this hypothesis beyond all doubt. However, in the view of both OFSTED and the Qualifications and Curriculum Authority (QCA), these trends do generally represent increasing levels of student attainment.

Figure 2.3: Pupils' achievements in selected GCSE examinations, 1991/92 to 1999/00

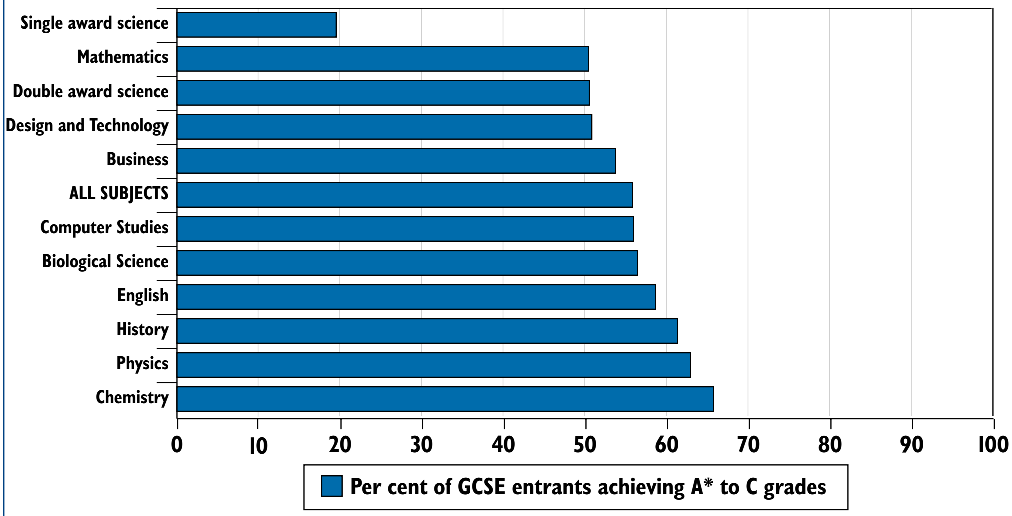


Source: DfEE/DfES (various years) Statistics of Education: Public Examinations GCSE and GCE in England.

2.16 As Figure 2.3 suggests (and as is clarified in Figure 2.4), there are considerable differences in the achievements of pupils in different subjects, with a lower proportion of pupils achieving grades A*-C in mathematics and the sciences than in other subjects.

2.17 Higher proportions of pupils achieve grades A*-C in the individual sciences (biological science, chemistry and physics) than in any other subject. The majority of pupils taking these subjects attend selective schools (often in the independent sector). Of the compulsory subjects, pupils tend to perform better in English than in mathematics or science. The low figure for the single award science course, reflects the fact that pupils on this course tend to be struggling more generally at school and may have special educational needs.

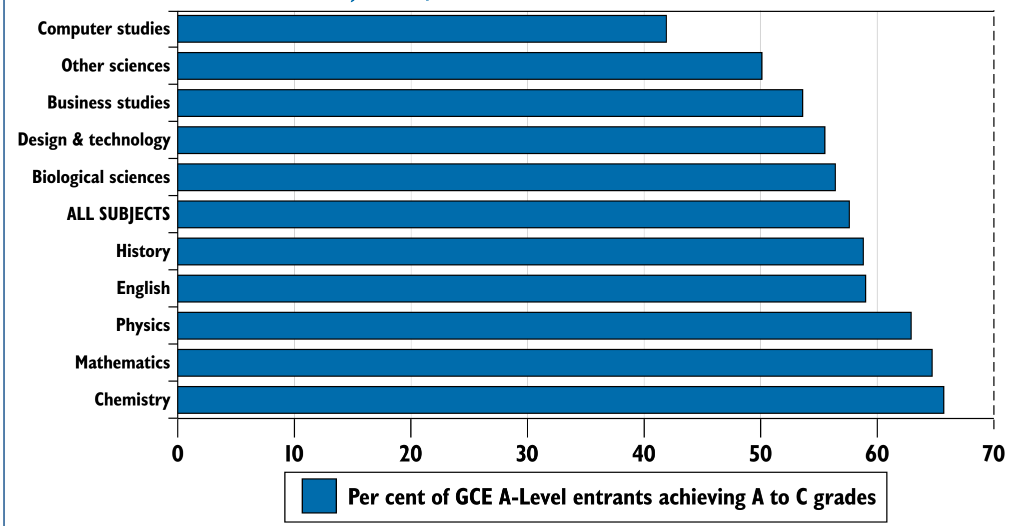
Figure 2.4: Pupils' achievements in selected GCSE examinations, 1999/00



Source: DfES (2001) Statistics of Education: Public Examinations GCSE/GNVQ and GCE/AGNVQ in England.

2.18 However, as Figure 2.5 shows, at A-level the subjects with the highest proportions of pupils with A-C grades are chemistry, mathematics and physics. A cause of this seems to be, in part, that pupils are keen to choose their strongest subjects at A-level, and – to generalise – often only choose mathematics, chemistry and physics if they know they will do well in them. This is consistent with the view of many pupils that these subjects are 'harder' than others – an issue to which the chapter returns later.

Figure 2.5: Pupils' achievements in selected A-level examinations, 1990/00



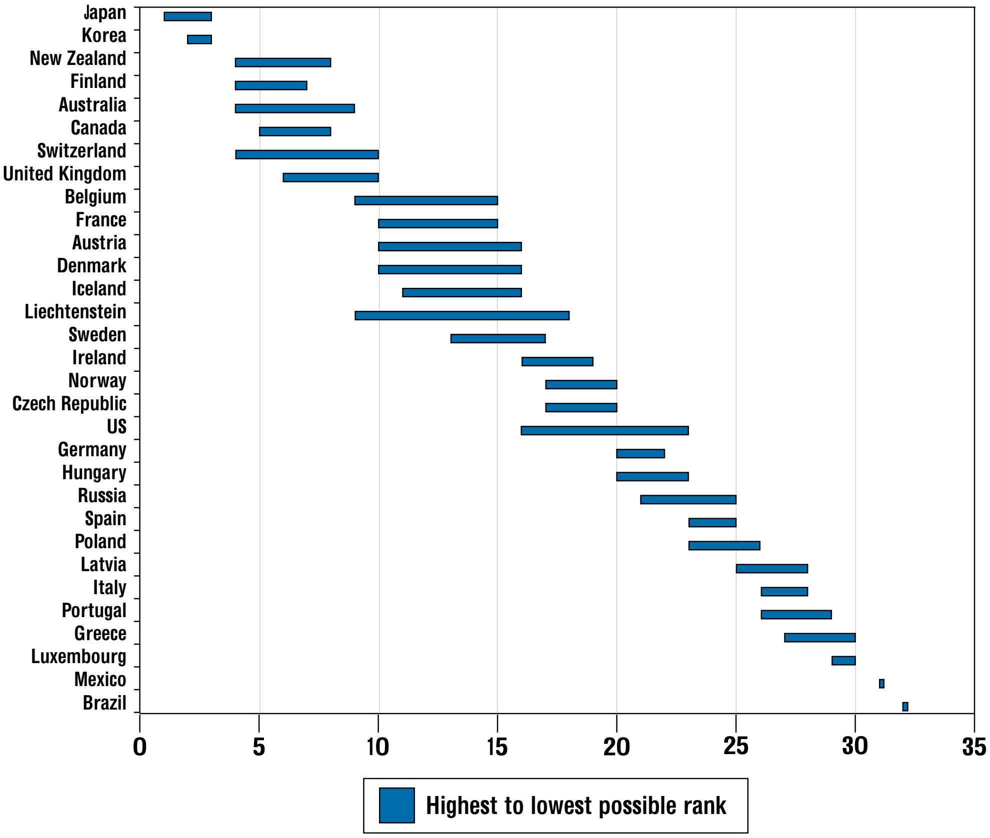
Source: DfES (2001) Statistics of Education: Public Examinations GCSE/GNVQ and GCE/AGNVQ in England.

International comparisons

2.19 The UK compares relatively favourably with other countries when it comes to pupils' achievements in mathematics and science. In the most recent study (the Programme for International Student Assessment (PISA) carried out by the OECD) the UK ranked in the top ten in measures of both mathematical and scientific literacy. The UK was also ranked in the top ten countries in terms of reading ability. Pupils in the UK and US showed a wide range of abilities in the assessments, which the US is addressing through the MSP[41] programme, and the UK through its Key Stage 3 strategy.

2.20 Although these international comparisons paint a reasonably positive picture of achievements by pupils in the UK, they do not measure the motivation they have to study these subjects at higher levels. Furthermore, as shown later in the chapter, there are concerns that many UK pupils' performance is impaired by factors that affect the environment in which mathematics and science are taught. This is particularly relevant given that the spread of pupils' abilities is wider in the UK than in many other countries.[42]

Figure 2.6: Ranks of pupils' mathematical literacy by country

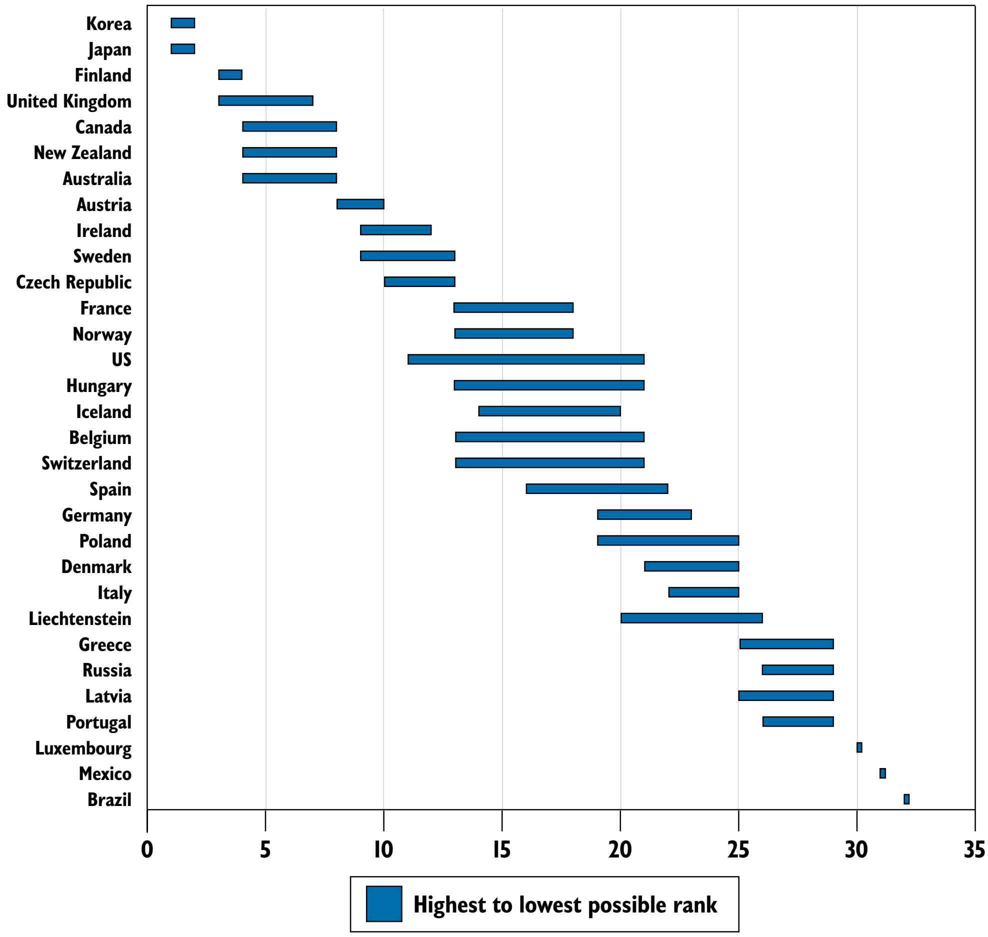


Source: OECD (2002) Programme for International Student Assessment PISA.

[41] Maths and Science Partnership Programme supports schools to work with universities and their community to improve science, technology and mathematics education, and ensure that no child is left behind.

[42] Source: Knowledge and Skills for Life – First results from PISA 2000, OECD, 2002.

Figure 2.7: Ranks of pupils' scientific literacy by country



Source: OECD (2002) Programme for International Student Assessment PISA.

Pupils' subject preferences

2.21 The earliest opportunity to judge accurately the enthusiasm and motivation that pupils have for SET[43] subjects is when they choose their AS- and A-level subjects (or equivalents). Until that point the study of mathematics, D&T and elements of the three main sciences is compulsory for the vast majority of pupils.[44] Examining the overall number of pupils studying mathematics, science, D&T and ICT courses at A-level shows that there has been a 4 per cent increase in the number of pupils taking technical or scientific A-levels between 1991/92 and 1999/2000. This upward trend reflects, in part, the growing number of pupils taking A-levels during this period. (There has also been a growing proportion of pupils receiving grades A–C in recent years.)

2.22 However, the trend in overall numbers disguises trends in the choice of individual subjects, which are important in the context of the increasing demand for people with high-level mathematical, scientific and technical skills.

[43] Science, engineering and technology (including mathematics).

[44] Pupils can be 'disapplied' from certain subjects (excused from studying) such as D&T and science in order to spend more time on other subjects.

2.23 Table 2.1 illustrates that in recent years the number of pupils taking mathematics and the physical sciences of chemistry and physics has fallen. The decline has been most marked in physics, where in the period 1991/02 to 1999/00, numbers taking A-levels fell by 21.2 per cent. Chemistry numbers fell by 3.1 per cent, and mathematics numbers fell by 8.5 per cent. Against this trend, numbers taking biology have increased by 12.9 per cent. Other science subjects – e.g. psychology – have also risen in popularity in this period, and in the same period entries to all subjects combined increased by 6 per cent.

Table 2.1: Pupils taking selected A-levels, 1991/92 to 1999/00

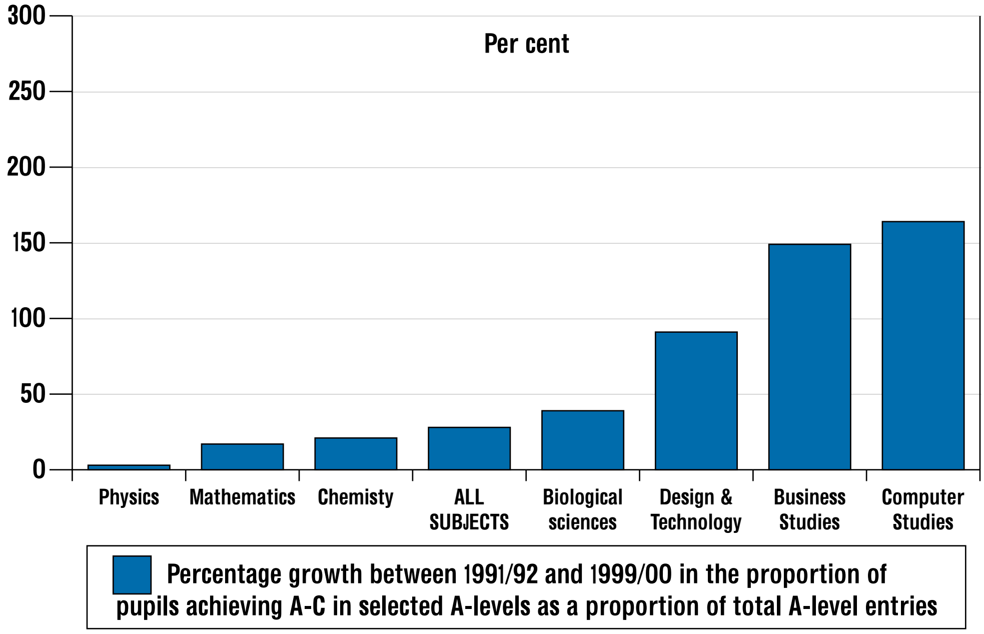
	1991/92	1999/00	Percentage change
Chemistry	37,855	36,696	–3.1
Physics	36,740	28,945	–21.2
Biological sciences	43,408	48,987	12.9
Computer studies	7,747	17,724	128.8
Mathematics	66,395	60,734	–8.5
Design & technology	8,953	13,764	53.7
Business studies	18,466	33,177	79.7
English	79,998	82,910	3.6
ALL SUBJECTS	669,584	709,580	6.0

Source: DfES.

2.24 Falls are also evident at AS-level, with numbers taking AS-levels in physics, chemistry, D&T, biological science and mathematics all falling over the 1990s. However, recent reforms – which aim to make AS-levels a more recognised qualification – should help to reverse this declining trend in AS-levels.

2.25 These trends in the number of pupils taking mathematics and the physical sciences at A-level feed through to smaller increases in the proportion of the whole entry who receive grades A-C in these subjects at A-level (Figure 2.8) and a decline in the proportion choosing to take these subjects at degree level (Table 2.2). Factors relating specifically to undergraduate education that may also be contributing to this fall are discussed in Chapter 3.

Figure 2.8: Percentage growth in proportion of pupils receiving grades A to C at A-level, 1991/2 to 1999/00



Source: DfES (various years) Public Examinations GCSE/GNVQ and GCE/AGNVQ in England

Table 2.2: Entries to selected first degree courses, 1994/95 to 1999/00[45]

Subject	1994/95	1999/00	Percentage change
Biological sciences	12,378	18,450	49.1
Mathematics and physical sciences	17,509	17,270	–1.4
Computer science	8,274	11,210	35.5
Engineering and technology	22,083	20,550	–6.9
All science and engineering subjects	60,244	67,480	12.0
ALL SUBJECTS	237,798	265,270	11.6

Source: UCAS.

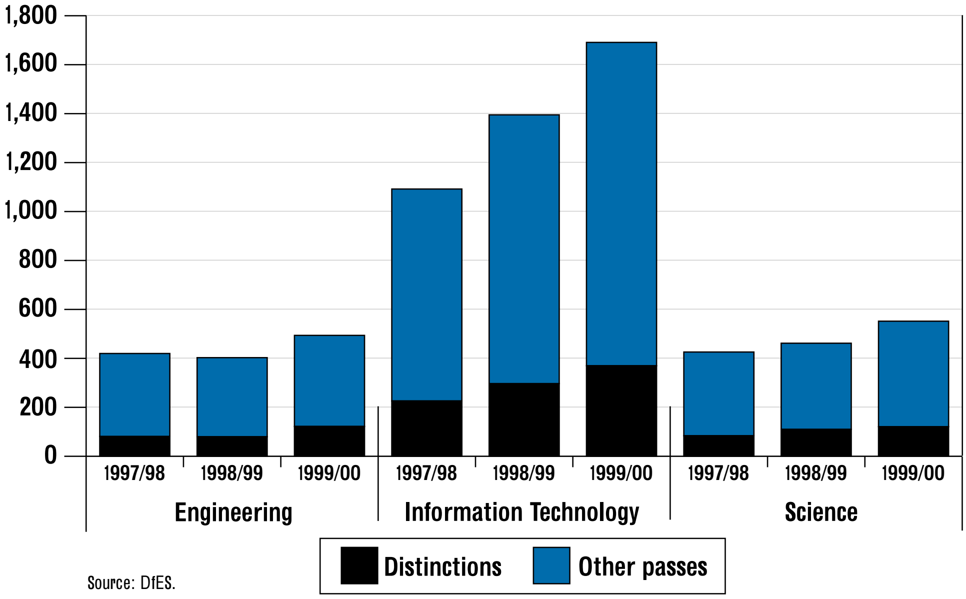
Vocational courses

2.26 The number of pupils studying for vocational qualifications that might lead on to higher education science and engineering courses is relatively small in comparison to those studying A-levels. Figure 2.9 demonstrates that although the numbers taking GNVQs[46] in science, ICT and engineering have increased in the last few years, these numbers are small in comparison, for example, to the nearly 40,000 pupils taking A-levels in chemistry.

[45] Entrants to first degree courses are presented from 1994/95 onwards only, due to data inconsistencies with earlier years (before 1994/95 the current university sector was split into universities and polytechnics).

[46] GVNQs now counted as VCEs.

Figure 2.9: Distinctions and passes in GNVQs, 1997/98 to 1999/00



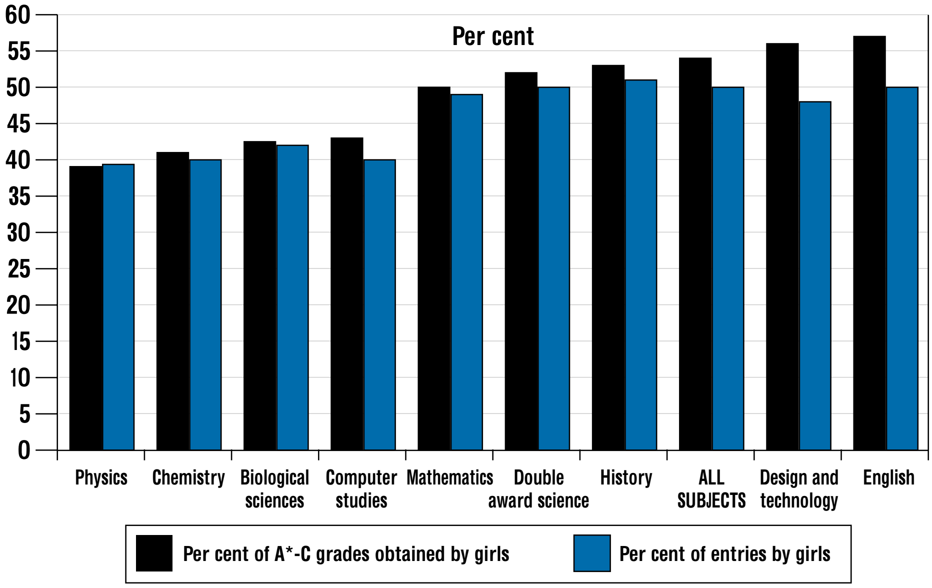
Source: DfES.

2.27 Advanced Modern Apprenticeships also provide a recognised route into higher education. Numbers following this route are small at present because the first cohorts are only now coming through.

Pupil achievements by gender, ethnic group and region

2.28 Before considering the reasons for these trends in the flow of pupils in SET subjects, it is important to consider, within these overall figures, whether there are notable differences between boys and girls, between pupils from different ethnic backgrounds, and by pupils in different regions. Figure 2.10 examines the achievements of girls in selected GCSEs, and shows that in every subject except physics the proportion of A-C grades awarded to girls exceeds the proportion of all those entering the course who are girls. This implies that girls tend to out-perform boys in every subject, with the exception of physics.

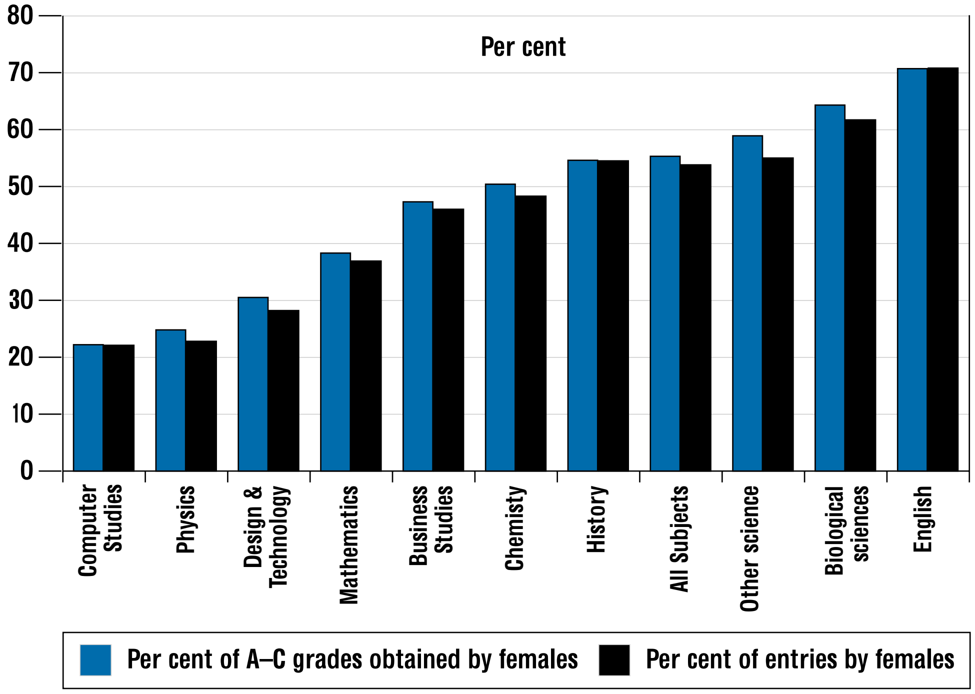
Figure 2.10: Entry and achievement by girls in selected GCSEs, 1999/00



Source: DfES (2001) Statistics of Education: Public Examinations GCSE/GNVQ and GCE/AGNVQ in England.

2.29 Figure 2.11 shows the proportions of those taking science and related subjects at A-level. Although the 'double award' science course has helped to mitigate gender differences between the biological sciences (taken predominantly by girls) and the physical sciences (taken predominantly by boys), these differences are still clear in the data.

Figure 2.11: Entry and achievement by girls in selected A-levels, 1999/00



Source: DfES (2001) Statistics of Education: Public Examinations GCSE/GNVQ and GCE/AGNVQ in England.

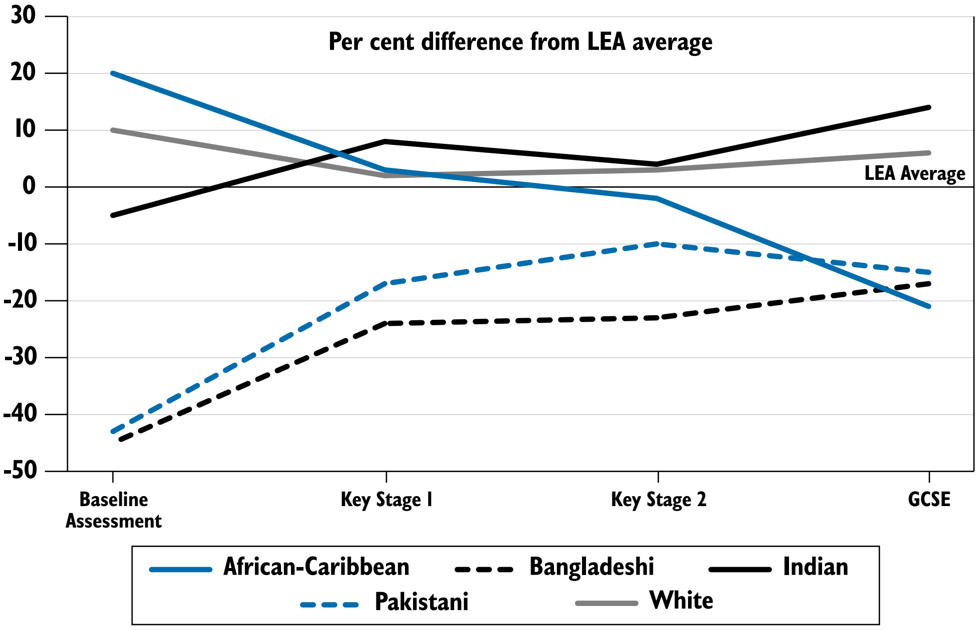
Recommendation 2.1: The participation of women in science and engineering

The Review notes that, despite some recent progress, the proportion of girls studying mathematics and the physical sciences post-16 is still considerably lower than that of boys, which contributes to the under-representation of women in science and engineering more generally. The Review is clear that the under-participation of women in SET is damaging the UK's supply of scientists and engineers, and a number of the recommendations set out in this report should have an important influence on the participation of women in science and engineering.

The Review is aware of a separate study led by Baroness Susan Greenfield, who has been asked by the Government to recommend how to achieve a step change in the effectiveness of measures being used to increase the participation of women in science and engineering. This Review has therefore sought not to duplicate the work of that study but firmly believes that action is required.

2.30 The Review sought to analyse differences in pupil performance between different ethnic groups, but found disturbingly little attention given to this issue. However, whilst the Review was preparing this report the Government announced the creation of a Task Force to examine issues in the achievement of pupils from an African-Caribbean background, which the Review welcomes. This is an area to which the Review urges the Government to give more attention, particularly since the evidence that does exist show considerable disparities between the achievement of pupils from different ethnic groups at various stages of their education.

Figure 2.12: Achievement in mathematics and science by ethnic group of pupil (Birmingham LEA, 1999)



Source: African-Caribbean Representation in Science & Technology (ACRISAT), April 2001.

2.31 Figure 2.12 shows that despite African-Caribbean pupils entering primary school with high levels of numerical and scientific ability and understanding, their achievement declines steadily relative to the average pupil. Pupils from other ethnic minorities (for example, Indian, Pakistani or Bangladeshi students) all tend to improve relative to the average pupil, although there are considerable differences in their initial and final abilities in mathematics and science.

Recommendation 2.2: The participation of ethnic minority groups in science and engineering

The Review is disappointed by the lack of awareness and analysis of differences in achievement and participation in science and engineering between ethnic groups. It is difficult to establish the root causes of these diffierences, based on the evidence available. However, the Review believes that they are significant and therefore recommends that the Government investigate this issue fully in schools, further education and higher education.

2.32 Pupil choices at A-level between regions do not vary greatly although a greater proportion of students in the London region seem to choose mathematics and chemistry than in other regions.

Table 2.3: A-level A–E grades in SET subjects as a percentage of A-E grades in all subjects, by English region

	Biological sciences	Chemistry	Physics	Mathematics	Computer studies	D&T
North East	16	12	9	19	6	4
North West	15	12	8	17	6	3
Yorkshire & Humberside	15	11	8	16	4	5
East Midlands	15	11	8	19	5	5
West Midlands	16	13	9	18	6	4
East of England	14	11	9	20	5	5
London	15	14	9	22	7	4
South East	14	10	9	19	5	4
South West	15	10	9	19	3	5
Total England	15	12	9	19	5	4

Source: DfES; the figures represent the percentage of all A-levels awarded in a region at grades A-E that were awarded in a particular subject. For example, 16 per cent of all A-levels in the NE of England were awarded in the biological sciences.

Summary – The supply of science and engineering skills from schools

There has been some progress in the proportion of those pupils entering SET subjects that achieve grades A*-C at GCSE and A-C at A-level. However, it is worrying that the numbers of pupils choosing to take mathematics and the physical sciences at A-level have fallen so sharply in the early 1990s and are still falling now – resulting in fewer pupils choosing to study these subjects at higher levels.

A shortage of graduates in these disciplines is likely to become increasingly serious since the UK economy – with its large financial services sector, strong science base and increasing focus on high-tech and high-value added manufacturing businesses – is likely to need more mathematics and physical science graduates, not fewer. Furthermore, advances in molecular biology and medical science will in the future depend on those with a quantitative background in physical sciences and mathematics. For these reasons, it is important to consider why more pupils are choosing to take other subjects at A-level and beyond.

An insight into reasons for declining numbers of pupils choosing to pursue mathematics and the physical sciences at higher levels can be gained from studies of pupils' attitudes both to science and to the different sciences. These studies provide evidence that many pupils are dissatisfied with, if not turned off by, the quality of the experience they receive in their school science education[47]. Consequently, the popularity amongst pupils of science, and of physics and chemistry in particular, is low.[48] Subsequent sections consider the underlying factors that cause pupils to turn away from the physical sciences and mathematics.

[47] Pupils and parents' views of the Role and Value of the Science Curriculum, Osborne and Collins, BERA Conference, 1999.
[48] Gender differences in Pupil Attitudes to the National Curriculum Foundation subjects of English, Mathematics, Science and Technology in Key Stage 3 in South Wales, Hendley, Parkinson, Stables and Tanner, Educational Studies, 21(1) (1995) 85-9.

Factors affecting pupils' subject choices

2.33 Four main factors important in improving pupils' achievements in and enthusiasm for particular subjects are:

- teachers, and their style / method of teaching;
- the teaching environment;
- the subject curricula, and subject-related extra-curricular activities; and
- other influences, such as the views that parents, teachers and society more generally have of particular subjects.

2.34 Numerous studies have considered the impact of these factors on pupils' achievements and subsequent choices of further study and eventual careers. However, given the difficulties in isolating any one of them from the others, quantitative evidence on their relative importance is scarce. Their inter-dependence means that tackling any one aspect whilst neglecting others is unlikely to deliver a strong overall improvement. This chapter continues by taking each factor in turn, and examines:

- their role in enthusing students to study science, mathematics, engineering, D&T and ICT;
- the extent to which they could be contributing to the declining popularity of mathematics and the physical sciences; and
- what further measures are necessary in order to secure a strong future supply of science and engineering skills.

Teachers

2.35 Teachers can and do make a huge difference to their pupils' enthusiasm for a subject, as well as directly influencing their pupils' achievements in it. Teachers' subject knowledge and teaching style are vital factors, but it is often their enthusiasm that captures pupil's interest and motivates them to study a subject.

2.36 The Review found considerable differences between the teacher-related issues in primary schools and those in secondary schools and further education establishments. This chapter therefore considers primary and secondary school teachers separately.

Primary school teachers

2.37 Teachers in primary schools generally teach an almost full range of subjects to their class, in order to build as strong as possible a relationship with the pupils. The subject knowledge that teachers require to teach science, mathematics, ICT and D&T in primary schools does not require primary school teachers to have an academic background in them. However, to teach science well, primary school teachers must be able to explain potentially complex scientific principles in an interesting and simple way to pupils, and relate these principles to contemporary issues and the experiences of their pupils. Given that very few teachers have a degree in a science or engineering related subject, it is important for teachers to have access to initial and ongoing science-related continuing professional development (CPD).

2.38 There is considerable concern that primary school teachers are sometimes unable to stretch their pupils adequately in science and mathematics – and that, in particular, there are long-standing weaknesses in the physical processes strand of science. The most recent OFSTED report on primary science found that:

> "Teachers' knowledge of National Curriculum science has improved considerably over recent years. However, as pupils reach the higher levels of attainment many teachers are working at the limits of their own knowledge and understanding, particularly in physical science. In order to address this, and so support the continuing trend of rising standards, particularly in physical processes and the newly formulated Scientific Enquiry, teachers' knowledge of science needs to be further improved."

2.39 This is supported by work carried out for the Council for Science and Technology,[49] which revealed that primary school teachers had less confidence teaching the physical processes and experimental investigation strands of science, than they had teaching the life and living processes strand. This weakness in the teaching of physical processes in primary schools is a serious concern given the declining numbers of pupils taking physics and chemistry at A-level and beyond.

2.40 Furthermore, given this shortfall in teachers' confidence and understanding of the physical sciences, it is worrying that few teachers develop their subject knowledge through CPD,[50] and that little personal reward follows if they do so. Primary school teachers' training is mostly taken up with school administration issues and national initiatives on numeracy and literacy and ICT. Difficulty in identifying suitable courses, as well as time and money, were also cited as reasons for low participation in subject-related CPD. The idea of a National Centre for Excellence in Science Teaching (discussed in more detail in the section relating to secondary schools and further education) should help in this regard.

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[49] Science Teachers: a report on supporting and developing the profession of science teaching in primary and secondary schools, CST, February 2000.

[50] A study into the professional views and needs of science teachers in primary and secondary schools in England, CST, January 2000.

Recommendation 2.3: Primary school teachers

The Review recommends that the Government ensure that primary school teachers receive greater subject-specific training (in particular, in relation to the physical sciences and mathematics) both in their initial training and through Continuing Professional Development to enable primary teachers to build on the progress they have made so far. Furthermore, the Government should review, in three years' time, the progress made in improving primary school teachers' confidence in teaching all areas of the mathematics and science curricula, and take further action as necessary.

Teachers in secondary schools and further education colleges

2.41 Many secondary schools and further education colleges have considerable difficulty in recruiting and retaining science and mathematics teachers (the problems also apply to a limited number of other subjects, such as modern foreign languages). A common characteristic of the subjects is the extent to which there is high demand from other employers for the skills – for example, high levels of numeracy, and strong analytical and problem-solving skills – that graduate teachers in these subjects are likely to possess.

2.42 The most recent OFSTED subject teaching reports revealed that:

- "[In mathematics] there are insufficient teachers to match the demands of the curriculum in one school in eight, a situation that has deteriorated from the previous year."
- "[In science] the shortage of physical science teachers is having a negative impact on the quality of teaching and management in a substantial number of departments."
- "[In Design and Technology] the shortage of specialist teachers, particularly for food technology and for systems and control, is now acute, especially in some parts of the country, and is depressing pupils' attainment."

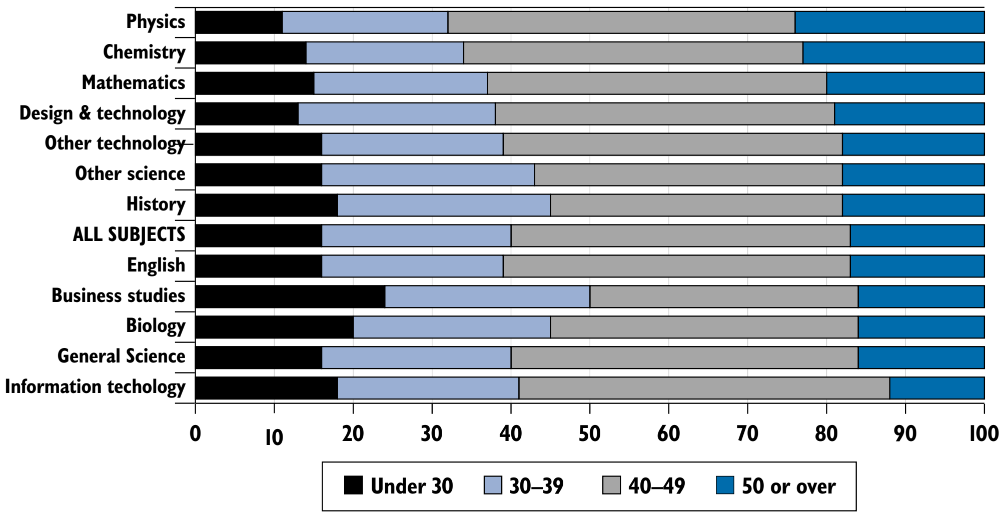
2.43 Analysis of data on vacancies as a percentage of teachers in post[51] confirms that shortages in teachers of mathematics (in particular) and science, D&T and ICT are more acute than for many other subjects. A survey by Smithers and Robinson (2000) found that head teachers had most difficulty filling posts in mathematics, physics and chemistry (and a limited number of other subjects). These shortages apply across the country but are particularly acute in London, where the high cost of living and perceptions of classes being more difficult to teach are seen as particularly off-putting factors. The Government only sets targets for science teachers, overall, and not for teachers of biology, chemistry and physics. As a result, the published shortages mask even more acute shortages in the physical sciences.[52] There is a growing trend of using biological science graduates, who are in more plentiful supply, to teach physics and chemistry.

[51] Source: DfES.

[52] A survey carried out by Smithers and Robinson (DfEE Research, University of Liverpool), in September 2000 indicated that school heads were experiencing particular difficulties in recruiting teachers capable of teaching physics and chemistry at higher levels.

2.44 International comparisons suggest that while other countries experience shortages of science and mathematics teachers the position in the UK is worse. Furthermore, these teacher shortages in mathematics, physics, chemistry and D&T could well worsen over time, since as shown in Figure 2.13 teachers whose main qualification is in these subjects tend to be older than their counterparts in other subjects.

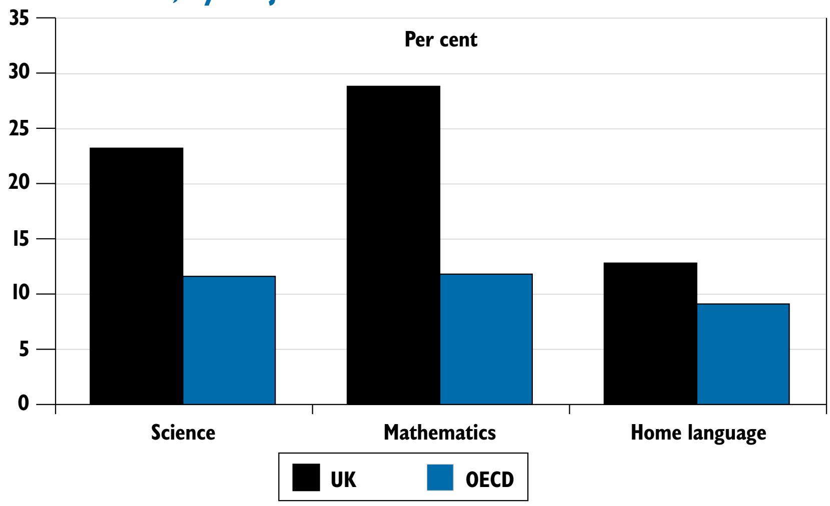
Figure 2.13: Teacher demographics by discipline



Source: 1996/97 Secondary Schools Curriculum and Staffing Survey.

2.45 Teachers shortages can adversely affect pupil performance. Figure 2.14 shows the proportion of head teachers who believe that a shortage or inadequacy of teachers is hindering the learning of pupils in different subjects either 'a lot' or 'some'.

Figure 2.14: Proportion of schools in which teacher shortages/ inadequacy are adversely affecting pupils' performance, 'a lot' or 'some', by subject



Source: OECD (2002) Programme for International Student Assessment PISA.

Teacher recruitment and retention

2.46 Teachers working in maintained schools in England must hold Qualified Teacher Status (QTS), which is usually obtained through completing Initial Teacher Training (ITT). There are three main routes for achieving QTS: as part of an undergraduate degree (mostly used for primary school teachers); through a postgraduate training course, often combined with study for a Postgraduate Certificate in Education (PGCE); or – for people over the age of 24 – via employment in schools on the Graduate Teacher Programme or (for those without a first degree but with two years' study in higher education) the Registered Teacher Programme. About 200 people enter science and mathematics teaching each year through either the Registered or Graduate Teacher Programme compared to over 4,000 entering through ITT.

2.47 Most postgraduate trainee teachers in England on an eligible ITT course will receive a £6,000 training bursary. An additional £4,000 is available for eligible postgraduates who go on to teach in shortage subjects in England,[53] and some further training awards are available to secondary school teacher trainees in shortage subjects based on financial need.[54]

2.48 These incentives have had an effect but, as Table 2.4 illustrates, there are still considerable difficulties in recruiting maths and science graduates to teaching. These figures, relating to those entering initial teacher training in 2001, are more encouraging than for previous years, and reflect the new measures (referred to in the previous paragraph) introduced to try and address teacher recruitment difficulties in shortage subjects. Nevertheless, significant numbers of mathematics and, to a lesser extent, science teacher places remain unfilled – a situation that has remained unchanged since the early 1990s.

Table 2.4: Targets and actual recruitment for Initial Teacher Training in England, 2001

Subject	Actual recruitment	Target	Percentage of target met
Mathematics	1,546	1,940	80
Modern languages	1,692	2,050	83
Science	2,591	2,810	92
History	922	900	102
English & drama	2,229	2,160	103

Sources: Recruitment – TTA ITT trainee number census, 2001; Targets – DfES.

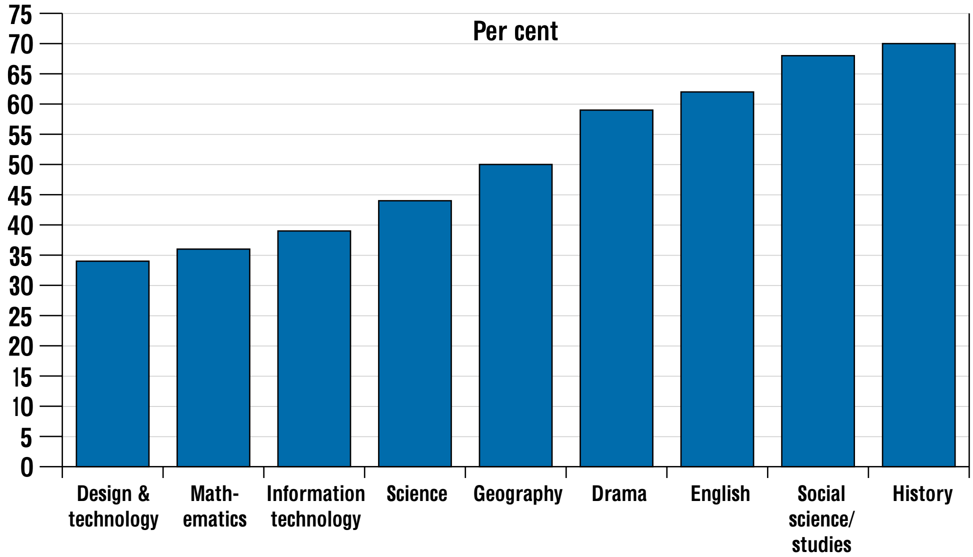
[53] This additional £4,000 is available for eligible postgraduates teaching mathematics, science, English, modern languages, design and technology or ICT in England. It can be claimed by those successfully completing induction within five years of the start of the first academic year after gaining Qualified Teacher Status and, within 12 months of completing induction, working in a relevant teaching post in the maintained sector.

[54] These awards are for secondary school teacher trainees on undergraduate and postgraduate ITT courses studying one of the following subjects: mathematics, science, modern foreign languages, design and technology, information and communications technology, religious education, music or geography. Maximum payments in any one year are £5,000 (£7,500 for those aged 25 or over). These maximum amounts are only awarded in exceptional circumstances and there is no automatic entitlement to any level of payment.

2.49 It is also important to consider the small but growing number of mature entrants to teaching and returners to the teaching profession. Given the relatively small number of graduates in mathematics and the physical sciences, late entrants to the teaching profession in these subjects are likely to become increasingly important. In this context, the Review supports the Government's "Welcome back bonus" for teachers returning to the profession. Teachers returning in a shortage subject such as mathematics receive £1,000 shortly after returning, plus £3,000 around a year later.

2.50 Alongside shortfalls in numbers, the data also suggest clear differences in the pool of recruits attracted to teaching different subjects. Figure 2.15 presents data relating to the proportion of recruits to Initial Teacher Training with a degree class of 2:1 or better. Whereas nearly 70 per cent of applicants to teach history achieve this standard, the proportion of maths and D&T applicants with a similar level of qualification is roughly half this. There is no necessary link between degree class and ability as a teacher (there are, for example, highly-qualified scientists and mathematicians who have poor communication skills and who would find it difficult to teach their subject well).[55] However, this chart clearly suggests that teaching is not attracting the same pool of talent in mathematics, D&T, science and ICT as it is in many other subjects.

Figure 2.15: Proportion of entrants to Initial Teacher Training with a 2:1 or better in their first degree, 2000



Source: Graduate Teacher Training Registry.

Teacher retention

2.51 Retention of qualified teachers is just as important as recruitment onto ITT courses. Evidence to the House of Lords Select Committee on Science and Technology – supplied as part of their review into science in schools – revealed that 30-40 per cent of newly qualified science teachers leave the profession within five years of joining, which is believed to be higher than other subjects

[55] It may be, however, that those teachers with a third class degree or lower, may benefit from more subject-specific Continuing Professional Development (CPD) than those receiving, for example, a first class degree.

(although data are not available to support this comparison directly). Reasons given by teachers for leaving, and the main factors that would need to be addressed to tempt them back, are: heavy workloads; poor pupil behaviour; low salaries; and what they view as an excessive number of government initiatives.

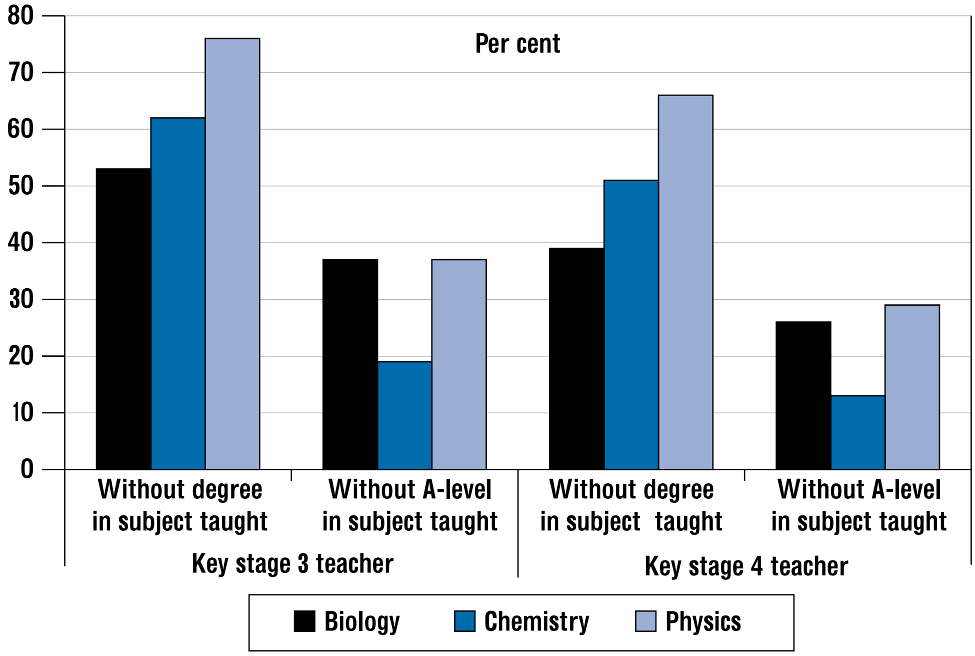
Subject specialisation in science teaching

2.52 The Review's consultation revealed widespread concern over the effect of teachers teaching areas of science that were not covered in their degree programme (for example, a biological science graduate teaching physics). In particular there is concern that the dwindling numbers of physical science graduates are feeding through into a falling number of teachers with a background in the physical sciences.

2.53 The introduction of the double award science course at GCSE has increased the phenomenon of science teachers teaching outside their area of expertise, since schools often prefer this to losing continuity in the classroom.[56] Recent work by the Council for Science and Technology shows the extent of this problem.

2.54 Since most science degrees tend to be in a single science (e.g. chemistry), and yet graduate teachers are often expected to teach across the science, it is expected that around two-thirds will not have a degree in the subject taught. However, Figure 2.16 shows over 75 per cent of the teachers teaching physics at Key Stage 3 did not study for a physics-oriented degree. This is substantially higher than the equivalent proportions for those teaching

Figure 2.16: Proportion of teachers of physics, chemistry and biology without qualifications in the subject



Source: Council for Science and Technology.

[56] Concern has also been expressed in D&T regarding a perceived inadequacy in the subject-content training element of ITT.

chemistry or biology. Furthermore, nearly 40 per cent of the teachers teaching physics at Key Stage 3 do not have an A-level in physics. This is similar to biology, but roughly double that for chemistry (reflecting the fact that, historically, many students studying physics or biology at A-level would also have taken chemistry – viewing it as a 'neighbouring' science, as well as a qualification which is a necessary requirement for entry to many biological science and medicine degree courses).

2.55 At Key Stage 4, there is slightly more subject specialisation, although nearly 30 per cent of those teaching physics do not have an A-level in the subject.

2.56 It is important to stress that science teachers may well be able to teach science outside their area of scientific expertise. Indeed, many currently do so and perform well. Such arrangements are essential given difficulties in the supply of teachers of the physical sciences. However, teachers are most likely to have an inspirational effect on pupils when teaching interests them most. The shortage of teachers with a background in physics and chemistry is likely to result in a vicious circle of fewer students choosing to pursue these subjects at a higher level and in turn, fewer teachers being available to inspire the next generation of students.

2.57 However, if science teachers are expected to teach outside their area of expertise, the importance of comprehensive cross-subject training as part of the ITT Programme – and the availability and uptake of subject-specific Continuing Professional Development – cannot be overestimated.

2.58 The Review consulted newly-qualified science teachers on the amount of support they were given during their ITT programme to teach outside their specialist area. The overwhelming view was that the amount of training and support provided was insufficient to improve significantly their confidence in teaching science outside the scope of their degree (particularly at Key Stage 4). Given the dominance of biological science entrants to ITT, the subject-specific training elements of ITT must be addressed if schools are to generate students wanting to study the physical science at university.[57]

Recommendation 2.4: Secondary school science teachers' training

The Review recommends that in order to enhance the quality of teaching across the sciences – and in the physical sciences in particular – the Government should act to improve significantly the subject-specific training and support given to science trainee teachers on initial teacher training and other teacher entry programmes. Furthermore, the Government should review, in three years' time, the progress made in improving secondary school teachers' confidence in teaching all areas of the science curriculum, and take further action as necessary.

The Review also recommends that in recruiting science graduates the Government should pay more attention to their areas of specialism (e.g. physics, chemistry or biology) to ensure an adequate supply of teachers able to teach the individual sciences (particularly physics and chemistry) at higher levels.

[57] Independent schools often avoid the above problems through keeping the individual sciences separate, even if their students take the double award science.

Improving the supply of science, mathematics, ICT and D&T teachers

2.59 The Review acknowledges that views of managing the delivery of teaching are being updated. In a speech to the Social Market Foundation last November, the Secretary of State for Education and Skills initiated a debate on the structure of the teaching profession – covering issues such as: the role of adults in the classroom and beyond; what teachers should and should not do; and the use of ICT. Through this debate the way in which the demand for fully qualified teachers is assessed is likely to evolve.

2.60 Nevertheless surveys of those entering teaching – or those who decided against entering teaching – identify a number of reasons that act to deter students from teaching. As shown in the table below, by far the main factor in deterring potential physics teachers is pay, with pupil behaviour a clear second. Amongst those not in teacher training, the intellectual challenge, lack of career prospects and the public perception of teachers also rank highly, although all are dwarfed by the issue of pay.

Table 2.5: Deterrents to teaching

	Trainee Teachers		Other students	
Issue	**rank**	**per cent**	**rank**	**per cent**
Pay	1	22.4	1	36.8
Pupil behaviour	2	13.7	2	22.8
Intellectually inferior	13	1.1	3	8.8
Public perception / status	=4	10.9	=4	7.0
Lack of career prospects	11	1.6	=4	7.0
Government interference	6	4.4	6	3.5
Stress / hard work	3	11.5	=7	1.8
Training problems (e.g. money)	=4	10.9	=7	1.8
Lack of confidence in teaching	10	10.2	=7	1.8

Source: Supply, recruitment and retention of physics teachers, Constable, Howson, Bolden and Spindler, TTA.

2.61 If the Government is seriously to address the recruitment and retention of teachers, action is required on a number of fronts. However, the review believes that this is most critical in two particular areas, namely teachers' remuneration and the need for Continuing Professional Development (CPD), which are considered in more detail below.

Teachers' remuneration

2.62 From 1 September 2002 teachers in maintained secondary schools will be paid on a new salary scale, on which most teachers will progress from £17,268 to £25,746 within six years, after which they will apply to pass a performance threshold (if successful, moving to a new pay scale of £27,894 to £32,250) or move to a different pay scale (for example, by becoming a head of department, or becoming an Advanced Skills Teacher).[58] One of five management allowances ranging in value from £1,593 to £10,275 may be awarded in addition to pay scale points to heads of department and other teachers with management responsibilities. The most senior teachers become assistant or deputy head teacher or head teachers on the leadership pay spine with a maximum of over £85,000.

2.63 Although in principle schools have considerable freedom over the pay of their teachers, few tend to vary significantly from the traditional pay scales and progression routes. Schools are also able to use recruitment and retention allowances – of between roughly £1,000 and £6,000 – to attract and keep key members of staff. At present, around 3 per cent of teachers receive such an allowance (rising to around 12 per cent for teachers in London). There are further graded allowances for staff living in Inner, Outer, and 'Fringe' London (of around £3,000, £2,000 and £1,000 respectively), reflecting the higher costs of living in and around London.

2.64 The Government has also gone further in seeking to target additional remuneration on teachers of shortage subjects. Specifically, trainee teachers in shortage subjects (which include mathematics and science) are offered golden hellos, worth £4,000. The Government has announced that teachers in shortage subjects will also benefit from having their student loans written off over a period of time. This would further increase the effective salaries of science, mathematics, ICT and D&T teachers, potentially by up to around £1,500 per year for the first ten years. The box below explains how the scheme for paying off student loans would work.

Writing off student loans

The Government is currently legislating to enable teachers in shortage subjects to have their student loans written off over a period of up to 10 years.[59] The shortage subjects for schools and further education establishments include mathematics, science, design and technology, ICT, engineering and construction. This would potentially be worth £11,715 spread over 10 years to a student with the maximum student loan who studied outside London, or 33 per cent more (around £1,500 per year) if the student had been on a four year degree, in a physical science for example. This inducement will have less impact on those students who did not take out loans or who have worked during their vacations to support themselves through university, and as a result have little debt. (However, training bursaries, golden hellos and other incentives will, of course, influence their decision making).

[58] The Advanced Skills Teacher (AST) grade was introduced in 1998 and offers a new career route with an enhanced salary scale (up to £46,000 a year) for excellent teachers who do not wish to take up management posts. ASTs continue to work mainly as classroom teachers but also spend time working with teachers in their own and other schools to raise teaching and learning standards. To qualify for an AST post teachers have to pass a rigorous assessment process. Schools receive a grant jointly funded by the DfES and the Local Education Authority to cover the additional cost of creating an AST post.

[59] The loans can either be general subsistence loans or mortgage loans, this box focuses on the former.

2.65 Finally, the Government has introduced two other measures to try improve the career progression of the 'best' teachers, or those considered to have the most potential: the Fast Track[60] and the Advanced Skills Teachers Scheme. To the extent that higher rates of training bursary, golden hellos and the writing off of student loans succeed in attracting more and better qualified science and engineering graduates to teaching, their career prospects and incentives can be improved through fast-tracking and other performance incentives. The Review encourages the Government to evaluate the impact of these recent and varied incentives to enter and remain in teaching, including the student loan write off once that policy becomes operational in autumn 2002.

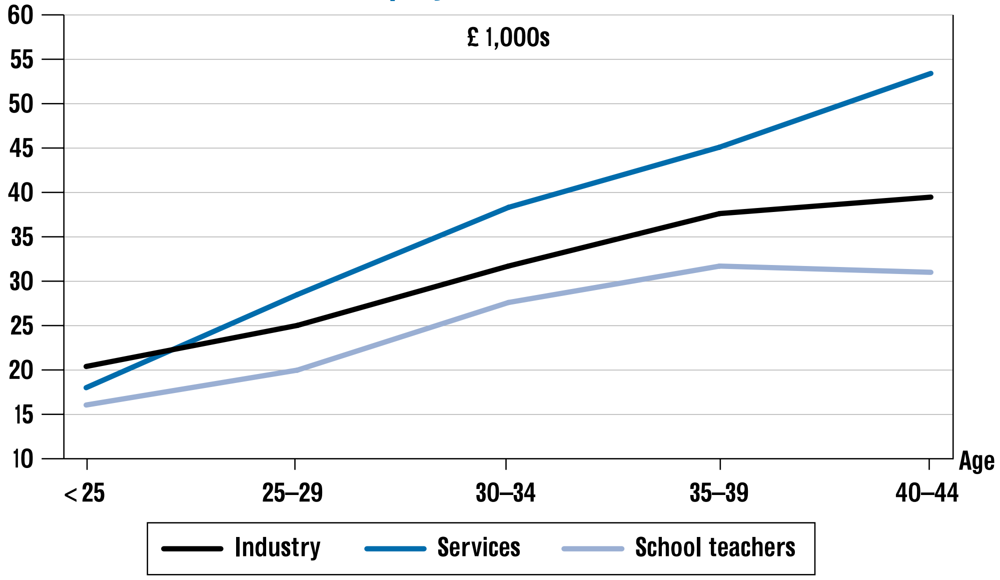
The effect of remuneration on teacher recruitment

2.66 The chapter has set out the structure of teachers' pay and the additional measures the Government has introduced to try to turn teaching into a 'career for the ambitious' and to address the particular shortages in subjects such as mathematics and science. These measures have begun to have an effect, with increasing numbers choosing to enrol on ITT courses. However, recruitment targets in mathematics and science are still being missed and the serious shortages in teachers of these subjects persist.

2.67 Figure 2.17 shows that physics teachers earn considerably less than they could in other sectors of employment. Based on a survey of its members, the Institute of Physics (IoP) estimates that, over their working lives, physics graduates choosing to teach would forego an average of £350,000 compared to their likely earnings in other jobs. Figure 1.7 in Chapter 1 also sets out the fact that physics (and mathematics, chemistry, ICT and engineering) graduates could expect to earn a significant premium above the average salary, of between 15 and 20 per cent. This helps to explain why the salary available as a teacher may appear less attractive to graduates of these disciplines than of others.

[60] Now in its second year of recruitment, the Fast Track Programme currently takes in around 100 applicants a year, with growth planned to take in several hundred per year in the near future. It aims to identify and develop individuals with the greatest leadership potential and is aimed at those who will become part of the senior management team of a school or an advanced skills teacher. In the first year, only new entrants to the teaching profession were eligible, but it has now been extended so that existing teachers can also apply. The long term aim is for 5% of the teaching profession to be on (or to have been through) the Fast Track scheme. Those on the Fast Track join the pay scale around £1,500 higher than normal, and receive an additional £5,000 bursary if they are new entrants to teaching. They progress up the pay scale at twice the speed – meaning they reach around £26,000 within three years (excluding additional allowances).

Figure 2.17: Median salaries of male physics graduates in different sectors of employment, 2001[61]



Source: Institute of Physics.

2.68 The issues surrounding the pay of science and mathematics teachers (and of other teachers whose skills are in very high demand elsewhere in the economy) also, of course, exist in many other countries. The box below sets out one innovative scheme in the US that is being used to address shortages in the supply of scientists and engineers.

North Carolina – Teacher shortage initiative

In North Carolina, teachers of mathematics, science or special education at middle and high schools with more than 80 per cent of pupils eligible for free or reduced school meals or with more than half of all pupils achieving below certain levels in mathematics and science, are eligible for annual bonuses of $1,800.

These additional pay incentives form part of a wider package aimed at improving the science and mathematics performance of underachieving pupils.

2.69 This analysis leads to the following recommendation, which the Review belives is important for the future supply of scientists and engineers in the UK.

[61] Data for women have been removed since the data are relatively volatile.

Recommendation 2.5: Teachers' remuneration

The Review recommends that, to solve the serious shortages in mathematics, science, ICT and D&T teachers, more must be done to address the pay and other incentives offered to teachers in these subjects. The Government, schools and colleges must compete for graduates in these disciplines in the labour market by, amongst other measures, providing more attractive remuneration for teachers in these subjects, to better enable schools to attract graduates who can earn higher salaries in other sectors of the economy. This will require head teachers and governing bodies to pay teachers in shortage subjects more than other teachers, which is the more economically efficient response to shortages in supply.

The Review therefore recommends that the Government tackle such recruitment and retention problems through increasing the remuneration offered to teachers of these shortage subjects – and also that head teachers and governing bodies use all the pay flexibility at their disposal. Furthermore, the Review recommends that this additional remuneration be linked – wherever possible – to teachers' take-up of CPD activities and opportunities, thereby rewarding those teachers who make particular efforts to improve further their subject knowledge and teaching style.

Continuing Professional Development

2.70 CPD is vital for all teachers, but especially for teachers in science and technology, who must stay abreast of technical and scientific progress in order to capture pupils' interest through engaging them in contemporary scientific issues. Teachers with knowledge of the latest developments in the sciences are better able to interest science and engineering students in these subjects and enthuse them to study the subject at a higher level. CPD is also an important element of the professional package that teachers should expect from their employer – in particular, giving them the ability to stay in touch with their specialist subjects. CPD is therefore important as a recruitment and retention mechanism and as a means of improving teaching quality.

2.71 When questioned by the House of Lord Committee on Science and Technology, Estelle Morris (in her then role as Minister for School Standards) agreed with the argument that science teachers require considerable CPD to stay at the forefront of science and technological progress:

> "I can quite see that scientists might make the case that their content knowledge changes and needs updating more than content knowledge elsewhere. I do not think I can argue with that."

2.72 As with their counterparts in primary schools, the Council for Science and Technology revealed that the secondary school science teachers at Key Stage 3 and Key Stage 4 had less confidence in teaching the physics elements than the biology and chemistry elements. Teachers' levels of confidence were found to be strongly correlated to the highest level of qualification that the teacher had in the subject. Teachers' confidence and understanding are important influences on the achievements of their pupils. These lower levels of confidence are therefore important factors in the decline in numbers of students choosing to study the physical sciences at higher levels. The House of Lords Committee[62] also concluded that teachers often lacked the confidence and knowledge to conduct experiments safely – an issue that needs to be addressed through CPD.

2.73 Public funding up to £500 is available for teachers in their fourth and fifth years of teaching to spend on a wide range of CPD activities. Schools can also pay for teachers to undertake voluntary CPD at weekends or during school holidays, although take-up of these opportunities is low at present. Teachers also get receive five days of INSET (In-Service Education and Training) during their conditioned hours of work. However, the House of Lords Select Committee on Science and Technology noted in their report on science in schools that, in their view, the majority of teachers are rewarded only very infrequently for undertaking CPD – in contrast with how CPD is viewed and used in a number of other countries. For example, in Canada science teachers can receive additional pay for engaging in project work alongside a local university.

2.74 In this context, the Review welcomes the Government's strategy to boost CPD, as set out in Learning and Teaching: a strategy for professional development launched on 1 March 2001. This puts increased opportunities for professional development at the heart of school improvement.

Recommendation 2.6: Secondary school teachers' Continuing Professional Development (CPD)

The Review recommends that the Government improve science teachers' access to, and take up of, subject related CPD, which will benefit their teaching and also act to improve retention. In particular, the Review recommends that all science teachers be incentivised to undertake CPD, and that the range of recognised CPD activities be as broad as possible. For example, it should include the possibility of participating in scientific research carried out in industry and universities. The Review welcomes the Government's commitment to a National Centre for Excellence in Science Teaching. It also notes the interest of the Wellcome Trust and hopes that the Government and the Trust can form the sort of partnership that has been so fruitful in other areas of science policy.

[62] House of Lords Select Committee on Science and Technology, First Report, 14 March 2001.

The teaching environment

2.75 Pupils' learning experiences are influenced not just by the teacher but also by the environment in which subjects are taught. There are a number of factors that influence the quality of the teaching environment. The consultation process identified three factors as particularly important for science and D&T:

- the quality of the laboratory and associated scientific and technical equipment;
- the support provided by laboratory technicians; and
- the support and guidance that pupils have in carrying out practical work (with particular reference to the adverse effect of high pupil-to-teacher ratios).

School science and D&T laboratories

2.76 Science and D&T laboratories and equipment are vital to pupils' education in these subjects – both in directly educating pupils about areas of science and technology and in interesting them and enthusing them to study these subjects further. However, it is widely considered that the standard of many school laboratories[63] in England has failed to keep up with the pace of scientific and technical progress, and many school laboratories have failed to receive the investment crucial to providing positive experiences for pupils.

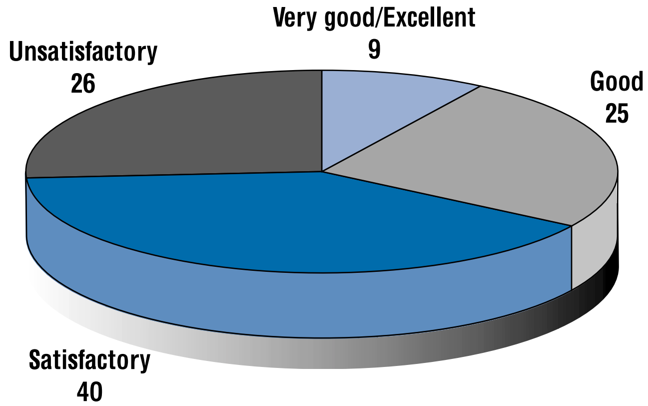
2.77 Recently, increased investment in schools more generally[64] has been coupled with specific investment of £60m over two years (2000/01 and 2001/02) aimed at rebuilding or modernising some laboratories that were in desperate need of improvement. However, although there are good examples of modern and well equipped laboratories, a substantial proportion of school laboratories are not satisfactory environments in which to teach science or design and technology. Nor do they often have suitable IT equipment to enhance the quality of the learning experience.

2.78 Regrettably, a full assessment of the state of school laboratories in England is not available since the data are not collected centrally. However, information gathered from OFSTED inspections suggests that around one-quarter of school science laboratories are 'unsatisfactory' for teaching science, and that only slightly more than a third provide a 'good' or 'very good' environment. This situation is comparable to the state of D&T laboratories, but is significantly worse than the state of accommodation used in nearly all other subjects.

[63] In this section the term 'laboratories' is intended to include scientific and technical equipment in the actual laboratory.

[64] In 1996/97 capital spend on schools (excluding IT) was £683 million. In 2002/03 it is £2.8 billion and in 2003/04, it will be £3.5 billion. These greatly increased levels of funding have allowed the most urgent repairs to be addressed, though not all the backlog is yet eliminated. However, the balance of investment is turning from patch and mend repairs to modernisation and suitability needs, including those of school science and D&T facilities.

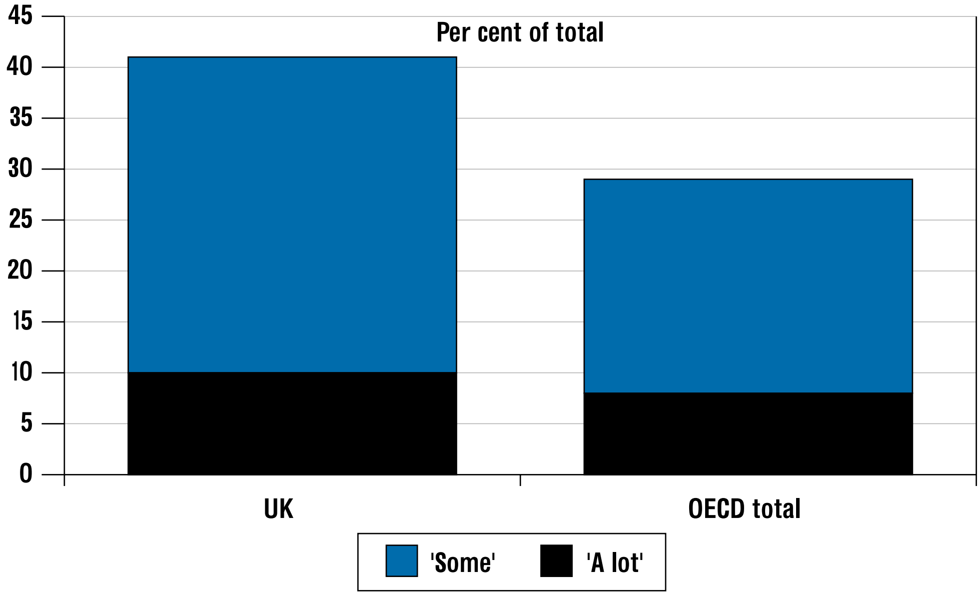
Figure 2.18: Adequacy of school laboratories, 2000/01



Source: OFSTED.

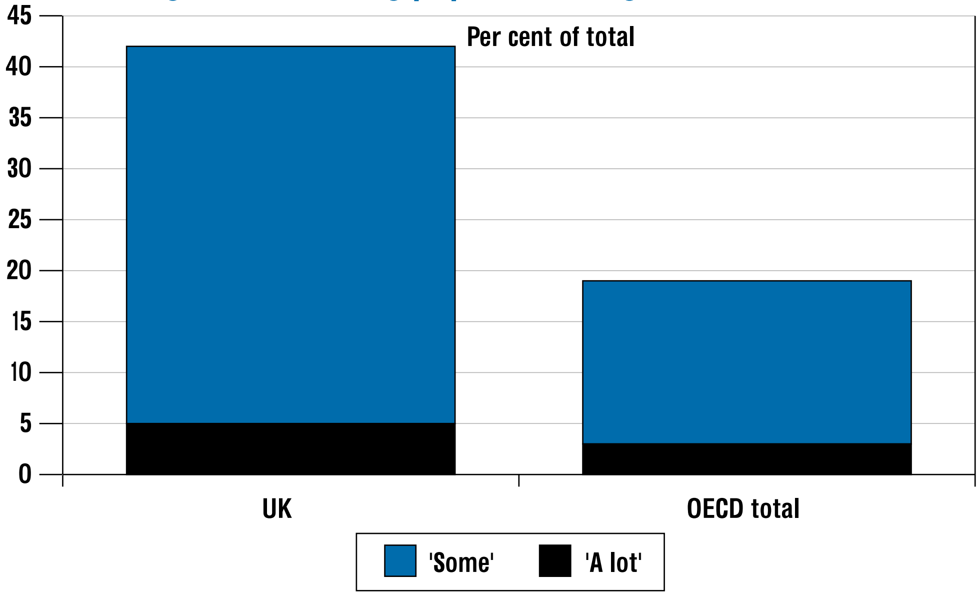
2.79 Information compiled by the OECD also suggests that the learning experiences of pupils in the UK may be hindered by the state of science equipment and buildings relative to other countries (Figures 2.19 and 2.20).

Figure 2.19: Proportion of schools in which inadequate science equipment is hindering pupils' learning



Source: OECD (2002) Programme for International Student Assessment PISA.

Figure 2.20: Proportion of schools in which inadequate buildings are hindering pupils' learning



Source: OECD (2002) Programme for International Student Assessment PISA.

Recommendation 2.7: School laboratories

School science and D&T laboratories are a vital part of pupils' learning experiences in these subjects, and should play an important role in encouraging pupils to study these subjects at higher levels. However, it is clear that for many pupils this is not the case. To address this, the Review recommends that the Government and Local Education Authorities prioritise school science and D&T laboratories, and ensure that investment is made available to bring all such laboratories up to a satisfactory standard (as measured by OFSTED) by 2005. Furthermore, the Review recommends that these laboratories should be brought up to a good or excellent standard (again, as measured by OFSTED) by 2010: a standard which is representative of the world of science and technology today and that will help to inspire and motivate students to study these subjects further. The Government should take all appropriate steps to ensure that these targets are met.

Science and D&T technicians

2.80 Science and D&T technicians perform vital roles in the department(s) in which they work – enabling the teachers to teach and the pupils to learn. Common areas for which technicians take responsibility include:

- preparing equipment and laboratories for practical classes;
- maintaining technical and scientific equipment and laboratories;
- ensuring teachers and students can teach and learn in a safe environment, through considering health and safety issues;
- directly supporting teachers in their practical classes, including assisting pupils to get the most out of experiments; and
- administrative and other functions underpinning the smooth running of the department.

2.81 However, schools find it difficult to attract and retain technicians, due, primarily, to the pay and career structure available to technicians in schools and colleges. Recently, a report by The Royal Society and the Association for Science Education made a number of recommendations aimed at improving students' education through improving the career structure of science technicians.[65] These recommendations included:

- creating best practice guidance on the management and deployment of technical staff;
- establishing proper career and pay structures for technicians; and
- providing technicians with greater opportunities and funding for CPD, and more recognition of the skills and knowledge obtained both prior to joining, and through ongoing CPD.

2.82 The Review agrees wholeheartedly with the thrust of the Royal Society report. Science and D&T technicians have a vital role to play in underpinning and directly improving pupils' learning experiences in science and D&T. The Review therefore welcomes the Government's commitment to take forward the work coming out of this report. This should include giving technicians access to the National Centre for Excellence in Science Teaching.

Teaching assistants

2.83 The report has already commented upon the crucial role that practical work can have in improving pupils' knowledge and understanding of science and D&T, and in enthusing them to study these subjects at higher levels. Pupils' experiences of practical work are determined by the quality of the equipment and the laboratory, but also by the support, teaching and supervision they receive during the practical work.

2.84 Practical classes can be difficult to supervise and teach. Supporting the pupils in carrying out practical work can be intensely demanding for teachers. The pupil-to-staff ratio is crucial and the relatively high pupil-to-staff ratio seen in schools in England may diminish the quality of pupils' experiences of practical work, and of science and D&T more generally.

2.85 Data from OFSTED school inspections reveal that the median science class size at Key Stage 3 in England was around 29.5, with a teaching assistant present in around one-quarter of these lessons (generally to support pupils with special educational needs). At Key Stage 4, the median double award science class size was found to be around 25, with a teaching assistant present in around 15 per cent of lessons.

[65] Supporting success: science technicians in schools and colleges, Royal Society and Associations for Science Education, 2002.

2.86 This compares unfavourably with the situation in Scotland and Northern Ireland, which have statutory limits on the size of science classes. In Scotland, for example, no more than 20 pupils are allowed in a practical class, allowing the teacher to give each pupil more time and support.

2.87 There are a number of ways in which education in Scotland differs from that in England, and a number of factors other than pupil-to-staff ratios affect the desire of pupils to pursue study and careers in science and engineering (including the supply of science and mathematics teachers and society's attitudes to science and engineering more generally). However, it is interesting that whereas 5.8 per cent of all entrants to higher education in the UK come from Scotland, 8.9 per cent of entrants for medicine come from Scotland, 7.4 per cent in the biological sciences, 6.4 per cent in the physical sciences and 9.3 per cent in engineering. It is therefore clear that, over and above sending a higher proportion of students to higher education, Scottish students are more inclined to study science and engineering courses than their counterparts in England. (It is no surprise, therefore, that shortages of scientists and engineers in Scotland seem less acute than in other parts of the UK). The same is also true for independent schools, which also tend to have lower pupil-to-staff ratios.

2.88 A number of schools address these issues by encouraging science and D&T technicians to act as teaching assistants, which can provide technicians with valuable and interesting work. Others invite postgraduate and sometimes undergraduate students into the classroom to assist the teacher in a number of ways, including providing an extra pair of eyes, ears and hands to help support pupils in their practical work. An additional advantage is that teachers often find that an external presence makes it easier for them to teach, with fewer cases of poor pupil behaviour disrupting lessons.

2.89 The higher education sector is also becoming more proactive in helping schools in this area. One scheme which supports postgraduate students' involvement in science teaching in schools is the Researchers in Residence scheme.[66] In addition there are a number of voluntary, unpaid initiatives to encourage undergraduate students to assist the teaching of science in schools.

2.90 The Government has also sought to encourage scientists and engineers working in business, higher education and elsewhere to support students' learning experiences in science, engineering and technology, through the Science and Engineering Ambassadors Programme.

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[66] The Researchers in Residence scheme is run by a number of the Research Councils and the Wellcome Trust, in collaboration with Sheffield Hallam University, and allows researchers working on a PhD to make a contribution to making school science more relevant and exciting for young people. The researchers can support the teaching of science in many ways – helping with anything from projects and practical work to careers advice for the students – as well providing excellent role models for the students. The exact role of the researcher is decided by the researcher and the school.

Science and Engineering Ambassadors Programme

This programme, launched in January 2002, is jointly sponsored by the Department for Trade and Industry and the Department for Education and Skills. It aims to encourage scientists and engineers to help in schools to:

- assist teachers to deliver the school curricula;
- run out-of-school activities, such as Clubs, schemes, awards and competitions;
- mentor groups of students and teachers;
- address school and class groups;
- support work experience placements; and, crucially,
- act as role models.

The programme is not intended to replace the existing initiatives, such as the Researchers in Residence and Neighbourhood Engineers Programme that already take people into schools. The intention is to strengthen, expand and build on them by creating a national framework.

Recommendation 2.8: Teaching assistants

The Review is convinced that the high pupil-to-staff ratios in schools in England – particularly in practical classes – is having an adverse effect on the quality of pupils' science and D&T education, and in turn on the supply of science and engineering skills. The Review believes these high pupil-to-staff ratios in practical classes are best addressed through the employment of skilled teaching assistants acting to support the teacher, and that science and engineering undergraduates and postgraduates are well placed to support teachers in this way since they have a good recent understanding not only of the subject but also of the school environment. They can also provide important role models for pupils.

The Review therefore recommends that the Government establish a major new programme, paying undergraduate and postgraduate students to support science and D&T teachers. The scheme should be implemented alongside the Researchers in Residence scheme, and should be open to postgraduates as well as undergraduates. The Government should pay students on a competitive footing with other sources of employment open to them. The Government should set an ambitious target for the number of science and engineering students participating in such a scheme by 2005.

The precise role of the teaching assistants should be for schools, universities and the students to decide locally, on the basis of guidance from the Government. Examples of possible roles could be direct support to teachers in supervising practical work, giving demonstrations or supporting science and D&T technicians. Naturally, it will be important to ensure that those participating have the skills and training to work in these capacities.[67]

Courses and curricula

2.91 The content of subjects studied and the way in which the content is presented will naturally be an important influence on pupils' subsequent choices. There is widespread concern that science, in particular, is taught in a way that does not appeal to many pupils and that the curriculum places too much emphasis

[67] The Science and Engineering Ambassadors programme could play a useful role in facilitating this recommendation.

on rote learning rather than relating theory to situations relevant to the pupil. There is also considerable concern over a number of other issues related to the course content:

- the impact of health and safety guidelines on the nature of practical work in the classroom;
- the ease with which pupils can make the transition from GCSE to A- and AS- levels;
- the perception that mathematics and the physical sciences are harder subjects; and
- the availability and take-up of measures and schemes to enhance the curriculum.

Science curricula

2.92 There has been considerable change in the style and content of science courses in the last twenty years, particularly with the advent of the double award science GCSE and the move towards ensuring that science courses – particularly at Key Stage 4 – can appeal to all pupils. The box below summarises the current aims of the curricula, and sets out changes proposed by the QCA.

Aims of the science curricula

The QCA believes that the science curricula should:

- help young people to acquire a broad, general understanding of the important ideas and explanatory frameworks of science, and of the procedures of scientific enquiry, which have had a major impact on our material environment and on our culture in general;
- seek to foster a sense of interest in science so that young people feel confident and competent to engage with scientific and technical issues and phenomena that they encounter in everyday life;
- motivate an appropriate pool of pupils to study science after the age of 16;
- prepare pupils for further study on AS/A level GCE courses in science and science-related subjects; and
- prepare pupils for further study on vocational courses in science and science-related areas.

In order better to deliver these aims at Key Stage 4, the QCA has proposed that science education should be split into a number of modules:

- Core modules, which would prepare pupils to be consumers, rather than producers of scientific knowledge, and which, taken together, would lead to a compulsory Single Award in science; and
- Applied and academic modules in a range of science options, which would bring the pupil up to a double award (or a triple award it they take all of the academic options in biology, physics and chemistry).

These courses would be piloted in September 2003.

2.93 There have been many studies in recent years of the science curriculum and its role in enthusing pupils to study science at higher levels. These studies have drawn on the views of pupils, parents, teachers and others with an interest in this area.[68] Their conclusions, which were matched by concerns expressed in the Review's consultation, were that:

- pupils are sometimes 'turned off' science by what they see as excessive repetition and too much emphasis on the volume of scientific knowledge required at the expense of discussion of potentially more enjoyable and contemporary elements of science;
- too many pupils view the curriculum, particularly those areas related to for physics and chemistry, as lacking relevance to everyday life and to topical science stories appearing in the media, and that this lack of relevance was seen as a particular issue for girls;
- the emphasis on knowledge and lack of relevance makes it hard for pupils to make a link between what they learn and potential careers;
- the curriculum is overcrowded and assessment is based too much on memorisation and recall, which is unrepresentative of how science is used later in life; and
- there are insufficient links made between issues covered in science and those covered in mathematics, ICT and D&T (in particular), which makes it more difficult for the pupil to see the close connections between these subjects, both in terms of further study and future careers.

2.94 In addition, although it was not universally the view of respondents to the consultation, studies by the Council for Science and Technology[69] and others have indicated that additional breadth in 16-18 study (for example, on the International Baccalaureate model) would be valuable to all pupils, including science and mathematics-focused pupils.

2.95 A five-yearly standards report for the QCA found that the standard of A-levels had been maintained, although to compare the equivalence of modular courses is difficult. The nature of question papers has changed in the period 1975-1995, with the mathematical content of examination questions reduced to enable greater discussion. This approach has many advantages in aiding and testing pupils' understanding, but has given rise to some concerns within higher education about the depth of pupils' mathematical abilities. These are discussed in Chapter 3 in the context of undergraduate quality.

[68] A particular study is Pupils and parents' view of the School Science Curriculum, J Osborne and S Collins, Kings College London, 2000.

[69] Imagination and understanding: A report on the Arts and Humanities in relation to Science and Technology, Council for Science and Technology, July 2001.

Recommendation 2.9: The science curriculum

The science curriculum – particularly in the physical sciences – is not, at present, sufficiently approachable nor appealing to all pupils between the ages of 11 and 16. This is a significant factor in the declining numbers of students taking these subjects at higher levels, and is widely thought to be a particularly important factor in discouraging girls.

The Review therefore welcomes both the QCA's ongoing work to modernise the science curriculum[70] and the Government's Key Stage 3 strategy. These are important elements in making the study of science more attractive to pupils, and, in turn, helping to enthuse pupils to study science and related subjects at a higher level. The Review recommends that the Government ensure that these changes deliver significant improvements to the way that the sciences (particularly the physical sciences) are taught. In particular:

- improving the ability of all pupils to relate the science they study to the world around them and to potential career opportunities;
- encouraging appropriate links to be made with other subjects (particularly D&T);
- ensuring that, while pupils continue to study the fundamental principles of science, the curricula and assessments are not dominated unhealthily by reliance on the overall volume of scientific knowledge.

The Review notes that modernising the curriculum must go hand-in-hand with providing teachers with the necessary support and training to teach the new curriculum in a way that appeals to all pupils (especially girls).

The Review further recommends that the Government should review, in three years' time, the progress in improving the attractiveness and relevance of the mathematics and science curriculum, and take further action as necessary.

Finally, the Review welcomes the QCA's proposals for reforming GCSE science, which are a necessary and positive step in increasing the appeal of science to pupils. However, it will be important to support schools and colleges in dealing with what is likely to be a more varied intake to A- and AS-level courses, and enable pupils successfully to make the transition to A- and AS-level science.

Health and safety

2.96 There is a perception amongst some that stricter health and safety regulations have directly resulted in the dropping of some of the more exciting experiments from the school science curriculum. However, discussions with teachers and others have indicated that these concerns are unjustified, although many LEAs and schools themselves are being conservative in their interpretation of the H&S regulations. While, naturally, the safety of pupils and teachers must be paramount, it is notable that, at the margin, there are few incentives on schools and LEAs to include interesting experiments with even minimal and controllable associated risks that are not mentioned explicitly in the curriculum.

[70] The QCA project, Keeping School Science in Step with the Changing Needs of the 21st Century, arose out of QCA's review of the National Curriculum. It was in response to views that constant slimming of National Curriculum orders did not provide the opportunity to review the orders with a view to updating them and making them relevant to the times and the needs of the pupils.

2.97 The Government is well placed to monitor regularly the impact of H&S regulations in schools, and ensure that sufficient guidance and support is given to teachers to enable them to use practical work to best effect. The proposed National Centre for Excellence in Science Teaching could play a useful role here in helping teachers to feel confident in trying new and more interesting experiments.

Transition between GCSE and A-level

2.98 In recent years concern has been expressed about the difficulty pupils can have in making the transition from studying science or mathematics at GCSE and studying it at A-level or AS-level. This has focussed on claims that the double award science course does not provide adequate preparation for pupils to go on to advanced study since, with less curriculum time available than if the pupil studied for GCSEs in the individual sciences, less material is covered. To address this, around 10 per cent of schools and colleges make special provision to help pupils make the transition to A-level.

2.99 A review conducted by the QCA in 1998 found that pupils with a double award background achieved – on average – between one-quarter and one-half of an A-level grade less than their counterparts who took all three sciences at GCSE. However, this tended to be true also for subjects other than science and is therefore more likely to be an institutional effect (a large proportion of those taking individual sciences are in selective schools) than one specific to science.

2.100 In addition, the changes in Curriculum 2000 should have helped to address this. However, pupils consulted during the review thought that there was still a significant step change in the education between GCSE and A-level mathematics and science (particularly in the physical sciences), although they tended to be less clear as to whether this 'jump' was bigger than in other subjects. It is concerning that pupils worried about making the transition to A- and AS-level science may decide not to study science or mathematics, and that this may be contributing to a fall in the numbers taking these subjects. The effect of AS-mathematics in 2001 is an isolated case in point.[71]

Recommendation 2.10: Transition from GCSE to A-level

The Review welcomes the proactive approach of the QCA in considering the transition from GCSE science and mathematics to AS- and A-levels in these subjects. However, the consultation process revealed that the issue may not yet have been fully addressed and the Review therefore recommends that the Government give it further consideration, and take suitable action to allow pupils to make the transition from GCSE to AS- and A-level study – particularly in the physical sciences and mathematics – smoothly.

[71] In 2001, as a result of a tough course and exam, there was a significant rise in the number of students failing the AS-mathematics exam. As a result, there has been a fall in those applying to read mathematics at university (applications are down 12 per cent this year). The Government is rightly concerned about this and the Review welcomes the emphasis that it is giving to addressing these issues quickly.

Pupil ability and achievements in SET subjects

2.101 There is a widespread belief that mathematics and the physical sciences in particular are 'hard' subjects. Given that a key determinant of whether a student chooses to continue with a particular subject is their current and expected future level of achievement (people naturally like to play to their strengths) then it is crucial to establish whether or not these subjects are indeed 'harder' than others.[72] If mathematics and science are found to be harder (or thought to be harder) then this is likely to contribute to fewer pupils studying these subjects at higher levels.

2.102 It is important that these perceptions of mathematics and science as being harder are not needlessly developed early in pupils' education – for example at Key Stage 2, where pupils' achievements in mathematics currently lag those in English significantly. The Review therefore fully supports the Government's objective to bring the standard in mathematics up to that in English by 2004, to avoid creating, at an early stage, the perception that mathematics is more difficult than English, both in the minds of pupils and in the minds of teachers and parents.

2.103 This point also applies to the GCSE examination results. Here, too, there are continuing discrepancies in the achievements of pupils in different subjects. As Figure 2.4 illustrated, the proportion of pupils achieving grades A*-C in English significantly exceeds the proportion receiving these grades in mathematics and double award science.[73]

2.104 Comparisons of achievement in mathematics with achievement in history are perhaps not as fair as, say, comparisons between mathematics and English. This is because, for example, a pupil who does not enjoy or do well in history is unlikely to choose it as a GCSE option, whereas all pupils must take mathematics and English irrespective of their enjoyment and achievement in these subjects. The same is true of the double award in science – although to a lesser extent, because pupils struggling at that stage of their education will often take single award science, rather than the double award course.

2.105 There is on-going research on the relative difficulty of A-level and AS-level courses. This research, carried out through the ALIS Project based at the University of Durham, has suggested that some subjects are harder than others at A-level. Their research has enabled them to produce trend lines for each subject to allow prediction of A-level grades from the average GCSE performance of a candidate and to show that the prior achievement levels of the intakes to the various subjects are quite different. For example, the sciences, foreign languages and mathematics enrol, on average, higher achieving students than sociology, psychology or law.

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[72] In this discussion, one subject is defined to be 'harder' than another if – for a given level of effort by a student – their expected level of achievement in the first subject is lower.

[73] Since pupils in the independent sector often still take individual sciences at GCSE level rather than the double award science course, the group of all pupils taking history should not be directly compared to the group of all pupils taking the double award science.

2.106 The research shows that the average GCSE grade is a good indicator of general abilities and provides the best available correlations and, therefore, predictions.The trend lines are different for each subject, reflecting their relative degree of difficulty. It is shown that pupils with the same GCSE profile achieve on average one grade lower in chemistry, physics and mathematics than the average A level grade obtained. The most difficult subjects are: chemistry; physics; Latin; French; mathematics; and biology (roughly in that order). Clearly the trends have to be calculated each year on that year's data to provide fair comparisons.

2.107 Given that sciences and mathematics appear to be harder subjects, there is a concern that schools could, at the margin, be encouraging their pupils to choose non-science subjects in order to raise their position in the examination 'league tables'. There is little more than anecdotal evidence to suggest that this might be the case, but it is an issue which the Review urges the Government to bear in mind.

Recommendation 2.11: Difficulty of subjects

The Review welcomes the attention that the QCA has given to the issue of inter-subject standards, and urges the Government to undertake definitive research into the greater apparent difficulty of science and mathematics A-levels and to take appropriate subsequent action. It is essential that pupils have a broadly equal chance to achieve high grades in science and mathematics as they would in other subjects. Without this, fewer pupils will choose to study science and mathematics at higher levels. The Review is firm that arguments about the merits of 'levelling up' or 'dumbing down' are a distraction – if pupils generally find it more difficult to achieve high marks in science and mathematics, this needs to be corrected. The Review believes that this can and should be done without compromising the core knowledge and skills needed for studying science and engineering courses in higher education.

2.108 A number of organisations and individuals have been in favour of financially rewarding pupils who receive, for example, an 'A' grade in mathematics, physics or chemistry at A-level. There are examples of such payments encouraging more pupils to take up particular courses. However, many in the education profession strongly object to such drastic measures, believing that pupils should be able freely to choose their subject combinations without what they see as 'bribes'.

2.109 The Review is sympathetic to these concerns and views the best approach to encouraging more pupils to take these subjects as being to improve the quality of the educational experience. The Review does not therefore recommend introducing such a scheme at this time. However, given the importance of securing a strong supply of these skills to the UK economy, this approach may need to be revisited later.

Curriculum enhancement

2.110 Pupils' enthusiasm for SET subjects within the school environment can be kindled outside the classroom as well as inside it. Visits to science and discovery centres and science-related museums and other attractions can help pupils to link the knowledge gained in the classroom to contemporary science issues, and through this help to stimulate their interest. The Government has also sought to enhance science and mathematics courses through initiatives such as Science Year,[74] a UK-wide educational initiative aimed at 10-19 year olds and their teachers, parents and other members of their community. Science Year follows 'Maths Year 2000', which attempted to do the same for maths by popularising it with parents as well as pupils, and has been succeeded by 'Count on', a campaign seeking to continue the promotion of mathematics as an enjoyable and interesting subject.

2.111 Although the Government can play its part in enhancing the curriculum, the role of private organisations and businesses in enhancing pupils' learning experiences in science, technology, engineering and mathematics is vital. Businesses and universities are well placed to help pupils relate the latest scientific breakthroughs to what they are currently learning.[75]

2.112 At present, there are some 1,200 plus national schemes, awards, competitions and other forms of resources and materials, sponsored by companies and other organisations, to support science and engineering education in schools.[76] These independently-provided schemes, awards, competitions and visits offer potentially excellent opportunities for enthusing and educating pupils in the fields of mathematics, science, technology, engineering and ICT. In particular, such schemes can help pupils to make the link between the subjects studied in the classroom and the world around them. However, from discussions with representatives from schools and the organisers it is clear that the collective impact of these schemes is not as high as it should be. Teachers often have considerable difficulty in identifying and accessing the right scheme. Furthermore, they tend to overlap considerably, with the same pupils benefiting from each scheme rather than the schemes being more widely available to other pupils.

2.113 In its report Science Teachers: a report on supporting and developing the profession of science teaching in primary and secondary schools (February 2000), the Council for Science and Technology estimated that only 5 per cent of such resources are actually used by schools. The review therefore welcomes the initiative, involving SETNET,[77] the Engineering & Technology Board, and the AstraZeneca Teaching Trust, which is looking at these issues.

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[74] Science Year aims to:

- create access and encourage participation in science and technology;
- demonstrate the relevance of science;
- inspire partnership and enable organisations to work together effectively; and
- build ownership and vision and to create scientific links where they might not be expected to build for the future; both for young people and for society.

[75] The Government is seeking to use these schemes to ensure that over the three years to the end of March 2004, every child under the age of 16 should have the opportunity, at least once in each Key Stage, or the equivalent, to participate in an appropriate STEM activity.

[76] For example, the Engineering Education Scheme, CREST, the Neighbourhood Engineers Programme and Techniquest.

[77] See paragraph 2.114.

2.114 The Government has sought to help schools make the most of these independently provided resources through part-funding SETNET (Science, Engineering and Technology Network), which aims to act as an enabling interface between businesses and schools through its 53 branches ("SETPoints"). SETNET will coordinate the Science and Engineering Ambassadors Programme and seeks to help schools identify the independently provided schemes that are right for them. The local SETPoints are intended to work closely with the Government's local Education Business Links Consortia.

Recommendation 2.12: Enhancing the curriculum

The profusion of independent schemes aimed at enthusing and educating pupils in science and engineering (for example, the Industrial Trust Scheme and CREST), and the lack of support that schools and teachers have in identifying those most suited to their pupils, is inhibiting the collective effect of these schemes. The Review therefore recommends that the Government establish a single recognised channel through which schools access these independently-provided schemes. This will help schools and teachers to identify the schemes most suited to pupils at different ages in different subjects, thereby lowering the burden on teachers. Without better co-ordination (and rationalisation) of the existing schemes, important opportunities and resources will continue to be wasted.

The Review recommends that SETNET and its network of SETPoints, be given this responsibility in the areas of science technology, engineering and mathematics, while still recognising the wider role of the Education Business Links Consortia in England. However, if SETNET is to fulfil this function (and deserve the additional funding that this Review recommends the Government provide), it is important that it emphasises all areas of science and engineering equally, and also that those in the science, engineering, IT, technology and mathematics communities (particularly the scientific community) accept SETNET as the channel of communication. SETNET should work with the proposed idea of a National Centre for Excellence in Science Teaching in delivering this.

Other influences on pupils' subject choices

2.115 Two main influences, outside pupil's direct learning experiences, were identified in the Review's consultation as having a significant impact on pupils' decisions to study science and engineering at higher levels: the public and media perception of science and engineering and careers advice.

Public perception of science and engineering

2.116 Much has been said on the subject of the perception of science and engineering in the UK, with a common view being that scientists and engineers have a poorer image in the UK than in other countries. This could affect both the pupils directly, but also indirectly, through parents, teachers and friends.

2.117 Qualitative and quantitative evidence does indicate that the ideas held by people in the UK of the work carried out by scientists and engineers, and of their working environment, can be outdated. The stereotype of a scientist (possibly 'different' in some way, working away in a small room on their own) is often reinforced by portrayal in the media – particularly television and film. Equally, engineers fear that their image suffers through being confused with mechanics. It is also thought by many that science and engineering have been adversely affected by association with what some see as a declining manufacturing sector. This said, other countries face similar issues. In the most recent extensive survey of people's views of different professions,[78] it was found that engineers were more highly regarded in the UK than in France, Germany or any other European country.

2.118 Nevertheless, there is a widely recognised need to improve public understanding of science. There have been a number of initiatives by the Government and independent organisations with links to science and engineering. For example, Copus, the UK Partnership for Science Communication, can provide a valuable strategic focus for science communication in all its forms, to improve connections between science and public audiences. The new Media Centre at The Royal Institution will also have a useful role in this regard. Influencing the views of a significant part of the population can only be achieved in the medium to long term, and is best done through changing the reality, not just through communication.

2.119 Ultimately, changing perceptions of science and engineering requires scientists and engineers themselves, and the organisations in which they work, to take a lead in presenting a clear and positive picture of their work. The Government can assist, by helping to bring all those with an interest together, but ultimately it is those involved in the fields of science and engineering who must take the initiative. Given the extensive ongoing activity directed at improving the public perception of science and engineering the Review does not make an explicit recommendation on this issue. However, the Review believes that its recommendations for improving the reality of science and engineering careers will have a positive effect on the public perception of science and engineering.

Careers advice

2.120 Discussions with pupils, teachers and organisations with an interest in these issues have indicated that many pupils do not receive up-to-date or accurate advice concerning opportunities arising from studying science, technology, engineering and mathematics subjects. This should not be regarded as a general criticism of the careers service in schools, as there are countless examples of pupils receiving excellent careers advice. Nevertheless, it is apparent that some pupils are being put off studying SET subjects – for example, after gaining the impression that these subjects are essentially vocational (i.e. you only study science to become a scientist) and act to close doors rather than open them (i.e. if you study science you can follow careers only as a scientist).

[78] Eurobarometer 55.2, Europeans, Science and Technology, Eurostat, December 2001.

2.121 A study funded by the Wellcome Trust[79] found that "There was little recognition that a science qualification may be as valuable a generic qualification as one in mathematics or English." This is a serious issue, particularly given the increasing breadth of opportunity for scientists and engineers, for example in ICT-related jobs, and needs to be corrected as soon as possible.

2.122 Research and responses to the Review's consultation reveal that pupils tend not to make links between GCSE science and future careers. Pupils choosing science post-16 were mostly keen on the subject. (Although in a few cases the pupil knew of specific career – e.g. medicine – they wanted to do). Those who planned not to take science further said they had based their decisions on experience of science in the classroom. This is consistent with schools often encouraging pupils to choose subjects that interest them, rather than to think about where their subject choices would take them in the future.

2.123 There have been many studies into the effect of careers advice on pupils' choices. One of the most authoritative, Choosing Science at 16, NICEC Project Report, 2000, examined the factors influencing pupils' choices at 16 and found a range of problems in the way in which careers advice relating to science is delivered.

- Teachers often do not see themselves as a source of information or advice about careers in science and technology – not feeling able to keep up with careers information, and instead leaving it to the careers advisers, with whom they had very little direct interaction. The highly content driven science curriculum gave no time for wider-ranging discussion about current science issues and careers.

- There is insufficient co-ordination between advisers and science departments on activities designed to enhance pupils' awareness of opportunities in science-related areas, such as parents' evenings, conventions/industry days and joint training days for careers advisers and teachers.

- The majority of the careers advisers surveyed were graduates with a humanities or social science background. Only one in ten had science degrees, with none possessing physical science backgrounds. (Such non-scientists and engineers will need more support from teachers, businesses and others in advising on science and engineering careers, whereas in fact the study found both a lack of systematic training and of updating of occupational information available to advisers.)

- Schools find it hard to secure work experience places in science and engineering for Years 10 and 11 because of insurance and health and safety issues, and a lack of local science-based employers.

[79] Pupils and parents' view of the School Science Curriculum, Osborne and Collins, Kings College London, 2000.

Recommendation 2.13: Improving the perception of careers in science and engineering

The Review believes that further action is needed from the Government, but also from businesses and others in scientific and technical fields, to ensure that pupils (especially girls) receive accurate and positive advice about the rewards (and the breadth of careers arising) from studying science and engineering. Specifically, the Review recommends that the Government establish a small central team of advisers (possibly within the new Connexions service, but working closely with SETNET) to support existing advisers, teachers and parents in advising pupils. Furthermore, the Government should review, in three years' time, the progress in improving pupils' knowledge of the rewards and the breadth of careers arising from studying science and engineering, and take further action as necessary.

A vision for science, mathematics, D&T and ICT education in schools and colleges

2.124 This chapter has examined how pupils' experiences while at school or further education are contributing to shortages of high-level science and engineering skills. It has shown that although pupils' levels of attainment are rising, there are a number of factors that need to be addressed in order to secure a strong future supply of scientists and engineers in the UK, including:

- improving the supply of science, mathematics, D&T and ICT teachers through improved remuneration and access to subject-related professional development;
- improving the quality of the school laboratories and equipment, and the support available to teachers and pupils in making the most of these facilities;
- modernising and improving the relevance of the school science curricula, and helping pupils and teachers enrich the learning experience; and
- assisting pupils in making positive decisions to study science and engineering subjects at higher levels and to pursue careers in science and engineering.

2.125 Delivering these improvements will require close cooperation between the Government, schools, unions, higher education and employers, with each playing an important role in fostering pupils' enthusiam for, and knowledge of, science, technology and mathematics. This means the Government providing the resources, incentives and frameworks for schools and colleges to offer technology and mathematics education that, with the help of higher education and business, captures the imagination of the pupils – girls and boys equally – and encourages and inspires them to pursue study and careers in fields which will be critical to the UK's economic success.

3 UNDERGRADUATE EDUCATION

Summary of issues

The rise in the overall supply of science and engineering graduates in the UK in recent years masks reductions in the number of physical science and engineering graduates which are likely to have increasingly serious consequences for the UK.

The declining numbers of students taking relevant subjects at A-level are significant factors in these reductions. However, there are a number of issues relating to students' transition to higher education, and their experiences of higher education itself that also contribute to these trends. These include:

- mismatches between school-level physical sciences and mathematics courses and undergraduate courses in related subjects (which prevent some students making the transition to higher education smoothly);
- the length and perceived difficulty of science and engineering degrees – in particular, the extent to which four year degrees and more structured study in many science and engineering courses act as a disincentive to studying these courses;
- the legacy of under-investment in universities' teaching laboratories, which has resulted in around half the teaching facilities in universities being judged as unsatisfactory (this is particularly the case for science and engineering courses that require expensive and up-to-date laboratories and equipment, without which the degree is less attractive and relevant);
- the lack of adequate information for science and engineering students on employment opportunities and postgraduate study options; and
- the apparent mismatch between the mix of skills and aptitudes possessed by SET graduates and those needed by businesses.

The Review makes a number of recommendations aimed at:

- improving the links between schools and universities to ensure that students are better able to make the transition to undergraduate degrees in science, engineering and mathematics smoothly;
- addressing the perception among prospective students that degrees in these subjects are relatively hard to succeed in and require too much work;
- improving the laboratory teaching facilities in universities in science and engineering subjects; and
- ensuring that science degrees provide graduates with the skills that employers need and value, and that there are rewarding career paths into further study and academia.

Higher education in England[80]

3.1 Individuals' interest in higher education (HE) develops at different points in life. Although mature students account for a significant proportion (20-25 per cent)[81] of both full- and part-time students in higher education, the majority of the undergraduate student body is still comprised of 18-21 year olds who have entered higher education more or less directly from further education colleges or secondary schools. This chapter concentrates mainly on this latter group and the issues affecting them. It sets out some background information about higher education before exploring issues affecting the demand for science and engineering courses. It also considers factors affecting the quality of students studying these courses, both as they enter higher education and as they graduate.

Funding of higher education

The current higher education funding system for Higher Education Institutions (HEIs) in England allocates block grants on the basis of the number and type of students at the institution; and the volume, quality and subject of research undertaken by the institution. Individual HEIs then choose how to use that funding within guidelines set out by the Higher Education Funding Council for England (HEFCE). Similar systems operate in Scotland, Wales and Northern Ireland. Public funds for research are also available from the Office of Science and Technology (OST), via the Research Councils, to assist research projects and some postgraduate studentships. Funding is also available to encourage HEIs to work closely with employers and their local communities.

Not all subjects are equally expensive to teach. To reflect this, some subjects attract more support per student from HEFCE than others. This is done by setting 'subject premia' for different types of academic subject according to the cost involved in running the related courses. Similar subject premia are used in other parts of the UK.[82]

Since 1998/99 undergraduate students have also been required to pay their HEI a tuition fee (now around £1,100), which covers around one quarter of the average cost of their tuition. However, for many students, part or all of the fee is waived on the basis of means testing.[83] Undergraduates are also expected to pay for their living costs each year, and receive a student loan of £3,390-3,905 (£4,175-4,815 in London; £2,700-3,090 for those living at home).[84]

Postgraduates on taught courses such as the MSc[85] often pay fees to universities from their own funds. These can be raised through career development loans or company sponsorship. Fees for research postgraduates are often paid for by the Research Councils or other sponsors, or from university funds.

[80] The Review was commissioned by the UK Government, and this report therefore focuses on its areas of responsibilities. The higher education systems in Scotland, Wales and Northern Ireland have significant differences from higher education in England.

[81] Supply and demand in higher education, HEFCE 01/62, October 2001 and UCAS 2001 entry statistics, UCAS, Feburary 2002.

[82] In Scotland, the premia system has just been reviewed, resulting in a decrease in the number of categories covered, but there remains a much wider range of premia than in England.

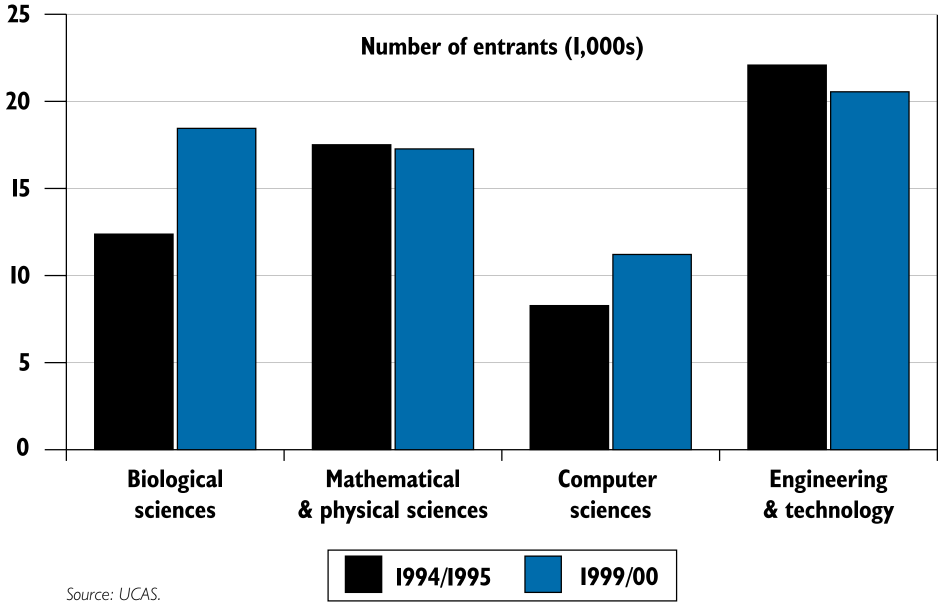
[83] Extra help is available for some students such as single parents, students with dependants and students with disabilities, and students in financial difficulty can also apply for assistance.

[84] Scottish students do not pay upfront tuition fees, following the 1999 Cubie report. The Welsh Assembly proposed in the 2001 Rees report that tuition fees for degree courses should be deferred until after students graduate.

[85] Master of Science (for further details see Chapter 5).

3.2 Just over 40 per cent of young people under the age of 30 enter higher education in the UK, of whom nearly a quarter (around 60,000) are accepted to study science and engineering subjects.[86] The numbers of science and engineering students are bolstered by sports science, computer science[87] and biology while the popularity of the physical sciences, mathematics and engineering has declined. This is illustrated in Figure 3.1 below. Subject areas in decline are discussed in more detail later in this chapter.

Figure 3.1: Changes in numbers of entrants onto SET courses, 1994/95 to 1999/00



Source: UCAS.

3.3 One third of all those accepted onto SET courses are women, although the proportions vary according to subject as shown in Figure 3.2. Men dominate the fields of computer science, engineering & technology, mathematics and physics,[88] whereas two thirds of biological science students are women. Biological sciences is the only SET subject area at undergraduate level where women account for more than 50 per cent of the total student population, and the proportion is increasing over time. This trend is attributed to various factors, including the ability of girls to relate to different areas of the science curricula and the high proportion of female science teachers who have a background in the biological sciences.

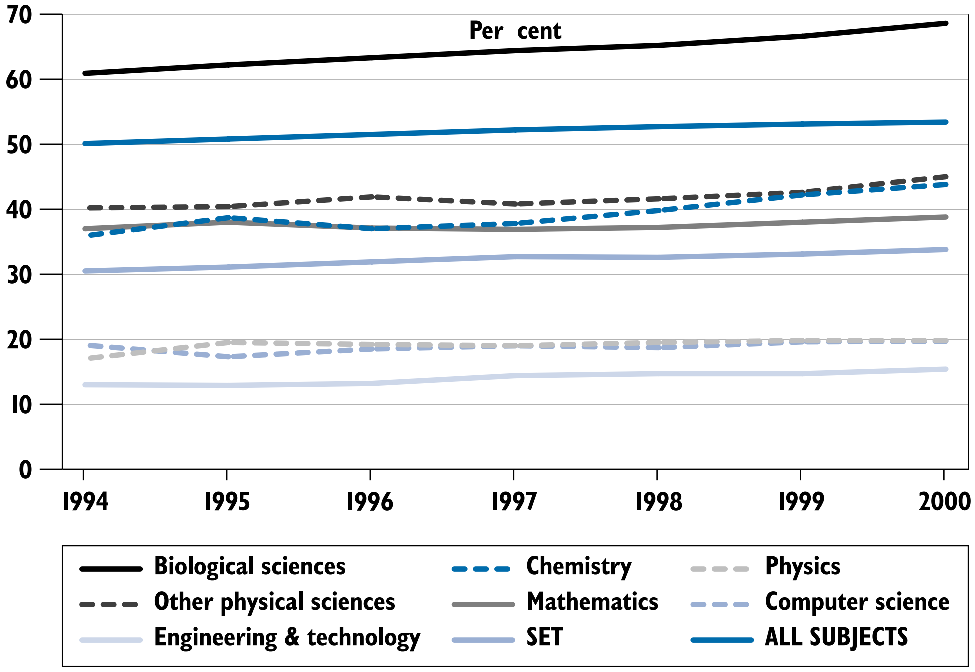
[86] UCAS 2001 entry statistics, UCAS, February 2002.

[87] Scientists and Engineers: A study paper on the flow of students with A levels into full time undergraduate courses of study, Council for Science and Technology, (to be published April 2002).

[88] The UK Graduate Career Survey 2001. The Times, 2001.

3.4 Within the other sciences and engineering, the proportion of women is around 30 per cent. The proportion of women has slightly increased between 1994 and 2000 in chemistry and other physical sciences, which includes earth, material and environmental sciences. Participation by women in undergraduate physics, mathematics and engineering & technology has remained low and static.

Figure 3.2: Proportion of female entrants to SET courses by subject, 1994 to 2000

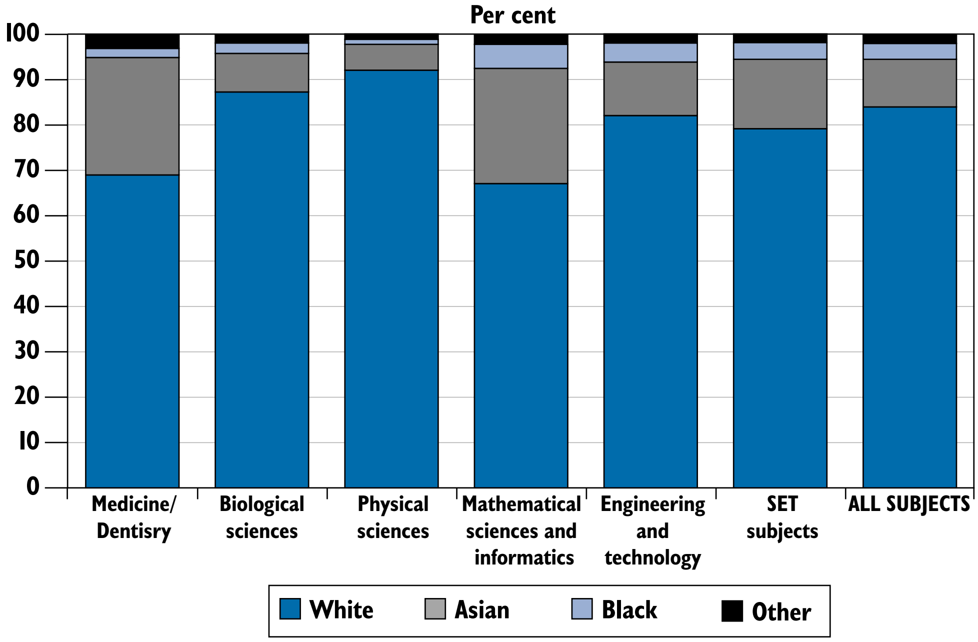


Source: UCAS.

3.5 Figure 3.3 below shows the ethnic balance of students in science and engineering compared to other subjects. The two most prominent points that emerge are the high proportion of Asian students studying medicine/dentistry and the high proportion of students studying the physical sciences who classify themselves as White. It is interesting to note that the gender balance within the group of African Caribbean students is reversed for science and engineering, compared to the white population, with women outnumbering men.[89]

[89] Note: for clarity a gender breakdown has not been included in Figure 3.3.

Figure 3.3: Ethnicity of SET course entrants in 2000



Source: UCAS.

Changes in demand for SET courses

3.6 The primary driver of change in HE course provision is student choice. Figure 1.4 in Chapter 1 illustrated that the number of undergraduates in SET was rising overall, driven by growth in biological science and computer science. However, fewer are studying for first degrees in the physical sciences (a fall of nearly 800 students between 1996 and 2000, or 8 per cent of the 1996 level[90]) and mathematics (172 fewer students, a 5 per cent fall). The proportion of all students studying engineering was down 0.8 per cent in the same period.

3.7 Furthermore, UCAS data[91] shows a decline between 2000 and 2001 in the number of students entering degree courses in chemistry (down 8 per cent), engineering (down 5 per cent), and mathematics (down 1 per cent, but predicted to fall by up to 12 per cent next year on the basis of applications currently received). The figures for physics entrants were about the same for the two years, although between 1996 and 2000 there was a 7 per cent decline in the number of entrants. Entries to first degree courses over a slightly longer period of time are presented in Table 2.2 in Chapter 2, which also demonstrates these declining trends.[92]

3.8 In contrast, the number of students studying other courses such as media studies and cinematics has grown significantly in recent years. Student numbers for these subjects were up by 22.1 per cent and 16.5 per cent respectively between 2000 and 2001 alone.

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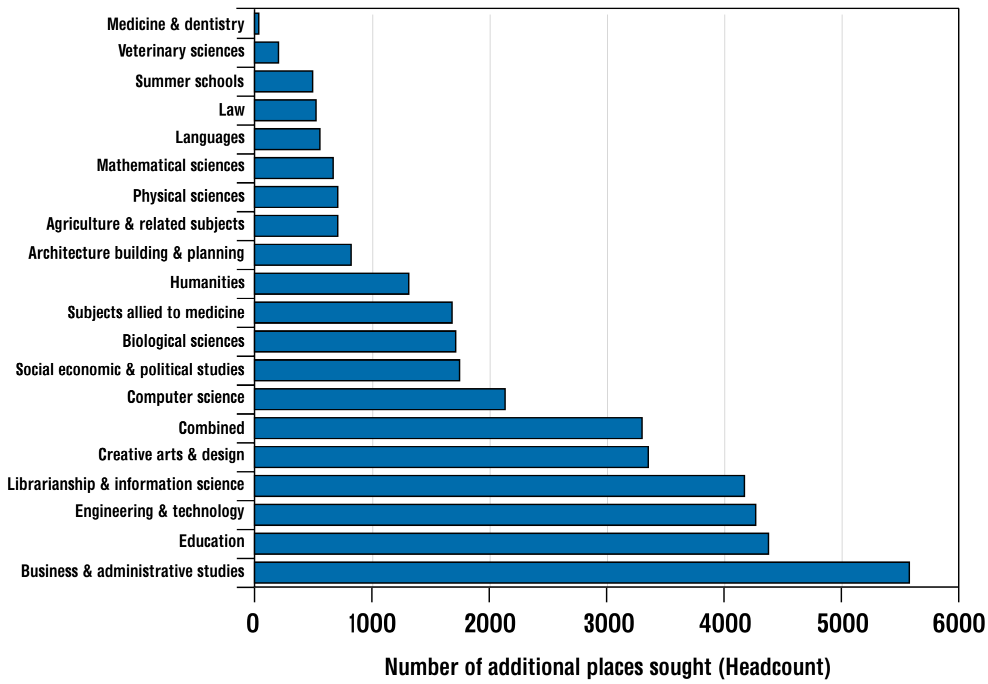
[90] Scientists and Engineers: A study paper on the flow of students with A levels into full time undergraduate courses of study, Council for Science and Technology, (to be published April 2002).

[91] 18,000 more students enter higher education in 2001, UCAS press notice, January 2002.

[92] Note: in Table 2.2 the physical sciences are not separated.

3.9 A picture of how HEIs are responding to these changes can be drawn from bids for additional student numbers. Before January 2002, HEFCE used to set a Maximum Allowable Student Numbers (MASN) figure for each HEI in England as a means of controlling public expenditure on student support. Additional student places were awarded to institutions in response to competitive bids (based on predicted areas of growth in certain subjects). HEFCE's figures relating to these bids, presented below in Figure 3.4, are a good source of information about areas of growth or change in course provision in academic year 2001/02; figures for 1999/00 are similar.

Figure 3.4: Bids for additional student numbers in 2000/01 by subject



Source: HEFCE (The numbers given are expressed as headcounts incorporating both full-time and part-time students).

3.10 The subject areas showing most growth in student demand were outside SET. Within SET, there were high bids for additional engineering and technology places, and substantial demand for both biological sciences and computer science. The physical and mathematical sciences, however, had low bids for additional places.

3.11 These figures do not, however, show the number of student places lost through the closure of some courses, notably physics. Comparing the changing number of graduates in each SET subject, as shown in Figure 1.5 in Chapter 1, to the demand for additional places leads to the following conclusions:

Table 3.1: Changes in student numbers for SET subjects

Subject	Student demand	Demand for additional places	Possible conclusions
Biosciences	Increasing	Significant	HEIs are demanding and offering additional places and are therefore able to accomodate new demand
Computer science	Increasing[93]	Significant	HEIs are demanding and offering additional places and are therefore able to accomodate new demand
Engineering & technology	Fairly static/ falling slightly	High	Restructuring of engineering provision may be occuring, with some HEIs opening new courses, bidding for additional places and accomodating demand, while others are closing departments or dropping certain courses as a result of falling demand
Physical sciences and mathematics	Falling	Low	Limited restructuring is occurring in these subjects, mostly in terms of closing or downsizing departments

Source: Review.

The quality of science and engineering undergraduates

3.12 There are concerns that the decline in pupils taking science A-levels, other than biological sciences and computer studies, may be reducing the quality of the SET undergraduate intake, and hence the quality of SET graduates. This problem arises if students of lower ability are accepted onto science courses to make up numbers as there is less competition for places. However, UCAS data on the A-level points scores of science and mathematics entrants to HE[94] show an increase in the period 1996-2000, with the exception of some individual subjects (by far the worst of which was computer systems engineering, where average points scores fell 15 per cent). Although these increases in average points scores are not as large as the increase in the proportion of students achieving A-level grades A and B in the same period, the average quality of entrants to SET degrees as measured by A-level points seems to have risen rather than fallen. This suggests that the overall entry standard of science and engineering students may have risen, although the rise has not been as great as in other subjects.

3.13 Paradoxically, the high levels of attainment at A-level of scientists and mathematicians entering SET degrees may contribute to the impression that these qualifications are 'hard' in the sense of attracting a higher proportion of able students. The proportion of mathematics entrants with 30+ A-level points was 34 per cent in 2000, while 26 per cent of physicists and 16 per cent of chemists had similar scores. Under 10 per cent of biologists and only

93 Intake was 75% higher in 2000 than in 1996 (9,204 students as opposed to 5,252); source: UCAS.

94 Scientists and Engineers: A study paper on the flow of students with A-levels into full time undergraduate courses of study, Council for Science and Technology (to be published April 2002).

5 per cent of computer scientists achieved similar levels of attainment. The less ostentatiously difficult subjects are the ones in highest demand by students. By way of comparison, only 19 per cent of history entrants, 15 per cent of new economists and 1.8 per cent of sociology entrants had 30+ A-level points.

3.14 The output of higher education is of course not solely determined by its input quality, but also by the quality of teaching in HEIs and the motivation of individual students. Having said that, it is also vital to the success of degree level study for entrants to have at least minimum standards of skills and knowledge, as a basis to build upon. Deficiencies of A-level students (particularly in mathematics) which affect the output quality of SET higher education are discussed later in this chapter.

Factors affecting undergraduate education

3.15 There are a number of issues that influence both students' demand for SET degrees and the skills they develop during the degree. These include:

- students' ability to make a smooth transition from school or further education to higher education (including concerns about difficulty of the course);
- the appeal of the structure and content of the course;
- the teaching facilities for SET subjects;
- the length of the course and the impact of student debt; and
- the employment prospects resulting from the course.

3.16 Employment prospects are particularly important, as students increasingly want to be sure about the type of job they are likely to be able to get and what they are likely to earn as a result of their degree.[95]

The transition from school and further education to higher education

3.17 As noted in Chapter 2, science and mathematics appear to be 'hard' subjects at school, and this perception carries forward into higher education. Degree level study is (rightly) more demanding than A-level but it is important for this level of rigour to be appropriate both to the subject (bearing in mind the needs of potential employers) and to the abilities of the student intake. If SET subjects are perceived as 'hard' without being equally rewarding in terms of degree class or career potential, they will not be attractive to students.

3.18 The Review has noted an example of rigour within schools that, this year, has deterred students from degree-level study in mathematics. This is thought to be a result of the new AS-level mathematics, which was seen to be exceptionally 'hard' by pupils. As a result, pupils are not continuing to the full A-level, which in turn is leading to fewer applications to study mathematics at degree level. The difficulty of SET courses in HE seems to have a similar effect: why study theoretical physics when history is perceived as 'easier' and no less rewarding?

[95] Grad facts 2000, The Guardian, 2000.

Mismatches between A-level and undergraduate entry requirements

3.19 Much of the perception of increased difficulty of university over school SET education comes from the different levels of demand on SET students. This can be in practical work (a four-hour practical session at university is usually far more complex than a succession of one-hour classes in school) and in mathematical rigour. Improved conditions for practical work in schools, as proposed in Chapter 2, will help alleviate the first problem by improving pupils' experience of practical work. The problem of students' scientific and mathematical abilities requires further attention.

3.20 Many HE staff believe that current science and mathematics A-level syllabuses, while covering a wide variety of interesting areas, do not necessarily equip students with the intellectual and conceptual tools required at degree level. Reductions in the depth of knowledge required at A-level in favour of breadth and relevance of study, are seen by some to weaken the usefulness of the A-level as an indicator of a student's ability to tackle the more complex and in-depth work at degree level.

3.21 Schools are limited by the A-level syllabuses offered by examination boards but they do have an element of choice over the modules selected within these syllabuses. Curriculum choices are based upon the ability and knowledge of teachers, the need to offer a good education in the subject, and the desire to produce good results for the pupils and the school. In striving to achieve these aims it is possible that schools may sometimes lose sight of the requirements of university degree courses, and so fail to prepare pupils as well as they could.

Mathematical skills of university entrants

3.22 Mathematics A-level syllabuses were identified by the Review's consultation as not always providing a sufficient grounding for undergraduate study of mathematics or the physical sciences, both of which require a good grasp of algebra and calculus.[96] Good grades at A-level, even among bright students, do not necessarily reflect adequate knowledge of or ability to use core mathematical techniques. As a result, a number of universities run what they see as remedial courses in the first semester or first term of the degree course in order to bridge the gap.[97,98]

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[96] A-level maths is also increasingly becoming an important grounding for the life sciences.

[97] Various research has been undertaken on mathematical skills of students, some of which suggest that students receive higher grades now than they would have in the past.

[98] An Historical Study of the Correlation between GCE Advanced Level Grades and the subsequent academic performance of well-qualified students in a University Engineering Department, K. Todd, Mathematics Today, Vol. 37 No. 5, IMA, 2001.

3.23 Mathematics A-levels contain a proportion of pure mathematics and at least one 'application' area – usually mechanics or statistics. The balance of subjects studied is generally chosen by schools. Until 2000 it was possible at A-level to cover a larger proportion of statistics than pure maths. The most recent QCA (Qualifications and Curriculum Authority) standards review report of mathematics at A-level[99] found a reduction in the level of pure mathematics ability demanded of students in the majority of the examining boards' A-level exams between 1995 and 1998. Pure mathematics content was judged to be less algebraic and more structured[100] or tested to a less demanding level.[101]

3.24 New course specifications to address this were introduced in September 2000. These new specifications gave effect to the changes proposed by the joint SCAA[102]/OFSTED report Standards in Public Examinations, 1975-1995, and reflected concerns raised by SCAA's Modular Question Paper review exercises and by Lord Dearing's Review of Qualifications for 16-19 Year Olds.

3.25 The current mathematics course specifications require 50 per cent or more pure mathematics and 25 per cent or more applications. However, they were found to be too challenging by teachers and students alike during 2000-2001, and produced a high failure rate in AS-mathematics in 2001. The QCA's report on phase two of Curriculum 2000 established that the changes from the 1995-2000 specifications had resulted in specifications that teachers could not readily deliver in the time available, and that students could not master in time for their AS examinations. The structure of these examinations is being reconsidered.

3.26 A-level mathematical specifications cannot easily return to the depth of, say, 15 years ago. However, it is important that in reviewing the A- and AS-level specifications, the QCA and awarding bodies consider the important role of A-level mathematics as a platform for degree level SET study. Nevertheless, HEIs must realise that the right balance is not one that overloads content and rigour into the A-level. A degree of flexibility in skills provision and knowledge at the school/HE interface is needed by HEIs.

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[99] Five year review of standards - A level mathematics, QCA, 2001.

[100] This comment was made of the AQA/A board (Assessment and Qualifications Alliance (Associated Examining Board)) and of the CCEA (Northern Ireland Council for the Curriculum, Examinations and Assessment).

[101] This comment was made of the OCR (Oxford Cambridge and RSA Examinations) board.

[102] SCAA – the School Curriculum and Assessment Authority (the predecessor to the QCA).

A-level subject mix: breadth and depth

3.27 Another problem reported by some lecturers arises from the mix of A-level subjects taken by students. Those taking a mixture of scientific and non-scientific subjects can sometimes find their choices at degree level limited.[103] It is argued that this is one of the causes of the drop in students studying certain subjects, and the rise in students studying others. For example, physics A-level is a prerequisite (in some HEIs) for electronic engineering[104] but not for computer science. Some students apply to study computer science when they discover that they will not be accepted onto an electronic engineering course.

3.28 There is a wider debate on the need for 'broader' or 'deeper' education, as highlighted by the Council for Science and Technology's Imagination and Understanding report.[105,106] Both insufficiently broad education and insufficiently deep education create problems for potential employers and individuals. The Review is sympathetic to the benefits for many students of having a broader education than currently, although the issues discussed above must also be considered.

Addressing problems of A-level and degree standards mismatch

3.29 Schools, colleges and the curriculum and examination bodies need to strike the right balance between the relevance and attractiveness of the A-level to pupils and its content and rigour in terms of preparation for further study. HEIs also need to adapt their teaching and curricula to the needs of schools and students; this is discussed later in the context of undergraduate course content more generally.

3.30 One method used to smooth the transition between A-level and degree-level study is to give new students additional study courses at or before entry. This can be in person and/or through e-learning. The Review believes that these 'entry support courses' can be important in preparing students for degree-level work in the physical sciences and mathematics in particular. The Review would therefore like to encourage more of these entry support courses, which would ideally be residential and could run either before or alongside the start of the course, rather than extending the length of the course. The courses could be run in conjunction with local FE colleges and/or through the HEI's science and engineering departments. The aims of such courses would be:

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103 The proportion of those students holding A-levels in three mixed science and non-science subject areas increased 15.6 per cent between 1996 and 2000. Scientists and Engineers: A study paper on the flow of students with A levels into full time undergraduate courses of study, Council for Science and Technology (to be published April 2002).

104 The labour market for engineering science and IT graduates: are there mismatches between supply and demand? G Mason, National Institute of Economic and Social Research, March 1999.

105 Imagination and understanding: A report on the Arts and Humanities in relation to Science and Technology, Council for Science and Technology, July 2001.

106 One employer has said: "We want talented people who understand engineering not with a broad understanding of geography and whatever else you like to mention". Anonymous quote in The Engineering Industry in the Next Two Decades: a Basis for Skills Outlook, D Birchall, J-N Ezingeard and N Spinks, Engineering Employers' Federation, January 2002.

- to enable HEIs to provide new science and engineering undergraduates, particularly weaker students, with the opportunity to reduce knowledge gaps in maths and science and increase their confidence in these areas, in advance of starting undergraduate SET courses;
- to encourage students who had not previously considered science or engineering at university to apply or to remain on science and engineering courses instead of transferring or dropping out (as part of the widening participation in higher education agenda);
- to allow students the opportunity to establish important relationships with members of staff prior to the academic year beginning; and
- to address in the short term the problems of the knowledge of science and engineering course entrants, without requiring HEIs to reduce the academic rigour of their degree courses.

3.31 The entry support course approach is likely to be most effective for weaker students. This is because it introduces students to the subject that they will be studying at a higher level and to the university teaching and study environment. It is also a directed approach to learning rather than one that requires independent study, providing a bridge between the school-level mode of study and the degree-level mode of study. This may not be a suitable model for all HEIs and some might find it more appropriate to develop distance-learning material for new students.[107]

3.32 Such entry support courses and/or distance-learning are likely to become increasingly important given the Government's commitment to widening participation, which will increasingly lead to students entering universities with varied educational qualifications and backgrounds.

[107] Experience with the DfES summer schools system established in 1999 may be relevant to entry support courses, although the DfES summer schools have different aims – they are intended to give year 11 students (those who have just completed GCSEs) a taster of university or college life for a week.

Recommendation 3.1: Quality of SET A-level students as degree-level entrants

Students sometimes struggle to make the transition from A-level study to degree level study in science, engineering and mathematics, since undergraduate courses often do not pick up where the students' A-level courses ended. Furthermore, the increasing modularisation of A-level courses has led to students entering higher education with wider variation in subject knowledge (differences in the mathematical knowledge of students are seen to cause particular problems in mathematics, physical science and engineering degrees). The Review recommends that to help students – particularly those in the past least likely to participate in higher education – make the transition from A-level study to degree level study in science, engineering and mathematics:

- A-level awarding bodies and the HE sector should, review science, engineering and (in particular) mathematics education at the boundary between school/further education and higher education, and adjust their courses accordingly to ensure that this transition can be made smoothly; and
- the Government should fund HEIs to use new 'entry support courses' and e-learning programmes to 'bridge' any gaps between students' A-level courses and their degree courses.

Furthermore, the Government should in three years' time review progress in reducing the gaps between A-level and degree-level courses – to ensure that students are not discouraged from studying these subjects, and retain interest in them – and take further action as necessary.

Undergraduate course content and structure

3.33 Many students who take science and/or mathematics at A-level choose not to study science and engineering at degree level. Particular issues are that science and engineering courses are perceived by some potential students as:

- 'hard' in the sense of being conceptually difficult;
- 'hard' in the sense of taking considerable time and effort to study[108] (contact hours for SET typically exceed those for arts and humanities courses; more than 25 contact hours per week for scientists is not unheard of, whereas 10 or fewer contact hours is not uncommon for some arts and humanities courses); and
- unrewarding (both in the sense of personal satisfaction, where some argue that the heavily factual nature of SET courses is restrictive and unappealing, and in respect of the career opportunities which they open up).

[108] The distinction here is that while it takes a lot of effort to do well at any subject, the necessary minimum level of effort (and the average level of time spent) to study SET subjects or medicine is perceived to be much higher than that for many other disciplines. The fact that SET study involves 'visible' and timetabled contact hours, rather than unseen, flexible study at home or in libraries, may underlie this perception.

3.34 Schools face a difficult task in making science and mathematics both attractive to students and a sufficient preparation for further and higher education. Should universities and colleges take more account of the abilities and levels of knowledge that the students have on entry, and alter their courses accordingly? The difficulty HEIs face in undergraduate education is in taking account of the competing needs of a number of stakeholders:

- schools, who seek good A-level results and broad educations for their students, and face the temptation to choose easier course options in pursuit of the former goal;
- employers, who want both breadth and depth of skills from graduates, and the ability to apply them to commercial problems;
- universities, who as postgraduate educators and future employers of postgraduates, have a particular need for depth of skills and knowledge; and
- students themselves, with a need for HE courses in SET to be attractive to students (on whom a large part of an HEI's income depends).

3.35 Insufficiently challenging undergraduate courses might meet the needs of schools but fail to satisfy employers. Equally, overly challenging courses could produce a few extremely able students, but fail to attract enough other students to justify the continued running of the course. In recent years, universities have tended to err on the side of maintaining historical standards at the risk of alienating students. For example, the Quality Assurance Agency's (QAA) quality assessment of chemistry teaching in 1993/94 found that:

> "The perception that there have been changes in science education in schools involving reductions in the factual content has, however, increased the temptation to overwhelm students with too much curricular material and too many class contact hours in undergraduate chemistry courses. As in any practically based subject, it is misleading to compare time spent in the laboratory with that spent in the classroom, but there has been general agreement that class contact hours need to be reduced to a level which provides the necessary theoretical and practical tuition, whilst allowing sufficient time for independent learning by students."[109]

3.36 Similarly, in 1990, undergraduate physics and chemistry degrees were considered to be 'cramped' following enormous developments in science over the previous fifty years. The Institute of Physics-led 'Higher Education Working Party' concluded at that time that the content of degrees should be cut by a third, and that the MPhys 'fourth year' should be created to build on a more realistic three-year programme as a basis for advanced professional work in physics.[110] This effectively redistributed the content of a 'cramped' three-

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[109] QO 2/95 Subject Overview Report - Chemistry, QAA (1995), http://www.qaa.ac.uk/revreps/subjrev/All/qo_2_95.htm.

[110] The Future Pattern of Higher Education in Physics - The Final Report of a Higher Education Working Party, The Institute of Physics, The Standing Conference of Physics Professors & The Committee of Heads of Physics in Polytechnics, August 1990.

year programme over four years, and also served to maintain student numbers. It did this both by reducing the intensity of the course, thus making it less 'hard' and more attractive to students, and by keeping students for four years rather than three.

3.37 The recent Institute of Physics' inquiry into undergraduate physics[111] moved on from this argument to recommend that university physics departments should consider re-balancing the content of undergraduate degree courses, in order to strengthen mathematical skills, transferable skills, and adapt to "the changing knowledge base of new undergraduates without losing the excitement of physics".

How should HEIs respond in the long term to changes in school curricula?

3.38 This Review has already explored a short-term solution to dealing with the mismatches between A-level and degree level SET subjects, in the form of entry support courses. In the medium term HEIs need to adapt their courses to reflect changes in school curricula, as well as increasing the attractiveness of the subjects, and teaching skills and knowledge valued by employers.

3.39 Moves towards 'action learning' and 'contextual learning' are particularly welcome in this respect. These involve group-based learning as well as individual skills development (for example, discussing how best to conduct an experiment in a group before carrying it out individually). In general, approaches to learning which are familiar to students will tend to obtain better results, and will help enable HEIs to retain high levels of intellectual content and technical challenge.

3.40 The exact solution to the problem will be for individual HEIs to determine. The Government, as the major funder of education, should however ensure that the needs of schools, employers and students are taken into account, as recommended above.

SET degree course structure

3.41 Most science and engineering subjects tend to require, in the first instance at least, the study of considerable amounts of core knowledge.[112] Professional standards in SET (for example the SARTOR standards for MEng courses) further define the material which must be included in the course. Science and engineering degree courses therefore involve a high number of teaching hours to cover this core material, backed up by tutorial work and self-study. Students also have to develop practical skills in laboratory work, which increasingly involves the use of specialist equipment not found in schools.

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[111] Physics – building a flourishing future, Report of the Inquiry into Undergraduate Physics, Institute of Physics, October 2001.

[112] This is in contrast to some arts and humanities courses which allow students considerable flexibility in their study.

3.42 All of this requires a high number of contact hours for science and engineering students throughout their first degree courses. As core knowledge and skills have been acquired, students are in more of a position to explore the use of both of these elements on work placements, and more specialised areas of study. It is at this point that businesses can meet their own needs by influencing course design. They can also offer suitable placements for academic staff to bring them up to date with the industrial environment that they are preparing their students for and the R&D work that they are involved in on the behalf of businesses.

3.43 Lord Dearing in his report in July 1997 from the National Committee of Enquiry into Higher Education suggested that more undergraduate courses should offer industrial placements as part of the course. The report acknowledged that employers placed importance on the level of work experience that new recruits had attained, and that both staff and students at the universities that had taken part in work experience schemes benefited from the experience, particularly when it was a structured part of the course.

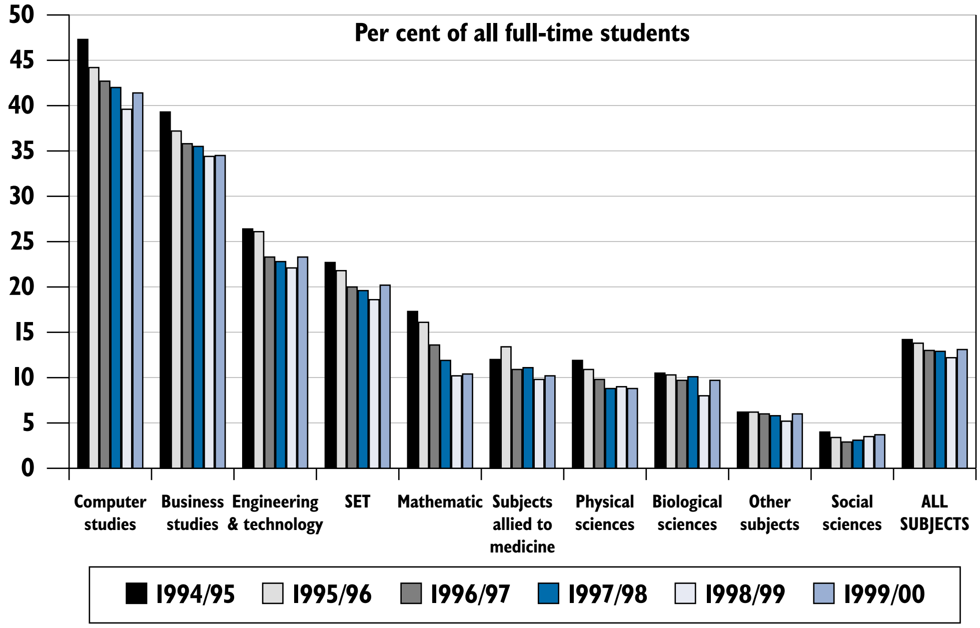
3.44 Figure 3.5 below shows that, in fact, fewer[113] undergraduates may be graduating in courses that offer industrial placements as part of the course,[114] although the proportion began to increase slightly in many cases in the academic year 1999/00. It is difficult to judge the reasons for this decline. It may be due to businesses and HEIs not collaborating effectively over these types of courses. Alternatively, students may simply be choosing to steer away from sandwich courses because they usually involve an extra year added to their course or, as commented on later in this chapter, they wish to avoid having to pay tuition fees for the sandwich year.

3.45 In the case of science and engineering, the Review believes that additional provision of structured work experience would help more students develop the skills that they need to work in SET businesses. It would also improve students' awareness of the job opportunities that exist in the sector. Student input into the choice of industrial placements, and businesses acting in collaboration with universities, could enhance the relevance of such placements to course options. HEIs should also strive to better market courses offering industrial experience, so as to encourage a wider take up of these opportunities.

[113] This is based on the assumption that industrial placements take place in sandwich years - of course some universities might encourage placements within vacation time, especially given that vacation employment is an increasingly common trend among undergraduates.

[114] This is not necessarily a true indication of the number of courses of this type that are on offer.

Figure 3.5: Sandwich students as a percentage of full-time first degree students, 1994/95 to 1999/00



Source: HESA.

Involving businesses in the development of SET courses

3.46 The National Committee of Enquiry into Higher Education recommended in 1997 that HEIs produce skills specifications for the courses that they offer, and identify ways of communicating these to industry representatives. At the same time, companies were recommended to take a strategic view of their relationship with higher education and to plan accordingly. This Review is concerned that there is little evidence of the outcome of these recommendations and/or (where they have been applied) their usefulness. Much work remains to be done to improve communication of skills needs and provision between both higher education institutions and companies of all sizes.

3.47 Universities usually liaise formally with businesses through industrial advisory boards. These involve representatives from different companies to advise on the curriculum. In practice, these boards often do not discuss skills needs with any coherence. In too many HEIs there seems to be no mechanism for feeding back any changes made to courses as a result of boards' input, and therefore no assessment of the value of the activity. This is not an effective way for businesses to communicate their skills needs to universities.

3.48 One difficulty HEIs face in altering courses to meet identified business needs is the rigidities imposed by professional bodies. These can both constrain the scale of changes and render the exercise more time-consuming if the course must be re-accredited after any appreciable change.

3.49 Occasionally companies seek to develop specific courses designed for their own needs, with a view to employing the graduates or influencing the R&D activity of the university.[115] The more usual relationship is not as direct, but skills communication appears to work best when universities are involved in regional and local partnerships based on particular business clusters or in the context of collaborative research. Chapter 6 describes a number of government-funded initiatives intended to encourage better collaboration between industry and the HE sector.

3.50 The Government announced in November 2001 that it would be providing £1 million over 2002-04 to improve the embedding of work-related skills more widely in HE provision. This will involve building on initiatives like Graduate Apprenticeships and foundation degrees[116] and transferring the good practice developed by individual HEIs more widely in the HE sector.

3.51 However, the Review is concerned that a step change is needed in the skills communications between employers (particularly businesses) and HEIs. Greater business involvement in course development would give HEIs, businesses and students more confidence that students are acquiring the right skills, and would keep businesses in touch with the skills sets on offer from universities.

Recommendation 3.2: Undergraduate course structure

Updating the nature and content of undergraduate courses to reflect the latest developments in science and engineering (through having lecturers who can draw on recent experience of work environments other than HEIs, and through explicit changes in course content) has the benefit of improving the attractiveness and relevance of the course to both students and employers. Accordingly, the Review recommends that employers and HEIs work more closely together, for example through:

- increasing the number of industrial placements offered to academic staff;
- encouraging industrialists to spend time in universities;
- encouraging greater engagement between businesses and careers services and, in turn, between careers services and science and engineering departments; and
- encouraging universities to be more innovative in course design in science and engineering.

These actions by HEIs and employers must be supported by those bodies that accredit science and engineering courses – for example, the Engineering and Technology Board and professional bodies which are members of the Science Council – who must work with universities to drive forward innovation in course design, and not allow the accrediting processes inadvertently to inhibit it. The Government should facilitate these forms of HEI/employer interactions through 'third stream' funding such as the Higher Education Innovation Fund (HEIF). Furthermore, the Government should in three years' time review progress in this area and take action as necessary to further improve HEI/employer interactions.

[115] An example of this is the Masters course run in collaboration between BAe Systems and Loughborough University.

[116] Foundation degrees are targeted at meeting skills needs for higher technician and associate professional jobs, and combine academic study with work-based learning. The courses are intended to attract many people who do not currently enter higher education, and employers and employer bodies are actively involved in their design.

Undergraduate skills development via the proposed teaching assistants scheme

3.52 Currently some undergraduates and doctoral students have the opportunity to help out in schools on a voluntary basis through taking part in schemes like the Researchers in Residence scheme,[117] in which doctoral students support the teaching of science in schools. Such work helps give students practice and confidence in communicating and dealing with other people and using their knowledge practically. SET students are felt to lag behind their peers in the development of interpersonal skills, particularly as they tend to have less time in the academic curriculum to devote to personal development. Working in schools would help them to develop these skills, which are valuable to them in their future careers. In Chapter 2 the Review recommends the introduction of a teaching assistants scheme, under which undergraduates and postgraduates would be paid to support teachers in schools in the teaching of science.

University science and engineering teaching facilities

3.53 Teaching of science and engineering requires suitable facilities. All academic courses, including SET, require lecture theatre space, seminar rooms, computer suites and libraries. Science and engineering subjects also require specialised laboratories and equipment that are often more expensive than other disciplines. For example, teaching bioinformatics, an area in high demand by employers, requires considerable computing power to match the available software, and hence considerable investment in IT hardware. Some science courses require clean rooms or fume cupboards; some engineering subjects need to accommodate heavy product engineering equipment. There is a need for some of this workspace to be developed into multi-use computer-simulation labs, involving a reduction in space required, but a need for new, very different and expensive resources.

3.54 If science and engineering students (including postgraduates) are to be able to develop their research, technical, teamwork and project management skills effectively, they need to be working in an up to date environment with high quality equipment.[118] However, many SET laboratories are far from this standard. HEIs approached by the Review commented on the improvements required in their SET departments, and in some cases on industry's expectations that students should be taught using the type of equipment they are likely to encounter in industry.

3.55 There is also concern that teaching laboratories are poorly staffed. Use of specialist equipment demands expert supervision and demonstration, as does the preparation of experiments and the use of consumables. Increases in student-to-staff ratios have decreased the tutor/student interaction, although academic staff are generally assisted by postgraduate students and research

[117] See footnote 66.

[118] The quality of undergraduate laboratories can also affect postgraduate facilities, which are often co-located.

staff. Provided that this does not decrease the level of senior staff participation too far, this is beneficial to the undergraduates and also to the postgraduates, who gain communication skills experience and financial benefit.

3.56 Businesses benefit from HEIs having up-to-date equipment in teaching labs because it ensures their future labour supply is trained to use such equipment. Although Government has a role in helping HEIs to provide appropriate equipment, businesses can assist themselves by donating suitable equipment to educational establishments such as universities. The Government encourages this through tax reliefs for businesses on equipment donations to charities and to educational establishments.[119] The Review believes that such reliefs are useful in improving collaboration and in providing good quality equipment, and would like to see more businesses making use of them.

Is the cost of scientific equipment increasing?

3.57 One reason for under-investment in teaching laboratories is that the cost of scientific equipment has increased relative to HEIs' income. Between the mid-1980s and the end of the 1990s, business expenditure on R&D per full-time equivalent (FTE) worker[120] rose by approximately 45 per cent. Although the Review did not have at its disposal data to compare HE R&D spending over the same period (OECD data for HE expenditure ends in 1993), between the mid 1980s and 1993 expenditure by the higher education sector per FTE R&D worker remained fairly constant.

3.58 It is possible that since 1987 HE funding has not adequately taken account of capital overheads.[121] Certainly universities have consistently under-invested in SET teaching facilities. While the Government has recently, with the Wellcome Trust, directed significant sums to research equipment and infrastructure, there remains a need to deal with a backlog in teaching investment.

Summary of teaching facility issues

3.59 To improve the quality of scientists and engineers coming through UK universities, substantial investment is urgently required in university teaching laboratories. HEFCE's Estate Department estimates that about half of all teaching labs in the UK are in urgent need of refurbishment, many of them not having been modernised since the 1960s. The lack of investment in laboratory facilities is in part a result of HEIs directing funds to other areas where they are judged to be needed more urgently (staff costs, for example) in preference to spending on teaching infrastructure.

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[119] HEIs usually fall into both these categories.

[120] Part-time employees count as a fraction of a full-time equivalent (FTE) worker. For example, if a full-time employee works 40 hours per week, a part-time worker who does 20 hours a week counts as 0.5 FTE worker.

[121] Prior to 1987 universities received their capital funding separately.

3.60 The backlog in teaching laboratory refurbishment is too large to be addressed simply by an increase in recurrent funding. It would take too long to bring the majority of labs up to an acceptable standard, and universities might, as previously, redirect funding to other needs.

Recommendation 3.3: University teaching laboratories

The Review recommends that the Government should introduce a major new stream of additional capital expenditure to tackle the backlog in the equipping and refurbishment of university teaching laboratories. The priority should be to ensure the availability of up-to-date equipment and then that, by 2010, all science and engineering laboratories should be classed as at a good standard or better, as measured by HEFCE. In delivering this recommendation, the Review believes it is important that the teaching infrastructure capital stream complements research infrastructure funding to facilitate the building, refurbishment or equipping of joint research and teaching facilities, where appropriate.

Recurrent funding for SET teaching

3.61 Laboratory based courses are inherently expensive to run given the costs associated with laboratories (chemicals, extra staff such as technicians for experimental classes, etc.), and the upkeep of the laboratories themselves. The Review has also found that academic salaries vary between different fields within SET. The per capita salary bills of physics and biological sciences departments usually proves greater than those of other departments, particularly engineering subjects and computer sciences.

3.62 The Review asked a sample of HEIs in England for information on their actual staff costs for science and engineering subjects, using history (where applicable) as a comparison. Respondents tended to put the average cost of full-time experienced lecturers/professors in history at around £45,000 p.a. In comparison, biological sciences ranged from £47,400 to £58,000 p.a., chemistry from £47,500 to £56,000 p.a., and physics from £49,000 to £56,500 p.a. Costs for engineering came in lower, ranging from £44,000 to £54,000 p.a. One university (not in London or the South East) however put science and engineering up to an average of £60,000 p.a.

3.63 On this evidence, SET per capita staff costs appear to be around £2,500-£15,000 per annum (or roughly 6 per cent to 33 per cent) greater than those for historians. Furthermore, as is shown in Chapter 5, a higher (and growing) proportion of academics in SET subjects are at senior levels, relative to most other disciplines. These are also subjects facing market pressures, as discussed in Chapter 5. All this is likely to mean higher overall cost differentials than the raw figures indicated above.

3.64 Funding for English HEIs' teaching costs is assigned by HEFCE on the basis of 'subject premia', which provide additional funding for subjects which are more expensive to teach, including most SET courses. These premia are set out in Table 3.2 below. The current premia were calculated using actual 1994/95 expenditure by institutions, which included staff salaries, cost of equipment etc. Although these values increase (at an inflationary rate) when they are reviewed each year, the cost weights have not changed since the subject premia were introduced in 1996.

3.65 For laboratory-based subjects these premia appear to be insufficient to allow universities to maintain their laboratories properly and to meet their staff and running costs. Given the systematic under-investment in teaching infrastructure described above, it is very likely that this under-investment was 'frozen-in' and has resulted in a continued under-resourcing of science and engineering departments. Furthermore, all the laboratory subjects are placed within the same price group, and do not differentiate between the staff costs of different science and engineering departments.

Table 3.2: HEFCE subject premia price groups

Price group	Description	Cost Weight	Approximate value per student (£ p.a. in 1995)[122]
A	The clinical stages of medicine and dentistry courses and veterinary science	4.5	12,915
B	Laboratory-based subjects (science, pre-clinical stages of medicine and dentistry, engineering and technology)	2	5,740
C	Subjects with a studio laboratory or field work element (includes mathematics and IT)	1.5	4,305
D	All other subjects	1	2,870

Source: HEFCE.

3.66 The cost of equipment and SET teaching staff has increased (and is still growing) relative to other subjects, and indeed there are differences within the costs of different subject areas within the same laboratory-based price group. These costs are greater than allowed for in the current funding maintain the quality of their laboratories and retain good teaching staff.

Recommendation 3.4: Recurrent funding for teaching

In order to ensure that in future higher education institutions can and do invest properly in science and engineering teaching laboratories, the Review recommends that HEFCE should formally review, and revise appropriately, the subject teaching premia for science and engineering subjects. The revisions should ensure that the funding of undergraduate study accurately reflects the costs – including paying the market rate for staff, as well as the capital costs – involved in teaching science and engineering subjects.

Student funding and debt

3.67 Student debt has increased in recent years from an estimated average of just under £2,500 in 1995/96 to around £3,500 in 1998/99.[123] More recently, reports[124,125,126] have suggested average student debt has between £6,000 and £12,000. However, despite increasing levels of debt, student expenditure on items such as mobile phones and socialising is in line with lifestyle patterns

[122] The values per student for each price group are presented in Table 3.2 at the recently announced 2002-03 levels, with a basic rate of £2,870 (compared to a basic rate of £2,600 when the premia were established in 1995).

[123] Changing student finances: income, expenditure and the take-up of student loans among full- and part-time higher education students in 1998/9, C Callender and M Kemp, South Bank University, December 2000.

[124] Student living report 2002, commissioned by Unite and conducted by MORI, January 2002.

[125] Students 'would be better off on benefit', W Woodward, The Guardian, 20 February 2002.

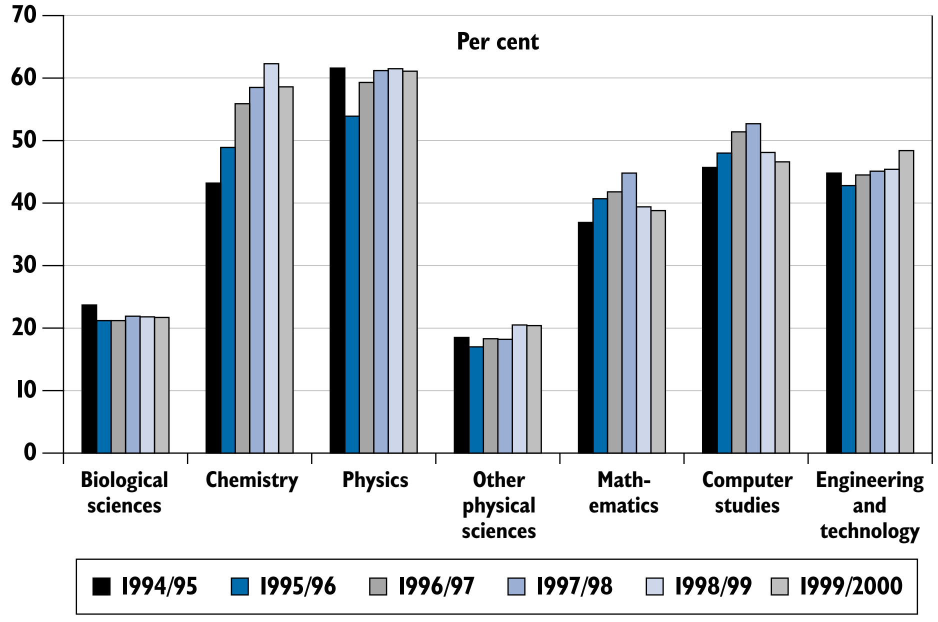
[126] Barclays estimates total student debt at £4.85 billion, Barclays News Release, 24 July 2001.

for 18-25 year olds in general. The Review did not find evidence that student debt is deterring students from undergraduate study in general. However, the Review gave further consideration to any effect of longer science and engineering courses on student choices.

Is the length of study deterring students from studying SET?

3.68 Until the 1990s, three-year undergraduate courses were normal for the majority of subject areas,[127] including science and engineering. During the mid 1990s, however, many universities began to offer four-year courses in some scientific subject areas, leading to an 'undergraduate' Masters qualification rather than a Bachelor's degree. The best established of these courses, the MEng (Master of Engineering), is the professional qualification for engineers.[128] For the most part, physical sciences and engineering courses, particularly within older HEIs, became four-year courses around this time. However, three-year courses continue to be offered, and in biology three-year courses are still relatively common (see Figure 3.6).

Figure 3.6: Proportion of SET first years expecting to study for over three years and less than four



Source: HESA.

[127] This model was specific to England, Wales and Northern Ireland, and differed in Scotland where four year honours courses have been the norm for some time.

[128] It is slightly different from other undergraduate Masters qualifications as it was devised in association with the Engineering Council and is accredited by them. An accredited MEng degree in an engineering discipline is the foundation qualification for those wishing to become Chartered Engineers. Engineering Council, http://www.engc.org.uk/engc/1/index.html

3.69 Another form of longer course is the ‘sandwich course’, which involves a year-long placement in employment as part of the course. It is possible that the requirement for students on sandwich courses to pay half of their normal tuition fee[129] for the year is disincentivising the take-up of these courses. The Review is aware that a number of students currently take years out of study in preference to a formal course placement to avoid paying tuition fees.

3.70 Over 60 per cent of students supplement their income through part-time work. It is recognised that the number of contact hours involved in science and engineering subjects greatly exceeds those expected of most arts and humanities and some business courses. The difference is mostly due to time expected of SET students in laboratory work. This factor reduces a student’s capacity to find part-time employment, which may act to deter some potential students from choosing SET courses – particularly those from low income or otherwise disadvantaged backgrounds.

3.71 The best evidence available to the Review[130,131,132] did not indicate that student debt deters people from participating in higher education, although it is clear that it is a source of much concern to students. The Review has also found no concrete evidence that prospective debt deters significant numbers of students from undertaking a four-year as opposed to a three-year degree. Rather, debt mainly becomes a deterrent when graduates consider postgraduate study. However, it is possible that there is a link between the decline in the number of chemistry and physics graduates and the proportion of four-year courses in these subjects. The Government should monitor this situation to ensure that it does not become a problem.

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129 The fees pay for the student’s continued support by the institution and broader costs of the course, not just ‘tuition’. In some cases the need for this funding and what it is spent on do not appear to have been explained to students, who often resent paying a ‘tuition fee’ when they receive little tuition in the year out from the course. In other cases the HEI may not have provided sufficient support to its sandwich-year students.

130 Changing student finances: income, expenditure and the take-up of student loans among full- and part-time higher education students in 1998/9, C Callender and M Kemp, South Bank University, December 2000.

131 Student living report 2002, commissioned by Unite and conducted by MORI, January 2002.

132 HEFCE 01/62, October 2001.

Recommendation 3.5: Undergraduate student funding

While student debt does not in general appear to be deterring potential students from undergraduate education, at the margin some undergraduates may be deterred from science and engineering courses, as they involve longer hours than other courses and as a result students find it more difficult to supplement their income by working part-time. In order for this not to deter the most disadvantaged students from studying science and engineering (and other courses with long 'contact hours'), and to assist with widening participation, the Review recommends that the Government (through its guidance to HEIs) should ensure that the Access Funds and Hardship Funds adequately provide for students on courses involving a high number of contact hours. The Review recommends that additional funding should be provided to accommodate this, and that HEFCE monitor the targeting of this additional funding to ensure it reaches those most in need.

The Review also recommends that the Government closely monitor the impact that an additional year of student debt has on students' choices of course, to ensure that the student funding system at undergraduate level is not discouraging students from studying (the longer) physical science and engineering courses.

The careers of SET graduates

Why work in SET?

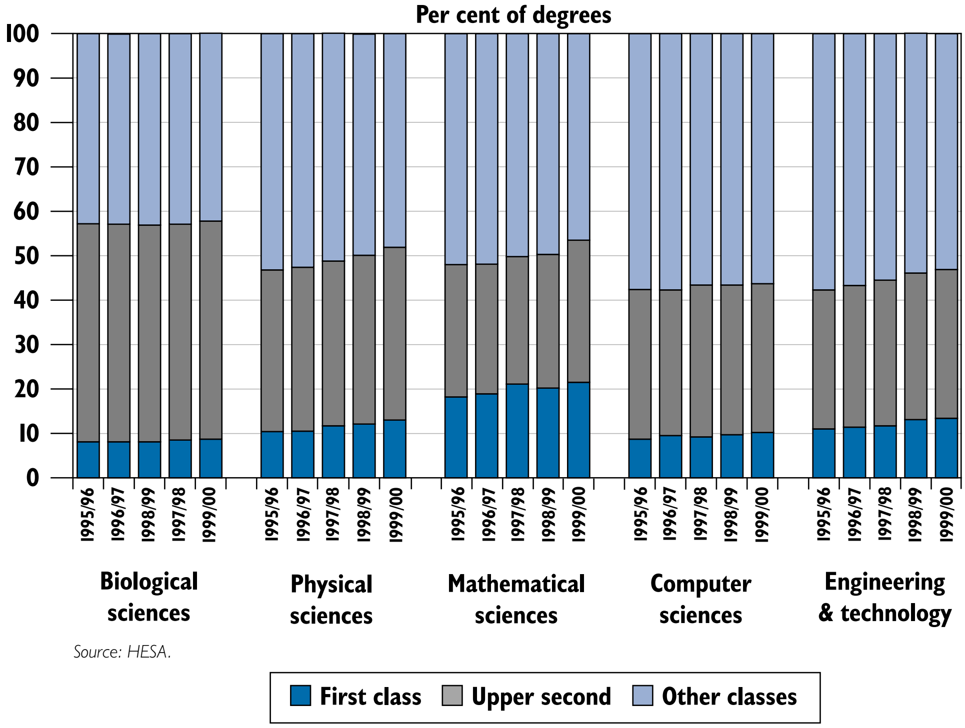
3.72 According to a recent report[133] for the Office for Science and Technology, men and women holding SET degrees had initially chosen to work in SET occupations because they had enjoyed their studies. Those that continued to work in these occupations, preferred the work because they found the work was varied, they enjoyed problem solving, they were not office bound and there were travel opportunities on offer. Those who disliked working in SET occupations found that their job was boring and repetitive, and they had little control over what they did and how they did it. They complained about poor working environments with little human interaction, not being able to see immediate results from their work, and about low rates of pay.

The quality of SET graduates

3.73 The careers open to SET students depend on their subject knowledge and ability (often measured by their degree class), and their skills. The small overall decrease in the number of physical science and mathematics students between 1995 and 2000 coincides with slight rises in the proportion of first class degrees and 2:1s awarded in these subjects, as shown in Figure 3.7 below. A similar effect is seen in engineering and technology. In the biological sciences, however, the proportion of first class and upper second class degrees awarded has stayed fairly constant. In computer science, the proportion of first class computer science degrees increased slightly but the proportion of 2:1s awarded remained constant.

[133] Maximising Returns to science, engineering and technology careers, prepared for the Office of Science and Technology, by People Science & Policy Ltd & Institute for Employment Research (University of Warwick), January 2002.

Figure 3.7: Number of SET undergraduate degrees by classification and subject over time



Source: HESA.

3.74 These patterns seem to indicate that the quality of SET graduates is stable or slowly improving. One interpretation is that the reduction in student numbers in some subjects comes from fewer weak students applying for these 'hard' subjects. The Review is aware that the A-level points scores of students with A-levels in maths, science and technology compares well with those in other disciplines. In 2000, both the maths and science intake had a higher points score than average (23.7 and 20.5 respectively, compared to an average of 18.8). Technology was slightly below average (17.6).[134]

3.75 However, employers are concerned about the application of graduates' skills and knowledge in the workplace, so a definition of quality is needed which rests on students' practical experience as well as their exam results. Employers' skills requirements and the career choices available to SET graduates are discussed below.

[134] Scientists and Engineers: A study paper on the flow of students with A levels into full time undergraduate courses of study, Council for Science and Technology, (to be published April 2002).

Employability of graduates

3.76 Final year undergraduates appear to show interest in the employment routes followed by their predecessors.[135] Many seem increasingly motivated by financial reward, and look to employers offering the highest starting salaries, such as finance, banking and consultancy, rather than to technological and engineering industries. Most of the highest paying graduate jobs in these sectors require a good quality degree (2:1 at least) and may ask graduates to demonstrate specific skills such as business awareness and analytical skills. Employers' judgements are frequently based on the reputation of the HEI awarding the degree, and the title and 'reputation' of the degree itself. Demand for SET graduates, including competition from non-R&D employers, and SET graduate pay are explored further in Chapter 6.

3.77 Recent graduate surveys conducted by both The Guardian and The Times show graduates' salary expectations have increased in recent years and tend to be unrealistically high,[136] although these studies do not indicate expectations specifically for SET graduates. Expectations about increases in salary after five years also appear unrealistic when compared to the actual situation indicated in Figure 6.4 in Chapter 6, other than for jobs in financial services and some other service industries.

3.78 These high expectations might explain why SET graduates motivated by money choose to use their skills in non-R&D related careers. For similar reasons, it might explain why some of the most able SET graduates choose not to go onto postgraduate study. Another factor that might deter postgraduate study is the incidence of students receiving job offers in advance of the completion of their degree, particularly students on courses that offer industrial placements. This is most common in computer science and related subjects, where young people with the right skills have been in high demand.

Employers' skills requirements

3.79 When recruiting SET graduates for scientific jobs, 'technical/practical knowledge' and 'academic skills and knowledge/attainment' are sometimes more important to employers than candidates' personal qualities and inter-personal skills. Nevertheless, the latter are still sought after and employers often regard SET graduates as being poor at applying and developing the knowledge and the skills that they have acquired (particularly practical skills).

3.80 Recruiters interviewed in the Mason report's 1998 survey[137] said that new graduates' jobs had in recent years become more complex and demanding. It is important that these changes and the skills required to respond to them

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[135] The labour market for engineering, science and IT graduates: are there mismatches between supply and demand?, G Mason, National Institute of Economic and Social Research, March 1999.

[136] Grad facts 2000, The Guardian, 2000 and The UK Graduate Career Survey 2001, The Times, 2001.

[137] The labour market for engineering science and IT graduates: are there mismatches between supply and demand?, G Mason, National Institute of Economic and Social Research, March 1999.

are reflected in the careers advice given to students. Employers interviewed for the Mason report[138] put lack of appropriate work experience highest on their list of poor qualities in graduate job applicants. In particular, graduates are expected to take responsibility and add value at a much earlier stage than previously. This is particularly important for SMEs.

3.81 A quality often sought by employers is 'commercial awareness'. There is a limit to how effectively this can be taught in HEIs, particularly by staff with limited commercial experience. The twelve Science Enterprise Centres in universities around the UK (ten in England and one each in Scotland and Northern Ireland) have an important role in educating HE staff and students in enterprise and entrepreneurship.

The role of careers advice in graduate career decisions

3.82 Chapter 2 explored the need for better advice at school about SET careers, which impacts on A-level combinations and in turn on degree course options. Students do not always enter higher education with clear career goals, often choosing their degree courses on the basis of the subjects they enjoyed and excelled in at school,[139] and careers advice is therefore important at university level too.

3.83 Students report receiving the best advice about skills required by industry, careers options, and areas of future growth from lecturers with industrial experience. Students welcomed discussions with lecturers about their industrial experiences, and the relevance of these in academia. A constraint on this is that currently there are not enough opportunities for industrial exchanges for academic staff. Industrialists could also benefit from experience of the way that universities work, and the current themes of their research. Industrial exchanges, therefore, promote links between universities and businesses, as well as benefiting students.

3.84 University careers services also play an important role in advising on future careers and postgraduate education. The Mason report indicated that those undergraduates who sought out university careers services found them helpful. However, careers services can be insufficiently pro-active, and fail to reach many students who do not realise that they need advice. A code of practice for HE careers services has been published by the Quality Assurance Agency for Higher Education.[140]

3.85 The Harris Report[141] noted that the prime function of university careers services "is to help the institution produce better-informed students who are self-reliant, able to plan and manage their own learning and have sound career management skills". It also said that "Clarity of mission, lines of accountability,

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[138] The labour market for engineering, science and IT graduates: are there mismatches between supply and demand?, G Mason, National Institute of Economic and Social Research, March 1999.

[139] Great Expectations – the new diversity of graduate skills and aspirations, K Purcell and J Pitcher, Institute for Employment Research, University of Warwick, October 1996.

[140] Guidance on preparing students for careers, Press notice – www.qaa.ac.uk, 23 January 2001.

[141] Developing Modern higher Education Careers Services, Sir M Harris, Manchester University, Higher Education Careers Services Review report for DfES, December 2000.

performance measurement and adequate resource allocation need to underpin every Higher Education Careers Service". In his report, Sir Martin Harris noted that students "have very different experiences of Careers Services" and that "resources devoted to these services varied considerably across institutions". Awareness about how to use careers services varied, and was low among socially disadvantaged groups, particular subject groups and mature learners. Many students obtained advice too late to influence study choices or undertake development activities.

3.86 This Review is concerned to see driven forward a number of recommendations from the Harris report, alongside the improvements to careers advice in schools recommended in Chapter 2:

- HEIs should develop meaningful links with businesses that complement work done by careers services, such as the offer of work placements;
- careers services should develop sound working relationships with Connexions Service Partnerships, so that young people (starting at 14) are able to recognise the career implications of their course choices; and
- careers services should review their links with employers and organisations such as the Small Business Service to ensure that academic departments are assisted in meeting needs and have contacts in new areas and areas where graduates are under-represented.

3.87 SET students should receive up-to-date advice on the career options open to them (particularly opportunities in R&D and the benefit of postgraduate study). Students also need advice on – and opportunities through appropriate courses to acquire – the generic skills needed to prepare them for work. Universities and businesses, therefore, need to work together more closely in order to best develop the skills that both employers need. Students themselves need to take responsibility for ensuring that, in the light of improved information, they do what they can to acquire the skills that will enhance their employability.

Recommendation 3.6: University careers advisory services

The Review welcomes the recommendations of the Harris report on improving university careers advisory services. It is important that science and engineering students have accurate, up-to-date careers advice on the rewards and range of opportunities available to them (particularly opportunities in research and development). In particular, the Review endorses the recommendations in his report aimed at improving the links between careers advisory services and businesses, particularly small businesses, which will require action by both HEIs and by businesses.

4 POSTGRADUATE EDUCATION

Summary of issues

The decline in A-level and undergraduate numbers in mathematics, the physical sciences and engineering has coincided with falls in the number of PhDs awarded in these subjects. The number of PhDs awarded in computer science has also fallen from its 1994 level despite higher intakes at undergraduate level.

There are also concerns that the quality of postgraduate student intake and output is declining. In some subjects this can been seen in lower proportions of PhD students with upper second and first class undergraduate degrees. PhD students are also seen to be poorly prepared for work in either academia or business. Over time these trends will reduce the ability of the UK to continue to carry out world class R&D.

The chapter first examines the number and calibre of students taking up postgraduate study in science and engineering. These are affected by the issues in schools, colleges and undergraduate education that were explored in Chapters 2 and 3. However, there are additional problems with postgraduate study that make it an unattractive option for able graduates in science and engineering subjects. The Review makes recommendations to overcome this by addressing:

- the fact that **PhD study is financially unattractive** in the short term. The gap between PhD stipends and the starting salaries of able graduates has increased dramatically over the last 25-30 years and more recently this is exacerbated by increasing levels of average undergraduate debt. Furthermore, careers in both academic and industrial research for which scientific PhDs are required are less financially attractive than some other options; and
- the problem that skills acquired by PhD graduates do not serve their long-term needs. Currently, **PhDs do not prepare people adequately for careers in business or academia**. In particular, there is insufficient access to training in interpersonal and communication skills, management and commercial awareness. This can be improved in many ways, including provision of more funded 4-year PhDs.

Postgraduate courses and qualifications

4.1 Scientific researchers almost invariably begin their research training in higher education. Some may enter R&D employment at the graduate level, others after a Masters degree, PhD or post-doctoral experience. Not all development work requires extensive research training, but often the research elements of R&D in academia and in industry require research experience that is generally gained only through a PhD.

4.2 Postgraduate study is therefore fundamental to the development of the highest level of science and engineering skills. It develops specialist knowledge and, particularly at the PhD level, trains students in the techniques and methods of scientific research. The majority of the UK's future scientific researchers will need postgraduate qualifications, as will those in other countries. Any reduction in the supply and quality of scientists and engineers trained to this level is therefore of primary importance to the UK economy.

4.3 After analysing the declining numbers of postgraduate science and engineering PhDs awarded, this chapter explores the reasons for this trend and makes recommendations to ensure that:

- postgraduate study is made attractive to the most able graduates. (in particular the chapter considers the case for increasing the level of the PhD stipend, and the length of PhDs);
- PhDs are producing people with the necessary balance of skills to conduct high quality research and development in industry, universities and the public sector. Currently, insufficient emphasis is placed on transferable skills.

4.4 Some of the Review's conclusions are mirrored in two recent reports that examine the current situation in the UK regarding postgraduate students: a report on doctoral research students in engineering by the Royal Academy of Engineering[142] and (outside the scope of this Review) the British Academy's review of graduate studies in the humanities and social sciences.[143]

Postgraduate qualifications

4.5 Postgraduate qualifications essentially divide into two categories, taught degrees (MSc) and research degrees (MPhil, PhD). However the MRes is a hybrid of the two, and newer doctoral programmes such as the EngD contain significant taught elements (see the box on postgraduate qualifications below for more detail). Taught qualifications can offer valuable training in specialist areas of science and engineering, but do not provide research training and were rarely mentioned by respondents to the Review's consultation. In the context of this Review, therefore, the MSc is not explicitly considered. The MRes is a relatively new qualification, and again did not attract significant comment in the consultation process. The focus of this Review (and of responses to the consultation) has therefore been on research degrees, particularly the PhD.

4.6 Postgraduate education generally requires a first degree at a high level – usually a 2:1 or a 1st class honours degree for a PhD (usually over three years) or a 2:2 for a Masters course which may either be taught or research-based (usually over one year). Many students often go on to postgraduate study immediately following their first degree, although a proportion return to academic study having spent time in business. This is particularly the case for taught courses like the MSc.

[142] Doctoral Level Research Students in Engineering: A national concern, Royal Academy of Engineering, February 2002.
[143] Review of Graduate Studies in the Humanities and Social Sciences, The British Academy, 2001.

Postgraduate qualifications

Master of Science (MSc)

The MSc is a one-year full time taught postgraduate course (generally also available part-time) that comprises a combination of taught modules, independent study, guided study programmes, lecture courses and project work. An MSc qualification indicates in-depth study in a subject beyond undergraduate level.

Master of Research (MRes)

This is a relatively new one year full-time course leading to a Master of Research (MRes) degree. Its purpose is to offer high quality postgraduate training in the methods and practice of research and in relevant transferable skills that are not normally offered in MSc courses. The MRes degree is intended to serve as a qualification for entry to a research career in industry or as an enhanced route to a PhD through further research. Each MRes course is structured to include a significant research component (comprising at least 50 per cent of the working year) and a series of supporting taught courses.

Master of Philosophy (MPhil)

The MPhil is a one or two year full time research course (2-3 years part-time). MPhil students typically join a research group, carry out a research project, and attend lecture courses and seminars appropriate to their topic. They write a dissertation on their research and have an oral examination at the end of the year. In some subjects – particularly those with 3-year undergraduate qualifications, and so mostly outside SET – an MPhil degree or equivalent is a necessary qualification for would-be PhD students.

Doctor of Philosophy (PhD, DPhil)

The PhD is usually a three year full time course (around five years part-time) involving training in and practice of original academic research. The student carries out and writes up a research project, which is examined by thesis and by an oral examination (the viva). In some HEIs the abbreviation DPhil is used; this report uses PhD to mean both.

Engineering Doctorate (EngD, DEng)

The Engineering Doctorate is a four-year postgraduate award intended for research engineers who aspire to managerial positions in industry. The core of the degree is the solution of one or more significant and challenging engineering problems within an industrial context, which includes taking factors such as financial constraints, timescales and personnel management into account.

The majority of EngD project work must be carried out within a sponsoring organisation conducting research in the UK. Supervision of the research is jointly between an industrial manager and an academic. Packages of training courses are tailored to the needs of individual candidates in order to develop a wide range of competencies in engineering business management, as well as specialist technical subjects. This taught component is assessed and forms an integral part of the degree.

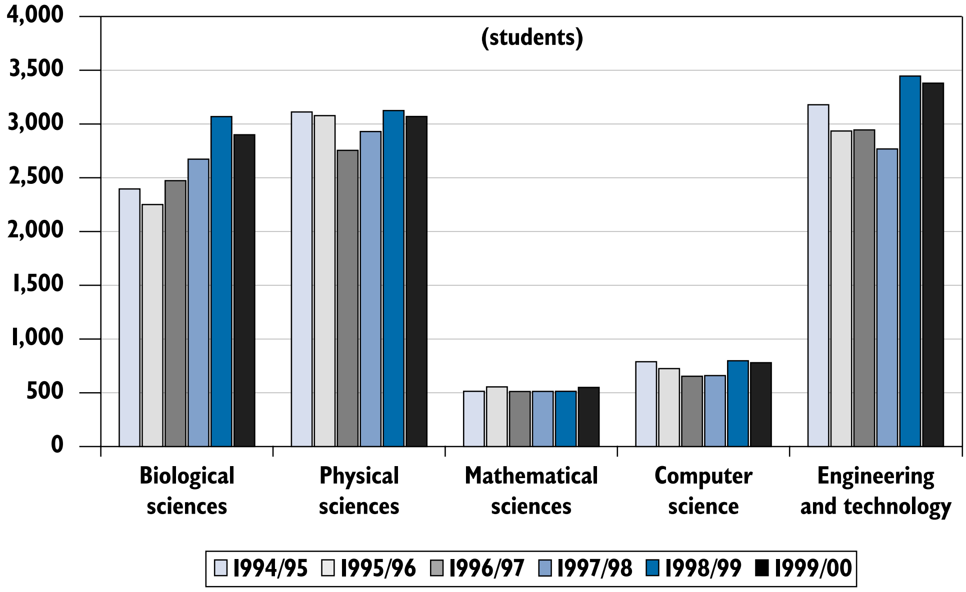
4.7 Funding for Masters degrees is often by the student, although some institutional support is available, and the Research Councils sponsor some places on MSc courses[144]. PhD funding comes from a variety of sources, including institutional (university) funds, industrial and charitable sponsors and the Research Councils, which support around a third of SET PhD students. Relatively few UK PhD students in SET self-fund.

The supply of postgraduate students

4.8 Each year, around 10,000 students enter science and engineering PhDs in the UK, of whom about a sixth are part-time. The UK produces over 7,000 PhD graduates a year in SET; exact figures are difficult to establish as a number of PhD students become 'dormant' (cease to be students at the HEI) before the eventual award of their PhD, and the proportion of these who are SET students is unknown.[145] Of those 6,000 gaining PhDs in SET subjects in 1999/2000 whose origins are recorded, 67 per cent are UK residents, 10 per cent from other EU countries and 23 per cent from outside the EU.

4.9 The number of doctorates awarded in the UK in all subjects increased by about 18 per cent between academic years 1995/96 and 1999/2000. The biggest growth areas for UK students were social studies and law (an 80 per cent increase in each), creative arts (over 110 per cent growth), and education and leisure (130 per cent growth). Over the same period, UK-domiciled students gained around 600 additional doctorates each year in medical,

Figure 4.1: Number of first year postgraduates (full & part-time), 1994/95 to 1999/00



Source: HESA.

[144] Historically, around 2500 Masters course places each year, the vast majority sponsored by EPSRC.

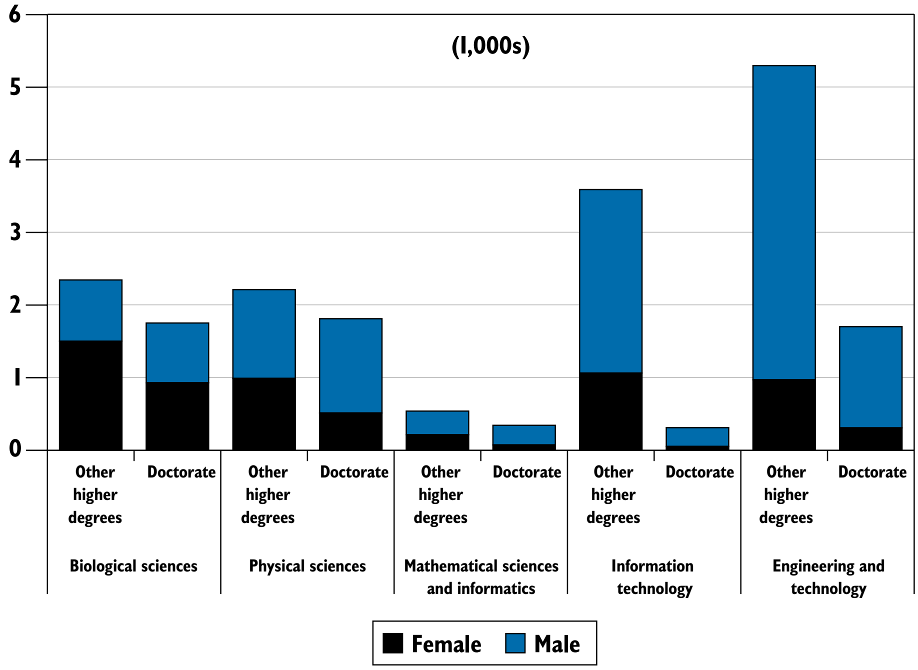
[145] These figures are taken from Students in Higher Education Institutions 1999/2000, HESA.

biological and related subjects. However, the number of doctorates awarded to UK-domiciled students in the physical sciences fell by 9 per cent between 1995/96 and 1999/2000.

4.10 Figure 4.1 shows improvements in recruitment to postgraduate study (predominantly PhDs[146]) at the end of the 1990s. These coincide with a significant increase in PhD stipends in 1998/99 (up 22 per cent to £6,455 in summer 1998), although numbers fall again in 1999/2000. A similar pattern to physical sciences is seen for computer science, for which the number of PhDs awarded has also fallen from its 1994 level, though again postgraduate recruitment has recovered after a dip in 1996/97.

4.11 Figure 4.2 illustrates that in physical and biological sciences around 40 per cent of all postgraduates are PhD students, whereas non-doctoral higher degrees are the most common postgraduate qualifications in computer science. Figure 4.3 illustrates a generally upward trend in women's participation in SET doctoral study, to over 50 per cent in the case of biological science. Although absolute levels of women's participation in SET subjects are low (15-30 per cent outside biological sciences), they are approximately in proportion to the percentage of women entering SET undergraduate courses three or four years earlier. Indeed, a higher proportion of women graduates than male graduates in engineering enter PhDs.

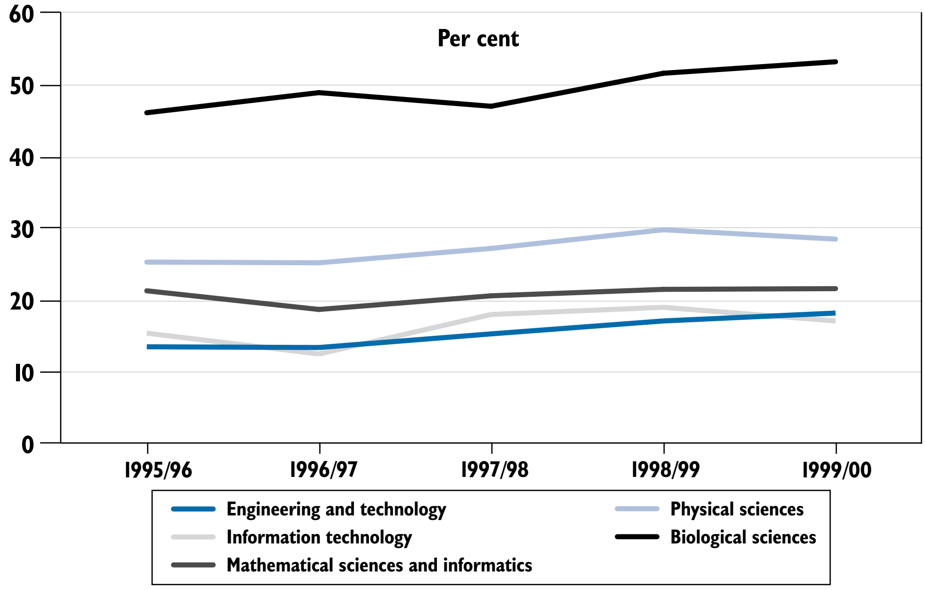
Figure 4.2: Gender and subject of qualifying postgraduates, 1999/00



Source: HESA.

[146] In many universities new students on PhD grants are initially registered for an MPhil or other postgraduate research qualification then transfer to a PhD course after a probationary period, and so cannot be distinguished from non-PhD students on MPhil courses.

Figure 4.3: Proportion of doctorates awarded to women, 1995/96 to 1999/00



Source: HESA.

The role of the Research Councils in PhD supply

4.12 The major influence on PhD availability and design are the Research Councils, which together fund around a third of the UK's PhDs in SET (around 4,000 across the Research Councils). The proportion of PhDs funded by the Research Councils varies greatly by subject area: over 45 per cent of physics PhDs and a third of maths PhDs are sponsored by a Research Council, whereas it is fewer than 20 per cent of PhDs in life sciences and electrical & electronic engineering and just over 10 per cent of PhDs in civil engineering. The principal funder of research activity is 'other' (which includes funding provided by the university), with 5-15 per cent of students funded as fee-paying overseas students and another 5-15 per cent funded by industry[147]. Around 650 PhD studentships are collaborative (CASE) awards involving an industrial sponsor with a track record in research; under EPSRC's Industrial CASE scheme (300 awards), the company defines the research topic, chooses a partner university, and may influence the choice of student.

4.13 The Quinquennial Review of the Research Councils published in November 2001 concluded that the Research Councils have a critical role to play in ensuring the supply of high-quality researchers in the UK, both by supporting postgraduate research training, and in fostering young scientists' early careers through fellowship schemes. The key recommendation of the Quinquennial Review concerning postgraduate training and research was that:

[147] Source: EPSRC data to support the 2001 Balance of Programme exercise, from www.epsrc.ac.uk

"The Research Councils, collectively and individually, should give greater attention to postgraduate training and postdoctoral research career support, taking note of the findings of the 'Roberts Review' in due course."

4.14 The Review makes its recommendations on postgraduates and on contract research staff (Chapter 5) in this context. Although the majority of PhD students are trained in HEIs, the Review intends these recommendations to apply in Public Sector Research Establishments and other non-HEIs in which PhD students work and learn.

The attractiveness of postgraduate study

4.15 Fluctuations in the numbers of SET postgraduates, particularly doctoral (PhD) candidates, have led to concerns by respondents to the Review that postgraduate education is becoming less attractive. A recent survey of postgraduate study intentions[148] shows that the long-term career goals of those graduates considering doctoral study are often to work as scientists and researchers, in academia and in industry. Reductions in the supply of PhD students are therefore likely to indicate reductions in the number of people wishing to enter these positions.

4.16 According to the postgraduate study intentions survey, 39 per cent of final year undergraduates across all subjects intended to pursue some form of postgraduate study, and another 28 per cent considered that they might. 30 per cent definitely would not pursue further study. Only 3 per cent had not considered it at all, indicating that promotion of postgraduate study is widespread within the higher education system. The survey found that undergraduates seem to be starting to plan their futures earlier, which may require changes in how universities market their postgraduate courses.

4.17 The major influences on whether an individual studies for a PhD or other postgraduate qualification are:

- the immediate financial reward to the individual, both in absolute terms and relative to other jobs and to the level of any debts the individual has;
- the perceived long-term financial and career effects of postgraduate study, including the attractiveness, or otherwise, of the careers in research and development for which a PhD is a prerequisite; and
- the non-financial attractiveness of postgraduate study versus other employment to the individual.

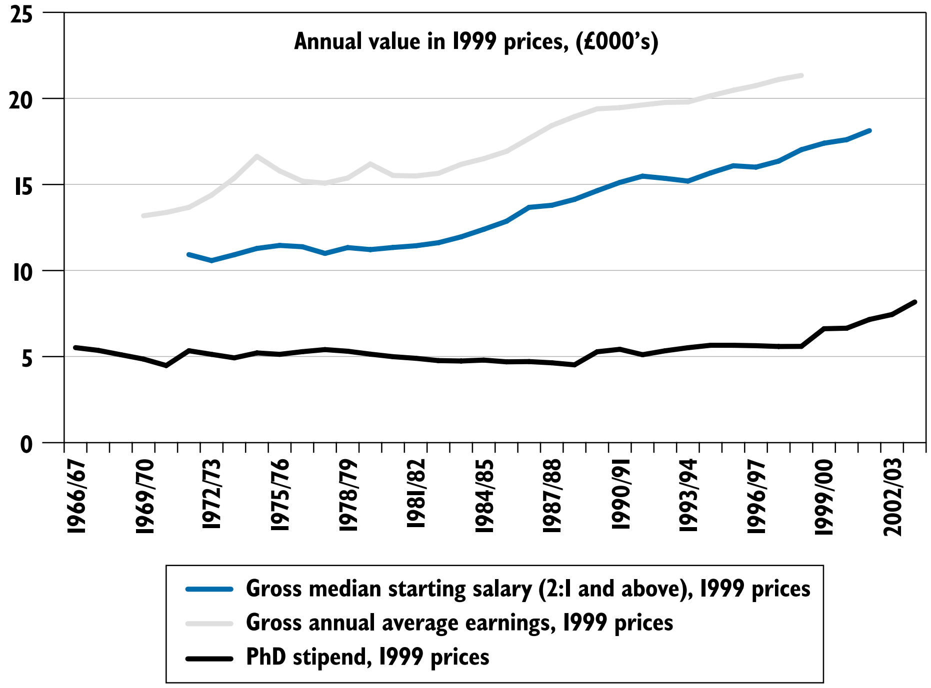
These issues are considered below in more detail.

[148] Report of the Findings of the 2000/2001 Survey of Postgraduate Study Intentions, M Phillips, University of Sheffield on behalf of the Office of Science and Technology (OST), 2001.

Short-term financial considerations in PhD study

4.18 PhD stipends are increasingly uncompetitive with the salaries of graduates, particularly those of able graduates in the physical sciences, mathematics, engineering and computer science. Figure 4.4 shows that in the 20 years from 1971/72, the PhD stipend fell by 4.5 per cent in real terms, while starting salaries for graduates with a 2:1 and above rose by 42 per cent. The recent increases in Research Council PhD stipends from £6,800 in 2000/01 to £7,500 in 2001/02, £8,000 in 2002/03 and £9,000 in 2003/04 announced in the Excellence and Opportunity White Paper (DTI, June 2000) have prevented the differential between stipends and salaries from increasing.

Figure 4.4: Comparison of PhD stipend, graduate starting salary and national average salary, 1966/67 to 2002/03



Note: 1998/99 figure was increased in summer 1998 following the Comprehensive Spending Review from the previously announced figure of £5455 to £6455

4.19 PhD stipends are currently comparable to the lowest incomes for full-time employment. The National Minimum Wage (NMW) is currently £4.10 for workers aged 22 or over. Employment at the NMW for 40 hours per week, 52 weeks per year would net £8,728 gross, or £7,477 after income tax and National Insurance (NI) contributions. This is approximately equal to the current level of PhD stipends (£7,500 in 2001–2002), which are not taxable. This sends a signal to prospective students that undertaking a PhD is likely to result in a rather Spartan existence.

4.20 PhD students typically undertake some small-group teaching or laboratory demonstrating, which in addition to developing transferable skills and improving the variety of PhD study also brings in income.[149] A student doing the EPSRC recommended maximum of 6 hours per week for 30 weeks per year (the work is generally with undergraduates who are not taught year-round) at £10 per hour would earn £1,800 per year, which is below income tax and National Insurance thresholds. A typical PhD student on a Research Council grant therefore earns around £9,300 p.a. net of tax; the median graduate salary of c. £17,500 (for those with a 2:1 or above) is worth around £13,500 net of tax. These comparisons are summarised in Table 4.1 below.

Table 4.1: Comparison of PhD stipend levels with available salaries

Annual income level	Net of tax & NI £ p.a.
National Minimum Wage (40 hours/week, 52 weeks/year)	7,477
PhD stipend 2001-02 (not taxable)	7,500
PhD stipend 2002-03 (not taxable)	8,000
PhD stipend 2003-04 (not taxable), minimum[150]	9,000
Mean graduate expected salary in 2000 (first job)	12,285
Wellcome Trust PhD stipend (bioscience, outside London, Year 1)	13,085
Median starting salaries of graduates with 2:1 or above	13,442
High calibre graduate job (e.g. consulting) starting salary	20,600

** assumes a single person under 65 in employment contracted into National Insurance financial year 2001/2.*

Source: Compiled from data quoted elsewhere in this report; estimate of high calibre graduate job income based on figure quoted in graduate recruitment brochure.

4.21 The growing gap between PhD stipends and graduate salaries, particularly for graduates in the more numerate and IT-intensive disciplines, is acting as a growing disincentive to PhD study. This is exacerbated by students' undergraduate debt, which is a major, and increasingly important, deterrent to postgraduate study.[151] The existence of undergraduate debt also seems to exert a psychological influence on graduates' career choices over and above the difficulties of repaying debt on a PhD stipend. (It should be noted that PhD students generally do not have to repay their student loans until after they complete their PhD programme.)

4.22 It is not uncommon for graduates to have debts of £10,000 or more on graduation, and – as noted in Chapter 3 – the average level of debt is increasing. In the 2001 Sheffield/OST survey of postgraduate study intentions,[152] 65 per cent of all graduates who had decided against further study reported debt to be a determining factor in the decision, and three quarters of those interested in postgraduate study were concerned about debt. The desire to enter employment immediately, which is often linked to

[149] Postgraduates' participation in these activities, and in the teaching assistants programme recommended in Chapter 2, should continue to be encouraged by institutions and must be supported by suitable training.

[150] Some Research Councils such as MRC pay more than this minimum rate; other sponsors of PhDs such as universities may pay less, though a few such as the Wellcome Trust pay more.

[151] Comparison of the 2001 Survey of Postgraduate Study Intentions results with the previous year's survey; see also the British Academy's Review of Graduate Studies in the Humanities and Social Sciences.

[152] Report of the Findings of the 2000/2001 Survey of Postgraduate Study Intentions, M Phillips, University of Sheffield on behalf of the Office of Science and Technology (OST), 2001.

the desire to clear debt, was also an important factor in undergraduate career choices for 76 per cent of those who had decided against postgraduate study.

4.23 The effect of debt, and particularly high-interest debt on credit cards, extends beyond its immediate financial implications in terms of interest payments. Although students do not seem to be particularly sensitive to accumulating debt (for example, many use student loans to achieve lifestyle objectives) this appears to go hand in hand with an intention and desire to pay off this debt on graduation. Graduates who have previously borrowed to finance lifestyle aspirations as undergraduates are unlikely (and probably unable) to do so throughout a PhD, particularly as overrunning the funding period will incur more debt.

4.24 The majority of PhD students do not have to start paying off student loan debt while studying, since they do not have taxable incomes over £10,000; the exceptions are PhD students employed as research assistants (who therefore earn more than the typical PhD student). However, graduates wishing to clear their debts immediately still see this postponed debt[153] as a problem. It is worth noting that a number of graduate employers pay 'golden hellos' of up to about £10,000 to help attract new graduates, which do not appear in the salary figures given in Figure 4.4. This may be valued psychologically by graduates (representing freedom from debt) as well as for its financial value, and may therefore exert a significant effect on some graduates' career choices.

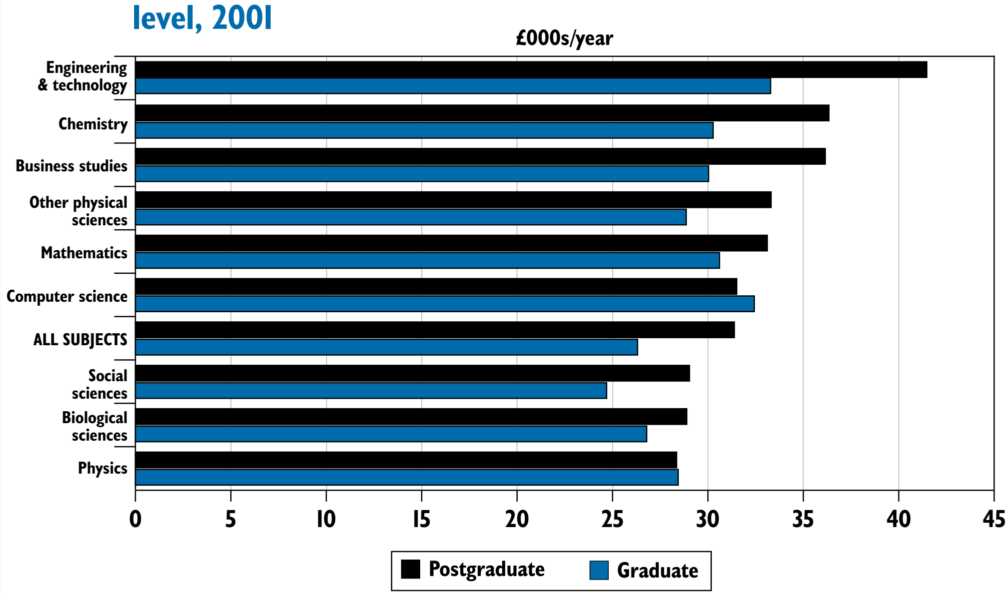
Long-term benefits of postgraduate study

4.25 The divergence between PhD stipend levels and graduate salaries, and the effect of growing undergraduate debt, are acting as disincentives to postgraduate study. However, this should to some extent be offset by the good long-term salary prospects of postgraduates.

4.26 The average salaries of SET postgraduates almost invariably exceed those of non-postgraduates, as illustrated in Figure 4.5 below. To some extent this represents the premium paid to higher-ability graduates, from whom postgraduates are generally drawn. The evidence is that a postgraduate qualification will tend to improve, rather than damage, career and earnings prospects, in the long term.

[153] at 0% real interest (the debt increases in line with inflation).

Figure 4.5: Gross annual pay in main job by discipline and level, 2001



Source: Labour Force Survey, March 2001.

4.27 The exceptions to this trend are computer science and physics, in which graduate and postgraduate average salaries are virtually identical. This is consistent with reports to the Review that the IT industry generally does not value computing postgraduates over graduates (in other words, does not pay a salary premium to postgraduates) and also has a high demand for skilled (graduate) labour.

4.28 Some career opportunities in business R&D and in academic research are open only to PhDs. Some undergraduates are disincentivised from postgraduate study because these careers are often reported to be poorly-paid and insecure, with poor working conditions. Although these jobs require a PhD, research students interviewed by the Review felt that these 'R&D employers' did not value postgraduates as much as other high-quality employers.[154] The general impression among postgraduates interviewed by the Review Team was that research jobs were unattractive for financial reasons, although a number still wished to pursue them for non-financial reasons, generally personal interest. The issue of career attractiveness is covered in more detail in Chapter 5 (employment in universities) and Chapter 6.

4.29 The long-term benefits of postgraduate study are therefore a potential motivator for students to do a PhD. Although starting salaries for SET postgraduates are not particularly high, and there are issues around the attractiveness of research jobs in both HE and business, postgraduates' long-term earnings potential is good. However, this is more than countered by the short-term disincentives to PhD study posed by low stipends and undergraduate debt. Furthermore, the lack of an initial salary premium for PhDs in many R&D jobs masks the potentially higher salaries which may be available later on.

[154] A view reported in *Doctoral Level Research Students in Engineering: A national concern*, Royal Academy of Engineering, February 2002.

Non-financial factors affecting the attractiveness of postgraduate study

4.30 The Review's discussions with current and recent PhD students have indicated that PhD courses attract highly able potential researchers who value the opportunity to carry out basic research, very often because of a strong interest in the subject and sometimes (again based on the Review's discussions with research students) due to an unwillingness to make career or employment choices in the run-up to graduation.

4.31 Careers advice plays a role in postgraduate recruitment, as noted in Chapter 3: over a quarter of those definitely intending to pursue postgraduate studies cited careers advice as a factor in this decision. If graduates are not aware of the career opportunities open to them as a direct result of attaining further qualifications, then they will be less likely to consider this option. Academic tutors are an even stronger influence on students: in the Sheffield/OST survey[152] of postgraduate study intentions, 57 per cent of students who had definitely decided on postgraduate study (of whom three quarters wanted to be PhD students) were influenced by their tutor. The immersion of SET undergraduates in an environment which values and respects postgraduates and the fostering of positive attitudes to research and to knowledge creation also aid PhD recruitment.

4.32 HEIs currently rely on such non-financial factors (essentially, the preferences of individual students) to attract students to PhD study. This tends to attract individuals with a strong interest in the research topic and the other non-financial aspects of a PhD and/or those who place the least value on the non-financial aspects of employment (including work environment and commercial ethos). This may act to conserve academic quality of PhD students at the expense of quality as perceived by business.

The current attractiveness of PhD study

4.33 The low stipend and low starting salaries for PhD holders mean that PhD study is increasingly unattractive to graduates. Many university departments report difficulty in finding sufficient numbers of PhD students – particularly UK PhD students – in certain disciplines such as engineering[155] and computer science. Improvement to PhD stipend levels is needed to ensure the UK's supply of scientists and engineers is maintained.[156]

4.34 In addition to problems in the quantity of PhD students in some disciplines, there are complaints from employers – particularly in industry – that the quality of PhD students is too low and/or declining. This is a particular criticism of their broader interpersonal and management skills, although some concern has been expressed both about the technical skills and the creativity of many

[155] Doctoral Level Research Students in Engineering: A national concern, Royal Academy of Engineering, February 2002.

[156] This was also recommended in The Funding of Higher Education, Council for Industry and Higher Education, December 2001, for example.

PhD graduates. The chapter therefore considers these issues of quality and makes recommendations to improve both the quality and quantity of PhD students.

The quality of PhD entrants

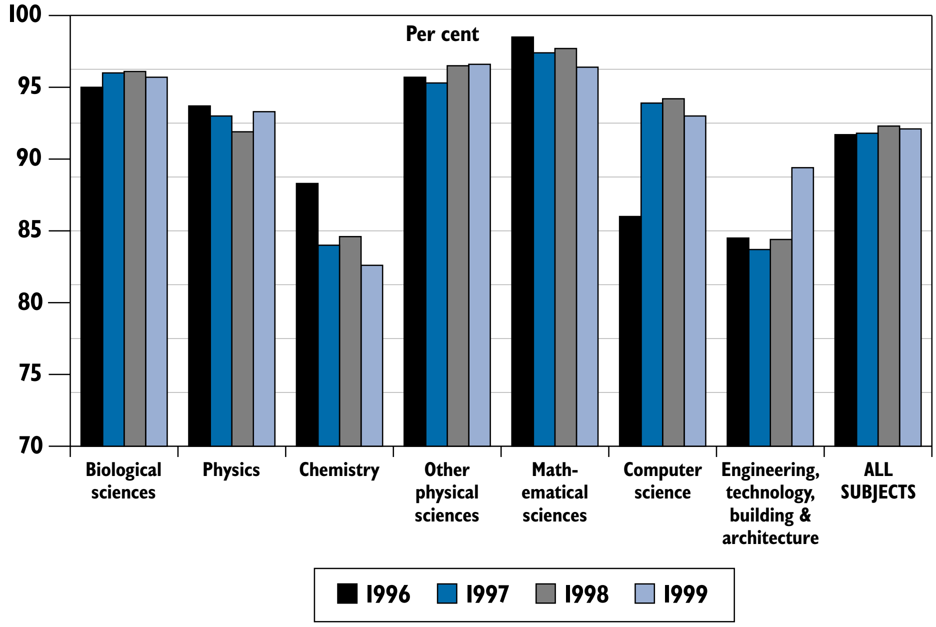
4.35 A particular concern of many respondents to the Review was the quality of PhD students, both at the commencement of their study and on completion of it. The overall quality of undergraduate education in science and engineering was discussed in the previous chapter. The quality of the PhD student intake and the factors affecting this are explored below, before turning to issues of the quality of PhD training and PhD holders.

4.36 The most easily obtained measures of the quality of those undergraduates going on to study for a PhD are their A-level points scores and degree classes. These are measures of academic rather than employer definitions of quality, although there is some correlation between the two.

4.37 Over the period 1996-2000, an increasing proportion of those beginning PhD study had 24+ A-level points. However, this increase needs to be understood in the context of recent substantial rises in the proportion of pupils achieving grades A and B in maths, physics, chemistry and biology A-level. As discussed in Chapter 3, many HE staff therefore believe that A-level points scores are a poor predictor of student quality at undergraduate and, by extension, postgraduate level. The Review therefore finds it difficult to assess whether A-level points scores show an improvement in PhD entrant quality.

4.38 By contrast, there is no significant general trend in the degree class of those entering PhDs, although as Figure 4.6 shows there are some subject-related trends. The proportion of PhD entrants with a First or 2:1 has remained largely unchanged in most SET subjects: there has been a very slight upward trend overall (driven by increases in computer science and engineering); a noticeable downward trend in chemistry; and a slight decline in maths. These trends need to be seen in the light of the slight increases in the proportions of first class degrees and 2:1s gained in most SET subjects shown in Figure 3.7 in Chapter 3. Given that there will be random fluctuations in the underlying data, the only reasonably firm conclusion to be drawn from this degree class information is that the quality of students beginning PhDs in chemistry seems to have declined over the last few years.

Figure 4.6: Per cent of PhD entrants with a 2:1 or First, 1996 to 1999



Source: Unpublished HEFCE analysis of HESA data.

The case for additional incentives to undertake PhDs

4.39 If the quality of students entering PhD programmes is not to decrease, PhD stipends must not fall further behind the expectations of highly able graduates. Given the increasing importance of non-salary elements of remuneration (golden hellos, travel opportunities) and the growing levels and effect of undergraduate student debt in choosing employment, there is a strong case that the gap needs to be closed even to maintain quality of PhD graduates. Any noticeable improvement in PhD quality will certainly require an uplift in stipends over and above those already announced up to 2003/04.

4.40 The actual level of stipend increase required will vary between particular areas of research and between different institutions, to reflect graduate salary expectations and living costs in the area, among other factors. This implies that institutions need to be able to respond to their particular market conditions; EPSRC's doctoral training grants[157] seem to be a good model for this. There is also a question of whether salary progression through a PhD should be introduced: this would reward progress by students, but given the

[157] A doctoral training grant provides the finance for a cohort of students within a university. Universities are able to decide on the level of stipend (at or above the national minimum); the project duration (up to 4 years full time support); the format (e.g. part-time, industrial placement), and to adjust the number and timing of awards within the year (so students can start PhDs throughout the year) and between years. Decisions on stipend and project duration can be balanced with considerations of the discipline, location and overall student numbers.
Further background information on doctoral training grants is available from http://www.epsrc.ac.uk/epsrcweb/main/training/inuni/Scheme_Conditions.htm and from http://www.epsrc.ac.uk/epsrcweb/main/training/inuni/34-99.htm.

importance of debt to potential postgraduate students it is important to pay enough up-front to service and/or pay off debt, if more indebted students are not to be deterred from PhD study.

Recommendation 4.1: PhD stipends

In order to recruit the best students to PhD courses, it is vital that PhD stipends keep pace with graduates' salary expectations, particularly given the increasing importance of student debt on graduates' career choices. It is also important that stipends better reflect the relative supply of, and market demand for, graduates in different disciplines. The Review therefore recommends that the Government and the Research Councils raise the average stipend paid to the students they fund over time to the tax-free equivalent of the average graduate starting salary (currently equivalent to just over £12,000), with variations in PhDs stipends to encourage recruitment in subjects where this is a problem. Furthermore, the Review recommends that a minimum PhD stipend of £10,000 is established, to ensure that HEIs do not use this extra flexibility to attract extra PhD students at the expense of quality.

4.41 Setting a higher levels of Research Council stipend (in particularly higher minimum stipends) should encourage other funders of PhDs to follow suit, if they wish to attract good-quality PhD students. (The Wellcome Trust already offers such stipends to its sponsored students.)

4.42 The Review is also concerned that the funding system currently incentivises HEIs to focus on the quantity, rather than quality, of PhD students. Responses to the Quinquennial Review of the Research Councils indicated that the number of PhD students was being increased at the expense of their quality, thus threatening the supply of high-quality researchers in the UK. A working party of the UK Life Sciences Committee in 2000 took a similar view.[158]

4.43 One reason for this behaviour on the part of English HEIs is that the funding system incentivises them to recruit more PhD students. Universities receive HEFCE funding for research students as follows:

- teaching funds for each first year student, on a similar basis to undergraduate students;
- supervision fees for each second and third year student (roughly equivalent in value to the teaching funds in year 1); and
- research ('QR') funding for each second and third year student, calculated on the basis that each student takes 3.5 years to complete the PhD.[159]

[158] Postgraduate training in the life sciences, UK Life Sciences Committee working party report, January 2000.

[159] Research funding is assigned to HEIs based on a department's Research Assessment Exercise (RAE) score and the number of research-active academic staff; each research student counts as 0.15 of a full-time academic. The money is calculated on the basis of each student doing 3.5 years' research, paid over 2 years.

4.44 The research funding and supervision fees can act as an incentive to employ as many PhD students as possible regardless of quality, since they are not linked to quality of supervision or training. The Review believes that additional funding for PhD students must go to improving the quality of the intake via raising stipends and better training, rather than being spent on increasing the number of lower-quality PhD students by offering more stipends, for example. HEFCE and the Research Councils should consider how best to achieve this and reduce any incentives to expand quantity at the expense of quality.

The quality of PhD graduates

4.45 Securing a high calibre of entrants to PhD programmes will not of itself ensure that PhD graduates are attractive to employers in education and in business. The definition of quality as it applies to PhD training and PhD graduates to some extent depends on what a PhD is meant to achieve.

4.46 The role and nature of the PhD has been the subject of continuing debate in the UK since its introduction in the early twentieth century. It was influenced both by the original German PhD, which emphasised preparation for becoming a scholar (i.e. an academic), and the PhDs developed in the US from the 1870s. The US PhDs were aimed at a continuation of the educational process rather than the development of qualitatively different aptitudes. This tension between the PhD as part of the cycle of education and the PhD as an academic apprenticeship is discussed by Blume.[160] Other studies contrast the elements of training (in the sense of developing the abilities of a researcher) with individual achievement (making an original contribution to knowledge; creativity), or – confusingly – between education (promoting broad understanding and capability) and training (learning specific skills).[161]

The PhD process

PhD training is conducted in the context of the relationship between the student and his or her supervisor, an academic with research interests similar to the student's. PhD students in SET generally join their supervisor's research group and begin a research project under his or her direction. The supervisor's role is to advise and support the student in learning to conduct original research.

PhD students are often officially admitted onto a university's MPhil programme to begin with. In order to progress to formal registration for a PhD, students must demonstrate their abilities, typically by a dissertation on their research so far and an oral examination. Successful students proceed to the PhD, while unsuccessful students may leave with an MPhil (if their work is good enough) or with no qualification. The student spends the next 2 years carrying out and writing up a research project, which is examined by thesis and by an oral examination (the viva).

[160] The Role and Function of Universities: postgraduate education in the 1980s, S Blume, OECD, 1987.
[161] The Nature of the PhD: A Discussion Document, Advisory Board of the Research Councils/OST, 1993.

PhD training is often delivered through the informal relationships between the student and other members of the research group, including (but not limited to) the supervisor. Particularly in larger groups, postdoctoral researchers can play an important part in developing a PhD student's skills. More formal training can take a number of forms, from advanced lecture courses to departmental research seminars, development workshops for interpersonal skills and instruction in the use of IT at a variety of levels.

4.47 Responses to the Review's consultation indicate that HEIs' definition of PhD quality has tended towards preparation for academic scholarship (in a fairly narrow sense, dominated by engagement in curiosity-driven research) rather than broader education and training. Research employers in HE and business both seek a balance of education and training; non-research employers that take on PhDs and postdocs unsurprisingly tend to value the broad educational elements over training in specific scientific skills or techniques. In general, employers' opinion of PhD students' scientific research and technical skills – with the possible exception of practical skills such as use of the latest equipment – is very high, while interpersonal skills, and students' awareness of these abilities, are felt to be less good.[162]

4.48 One perception of business respondents to the Review is that PhD training and the postdoctoral research experience are not adapted to businesses' R&D needs, but reflect only the aims of the academic community. This perception seems if anything to have grown, which is surprising, given the increasing awareness of the need for business, enterprise and communication skills training in higher education. (The new Science Enterprise Centres[163] are beginning to play an important role in providing training in these areas.) It is possible that business expectations have increased, for example as a result of changes in the education systems of other developed countries, and also that the skills profiles of many jobs within business have altered, requiring greater breadth of skills and aptitudes. Another explanation would be that the quality of those attracted onto PhD courses has altered in this respect.

4.49 There is also cause for concern that UK PhD study and postdoctoral work is not particularly good training for would-be academic staff, because of its near-exclusive focus on research and its lack of preparation for other elements of the academic role including teaching, knowledge transfer/reach-out activity and student welfare.

[162] Very similar problems were identified in The Chemistry PhD – the Enhancement of its Quality, Royal Society of Chemistry, April 1995; however, the importance of the issue seems to have increased since then.

[163] See http://www.dti.gov.uk/ost/ostbusiness/sec.htm for further information.

4.50 Current arrangements do not therefore give satisfactory training in communication (including teaching), management and commercial awareness to fully equip researchers for the professional demands of modern academic life[164] and employment in R&D. A 1998 survey of all HEIs and EPSRC-supported research students revealed considerable variance between HEIs and university departments in the provision of training in these transferable skills. Largely as a result of these deficiencies, PhD graduates rarely attract a salary premium from employers.

4.51 Ways in which the quality of PhD graduates could be improved include:

- improving the quality of the intake by making PhD study more attractive, as discussed above;
- stronger quality control in PhD training by institutions, particularly in registration of students for the PhD degree;
- more emphasis by institutions on training in transferable, non-technical skills within current PhDs, and on promoting the value of this training to PhD students;
- giving individual PhD students more control over the nature of their training; and
- the introduction of longer (4 year) PhDs, with a higher component of skills training, advanced education in relevant scientific topics, and/or more challenging research projects.

These are discussed in more detail below.

Stronger quality control in PhD training

4.52 Learning transferable skills should be an important part of the PhD process. Today's PhD student is the highly-skilled academic or business researcher of tomorrow, and will need interpersonal and management skills to fill these roles effectively. HEIs have a vital part to play in educating their students about the benefits of such training, and must do more to encourage participation and provide high-quality and appropriate training. The recent HEFCE Review of Research recommended establishing threshold standards of good practice in research training provision:

"The HEFCE, together with the Research Councils and other stakeholders such as industry and charities, should develop minimum requirements which departments would need to satisfy in order to be eligible for HEFCE funding for postgraduate research training. The research assessment process should be extended to establish whether departments comply with these minimum standards."

[164] The Chemistry PhD – the Enhancement of its Quality, Royal Society of Chemistry, April 1995, http://www.rsc.org/lap/polacts/phd.htm contains an excellent discussion of this problem and how it should be addressed.

4.53 The Joint Funding Councils Review of Research Training, begun in late 2001, is seeking to determine suitable standards. The Review has identified a number of areas to be dealt with:

- ensuring PhD students' work is creative and original;
- supporting and rewarding good PhD supervision; and
- increasing students' participation in and learning from training in transferable skills.

It is important that these standards are seen to be challenging rather than a simple endorsement of current practice.

4.54 One particular concern which has come to the Review's attention is that institutions are insufficiently searching in testing PhD students' abilities. As part of their quality control procedures, most institutions register new PhD students for a lower degree such as an MPhil. On satisfactory progress (generally demonstrated by a written report and an oral examination and/or presentation) the student is formally registered for or 'transferred' to the PhD degree.[165] The Review is concerned that in some cases this test does not require the student to demonstrate sufficiently the qualities of creativity and original thought which are vital to research and much prized by employers. For this reason, the Review is particularly keen to see a strengthening of quality assurance procedures.

4.55 The function of a supervisor in supporting and mentoring students is vital in developing them into capable researchers. It is the supervisor who is best placed to develop a research student's judgement about research method, and to stimulate creativity and analytical thinking. Good supervisors also play a role in helping students identify suitable training, and in encouraging them to make the most of such opportunities. Poor supervision (including the deliberate choice of relatively undemanding projects for PhD students, a problem which seems commonest in large research groups) can potentially suppress all of these desirable qualities.

Provision of training in transferable skills

4.56 The Research Councils, which collectively are the single largest PhD funder in the UK, are major influences on PhD training standards. All Research Council students have access to a special week of transferable skills training and careers advice under the Research Councils Graduate Skills Programme (RCGSP) described below.[166] The Research Councils also published jointly a Concordat setting out the skills a PhD student should acquire as part of their training. The recent Quinquennial Review of the Research Councils (December

[165] The language used to describe this 'transfer' process varies greatly between universities, but the principles – as outlined – are broadly the same.

[166] All EPSRC-sponsored students are now required to attend a Graduate School, or an equivalent training programme, during the second or third year of a 3-year PhD. The other Research Councils strongly recommend participation.

2001) recommended that the Research Councils should monitor the quality of research training and career development, and needed to examine how training could better meet the needs of employers, without jeopardising high quality research content.

4.57 The Graduate Schools offered by the RCGSP are five-day residential workshops at which PhD students – working with young managers and under the guidance of a course director and tutors – develop their team-working and communication skills. This is achieved using 'active learning', a mixture of case studies and business games including simulations relating to research and development, product development, marketing and crisis management. Career development and awareness is promoted through hearing about the experiences of the young managers and in sessions on interviewing and CV-writing skills. Participation rates for Research Council students at the largest Research Council-funded HEIs are given in Table 4.2.

Table 4.2: Uptake of RCGSP places by SET students, 2001

Institution	RCGSP attendance Per cent
University of Sheffield[167]	70
University of Birmingham	55
University of Nottingham	55
University of Edinburgh	45
University of Leeds	45
University of Manchester	40
University of York	40
University of Cambridge	35
University of Oxford	35
UMIST	33
University of Liverpool	33
University of Bristol	33
University College London	33
University of Newcastle	30
Imperial College of Science, Technology and Medicine	30
University of Glasgow	25
University of Southampton	25
University of Warwick	20
University of Wales, Cardiff	15
University of Sussex	10
Average	**35**

Source: Research Councils Graduate Schools Programme – figures for the 20 largest Research Council[168] funded HEIs only (unpublished data).

[167] The University of Sheffield accepts RCGSP attendance against its compulsory credit-based Research Training Programme.

[168] Students funded by BBSRC, EPSRC, MRC, NERC & PPARC.

4.58 The difference in RCGSP participation rates between the three institutions listed at the top of Table 4.2 (55 per cent or more) and the three at the bottom (20 per cent or less) may in part be due to alternative skills training provision in the latter. However, the disparities suggest that institutional attitudes play a major part in ensuring students engage in suitable training, and that many institutions need to take PhD training more seriously.

The role of the individual research student in training

4.59 Comments made to the Review by businesses, universities and others have mainly concentrated on how the providers of research training should alter the PhD. However, the effectiveness of training also critically depends on the individual. Students need to be aware of the nature and value of their own transferable skills, and to take ownership and responsibility for their learning. If this is not encouraged, the PhD student can feel himself or herself to be a passive client of the university, to be trained according to a particular imposed programme.

4.60 The Review Team's visits to HEIs indicated that even in universities where training is provided and a "charter" of PhD students' entitlements exist, awareness of this entitlement is not widespread. The Review also encountered some instances of research students wanting to undertake training which was available within the university, but was not accessible to them. The skills students wished to acquire varied considerably: one physicist wanted to train as a teacher (PGCE) while studying for a PhD, while others wanted to study languages or specialist IT courses, for example. The Review is concerned that PhD students wishing to obtain training of clear professional relevance (present or future) have difficulty doing so, although the potential cost implications for universities of providing more free-form and/or extensive training are acknowledged.

4.61 Clearly there is a place for structured training and education, using the institution's experience to develop courses for the benefit of the individual learner. However, given both the individual nature of researchers and research projects, and the increasing need for people to take charge of their own learning throughout their lifetime, there would be value in placing more control of training in the hands of the student rather than the institution.

Recommendation 4.2: PhD training elements

Despite the welcome current moves by the Funding Councils to improve the quality of PhD training, institutions are not adapting quickly enough to the needs of industry or the expectations of potential students. The Review therefore believes that the training elements of a PhD – particularly training in transferable skills – need to be strengthened considerably. In particular, the Review recommends that HEFCE and the Research Councils, as major funders of PhD students, should make all funding related to PhD students conditional on students' training meeting stringent minimum standards. These minimum standards should include the provision of at least two weeks' dedicated training a year, principally in transferable skills, for which additional funding should be provided and over which the student should be given some control. There should be no requirement on the student to choose training at their host institution. The minimum standards should also include the requirement that HEIs – and other organisations in which PhD students work – reward good supervision of PhD students, and ensure that these principles are reflected in their human resources strategies and staff appraisal processes.

Furthermore, in order to assure employers of the quality of PhD students, as part of these standards the Review recommends that institutions should introduce or tighten their procedures for the transfer of students to the PhD. In particular, the Review believes that HEIs must encourage PhD projects that test or develop the creativity prized by employers.

The duration and content of the PhD

4.62 One possibility which a number of respondents to the Review explored was that the composition and length of the PhD should be altered. This would reflect the 'real' length of the three year PhD (the majority of students take between 3-4 years to complete a PhD, as illustrated for Research Council students in Table 4.3, and very few take less[169]) and could potentially incorporate more explicit training and education and/or more challenging projects. A longer PhD could be a formal programme of four years or of some intermediate length between three and four years, for example. The Quinquennial Review of the Research Councils (2001), on the other hand, opposed unduly extending the PhD period to achieve this, although it also noted that "it is appropriate that subject discipline should predicate different approaches to postgraduate training".

[169] See for example Career Paths of a 1988-1990 Prize Student Cohort, The Wellcome Trust (March 2000), which shows around 80% of a sample of 125 bioscience PhD students taking 3-4 years to complete a PhD (Figure 3.1 in Chapter 3) but only 3 out of 125 completing within 3 years.

Table 4.3: Thesis submission rates for Research Council students, 1994-1999

PhD commenced:	1990	1991	1992	1993	1994	1995
Proportion submitted within 4 years, i.e. by:	1994 per cent	1995 per cent	1996 per cent	1997 per cent	1998 per cent	1999 per cent
BBSRC	70	77	77	83	85	86
ESRC	73	71	75	80	75	80
MRC	64	58	67	69	72	73
NERC	73	72	71	73	73	67
EPSRC	67	68	67	73	72	74
PPARC	82	82	81	80	81	83

Source: ESRC.

4.63 There are a number of existing or developing models for 4-year PhDs in the UK. The New Route PhDs developed in ten English HEIs using HEFCE funding are intended to be integrated PhD courses somewhat like the US PhD, with a significant taught component. The Engineering Doctorate is more established and highly respected, with a particular emphasis on business involvement and transferable skills, including management. A '1+3' model for PhD study, whereby a student completes a 1-year MPhil or MRes course before beginning a 3-year PhD[170] would also be feasible.[171] Other uses for an extended PhD period could include experience of work outside the research group (in a company or another research group), teacher training (suggested to the review by both students and HEIs) and – if the project generates commercially valuable knowledge – the technology transfer process. There is also the potential for longer and more challenging research projects to be undertaken, while still allowing more time and flexibility for other training and development than a 3-year programme. The arguments for retaining a 3-year PhD versus adopting a 4-year PhD, assuming the same length of undergraduate course in both cases, can be summarised as follows:

Table: 4.4: Comparison of benefits of 3 year and 4 year PhDs

Advantages	Disadvantages (of 4 year PhD over 3 year)
Student has more time for research and training	Student takes longer to enter labour market; debt will deter more students
Allows more ambitious projects	Students' work may be slower or may 'drift' as urgency of shorter PhD is lost
May reduce 'overrun' – PhD students usually take longer than 3 years to complete a PhD and so more students will be able to complete in the time available	Overrun may remain or even get worse as supervisors require 4 years' lab work and writing up takes longer as there is more material
Closer to European and world standard length of PhD	Possible loss of UK competitive advantage if high-quality UK 3-year PhD disappears
Better trained and more experienced (hence, more valuable) PhDs	Additional cost per PhD

Source: Review.

[170] The 1+3 model is common in arts and social sciences; ESRC now requires its students to follow a 1+3 route.

[171] According to the UK Life Sciences Committee Working Party report Postgraduate Training in the life sciences, over 20 per cent of BBSRC PhD students have a postgraduate Masters qualification – mostly an MSc.

Possible models for a 4 year PhD

4.64 As noted by the most recent Quinquennial Review of the Research Councils, different patterns of PhD provision may be appropriate in different subjects. In particular, subjects where 3-year undergraduate courses predominate, such as the biological sciences, may derive particular value from operating 4-year PhD courses. In engineering, on the other hand, the 4-year MEng undergraduate degree is the norm for chartered engineers, and 4-year PhDs may be of more limited value.

The 'early entry' 4-year PhD

4.65 Students entering a 4-year PhD from a 4-year undergraduate programme would have spent 8 years or longer in higher education, and thus would not have participated in the labour market or begun to pay off student debt until their mid-20s at the earliest. One way of circumventing the late entry to the labour market of a 4-year PhD is to start the PhD earlier. It would be possible for HEIs to identify able students and encourage them to graduate with a BSc after three years and begin a four year PhD,[172] as an alternative to a four year undergraduate degree plus a three year PhD. Under these arrangements each student would do around 15 extra weeks' research and training (the difference between a 30-week, 9 month undergraduate course and a 12 month PhD) without extending the overall seven year duration of study.

4.66 While this model helps individual HEIs recruit more students from their undergraduate supply, it also inhibits the flow of students between institutions, as it ties undergraduates who might have studied at other universities into their 'home' institution. Students leaving after year 3 of a 4-year undergraduate programme with a Bachelors degree may also be perceived as having an inferior qualification, particularly when the undergraduate Masters has professional significance (such as the MEng in engineering). Although there may be individual cases where this method can help recruit and train better researchers, its drawbacks mean it is not a suitable general model for PhD provision in the UK.

The Wellcome Trust PhD

4.67 The key feature of the 4-year Wellcome Trust PhDs in life science is an introductory year involving three 12-week advanced courses and associated practical mini-projects, followed by three months learning research techniques and developing a thesis proposal. This helps inform students' choice of research projects (and allows more complex projects) as well as bringing students from different backgrounds up to speed with modern molecular and cellular biology. The Wellcome Trust also offers students a Science Communication course as part of the 4-year programme.

[172] This mechanism is already used by some HEIs to select 3-year PhD students from their third-year undergraduates.

The New Route PhD

4.68 The New Route PhD – developed in ten English universities – combines a specific research project and research training (comprising approximately 60-70 per cent of the programme) with a programme of formal coursework throughout the programme. The idea is for students to develop a fuller and individually-tailored range of skills, including from discipline-specific specialist taught courses and broader skills (e.g. management and enterprise) training, alongside research training and a major piece of research. The length of a New Route PhD would normally be four years (or potentially three years for students with Masters' level entry qualifications).

Flexible funding to cover a range of PhD durations

4.69 There are good arguments for extending the period of PhD training (and funding) in order to increase the depth and breadth of skills acquired – through spending time in industry, for example – and to attract potential students who would value this approach more than a traditional three-year PhD. However, increasing the length of time before a student can begin paid employment can be a disincentive to recruitment, and there is international demand for 3-year UK PhD courses. It is therefore clear that a mixture of PhD provision, both in length and in content, is necessary to attract the full range of potential researchers into PhD training.[173] Institutions should be funded and encouraged to develop a diversity of approaches to the PhD. All PhDs should be examined to the same standard in the final thesis and viva, although longer PhD programmes would involve additional elements.

4.70 The majority of PhD students take between three and four years to complete their studies. The Review's discussions with PhD students indicated that most students expected to need extra time to write up their PhDs at the end of three years. The Review believes that the funding system should acknowledge this, and provide institutions with sufficient financial flexibility to allow them to support students whose projects do not fit neatly into 3- or 4-year programmes. This will allow institutions to set more challenging projects without imposing severe financial consequences on the student if the project over-runs, or to incorporate advanced courses and additional transferable skills training.

4.71 HEFCE already allocates research funds to HEIs on the basis that a PhD takes an average of 3.5 years, and could pay the supervision fees for second and third year students on a similar basis. Research Councils currently provide funding (stipends etc.) on the basis of three years of study, although the EPSRC doctoral training grant model allows more flexibility. Allocating PhD

[173] Comments by Wellcome Trust PhD students on a mixture of three and four year PhD courses indicate that both approaches appeal to some students but not to others; see Review of Wellcome Trust PhD Research Training: The Student Perspective, The Wellcome Trust, March 2000 for further details.

student support by HEFCE and the Research Councils to institutions on the basis of 3.5 year average course durations would give them the ability to vary:

- the length of formal course offered (3 years or 4 years, or of intermediate length);
- the length of support to individual students, to allow more flexibility to engage in multidisciplinary projects and training, for example, or to provide additional paid time for students to write up their projects; and
- stipend levels (subject to a minimum level, as discussed previously).

Recommendation 4.3: Length and nature of PhD programmes

The Review believes that measures should be put in place to help nurture a diverse range of PhD programmes to train able students in research methods and technical skills, and help them acquire the advanced knowledge and transferable skills they will need in their future careers. This should include encouraging part-time working and the gaining of experience in business R&D. Individual institutions should be given flexibility to offer a range of provision. The Review therefore recommends that:

- the Government and the Research Councils should fund their present numbers of PhD students on the basis that the average full-time student requires funding for $3^1/_2$ years;
- it should be possible for the institution to use the funding flexibly to run three- and four-year full-time programmes (and also study of intermediate length) to support longer and more challenging projects, advanced courses and transferable skills training;
- both three- and four-year courses should be examined to the same standards, which should be at least as high as the current standards; and
- students should be able to exit early from PhDs (subject to satisfactory performance) with an MRes or an MPhil.

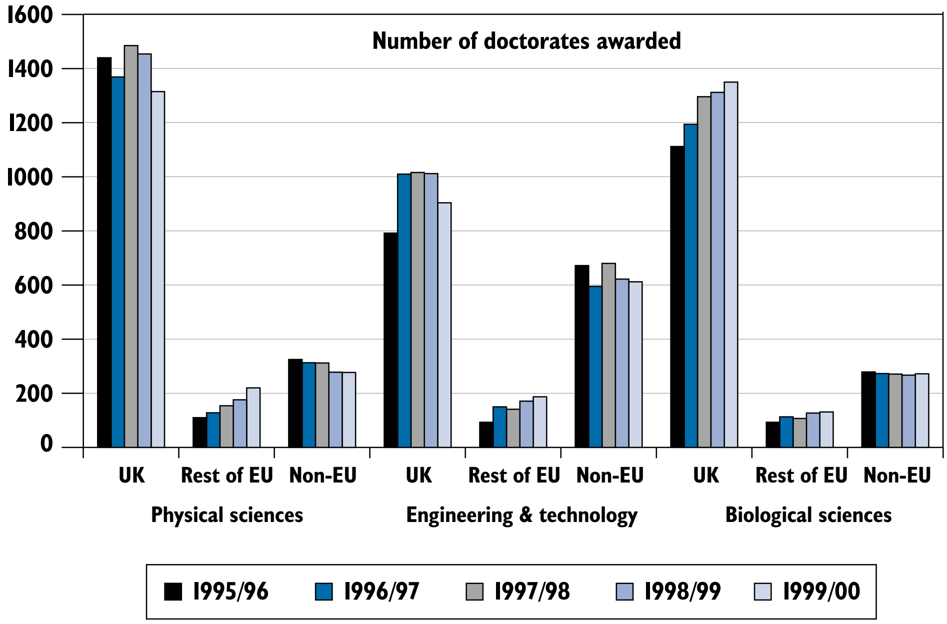
The Review believes that the EPSRC's doctoral training grants system represents a good way of achieving this flexibility, and urges other Research Councils to implement similar mechanisms.

Retention of PhD students in the UK

4.72 It was suggested by a number of respondents to the Review's June 2001 consultation document that the UK is increasingly losing its science and engineering PhD graduates overseas. It is also the perception that overseas students who take PhDs in the UK do not remain once they have obtained their PhD. On the other hand, some respondents pressed for Research Council funding to cover maintenance awards for EU postgraduate students, wanting to encourage these students to come to the UK to improve the quality of intake onto PhD programmes.

4.73 There are two aspects to the retention of PhD students in the UK: the number of students of UK origin taking PhDs in science and engineering, and the net flow of people with such PhDs into and out of the UK. Retention is itself a difficult concept, as in the global market for researchers people will often live and work outside their country of origin. Mobility of researchers is encouraged both within the EU and within the global research community. Furthermore, tracking the movement of skilled researchers is extremely difficult.[174] In particular, information on postgraduates' first destinations can be misleading, particularly for researchers, for whom a postdoctoral post outside the UK (e.g. in the US) is often encouraged as a good career move.

Figure 4.7: Number of UK doctorates by discipline and student origin, 1995/96 to 1999/00



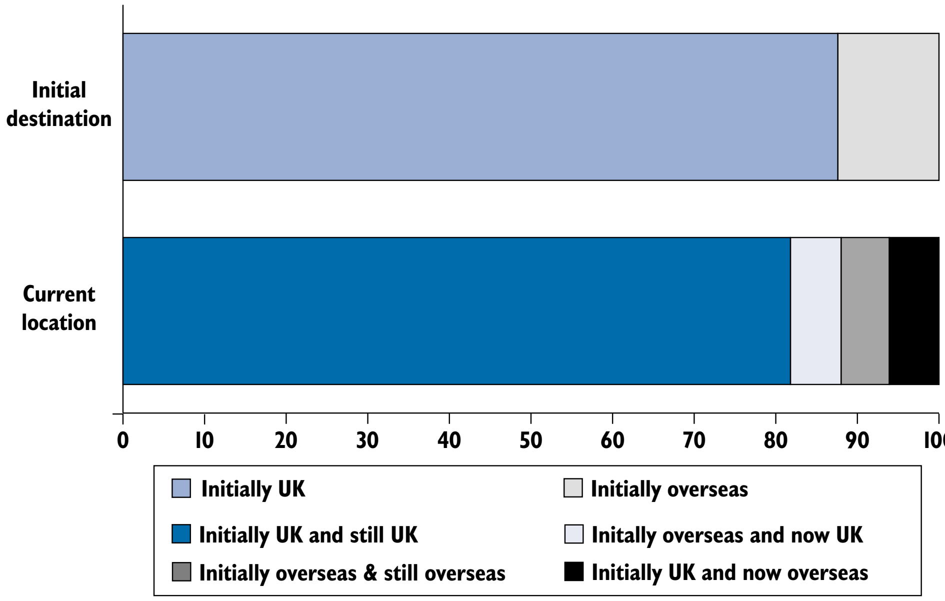
Source: HESA Student Returns (unpublished DfES data) – excludes students gaining doctoral qualifications from dormant status (i.e. those who were not students immediately prior to award and whose origin was therefore unknown).

4.74 Of those students who leave the UK on completion of a PhD, many return quite quickly; a study by EPSRC of career progress for its postgraduates 6-7 years after the end of the studentship showed that a large proportion (almost 15 per cent) of chemistry PhDs went to the US as a first destination, but over half of these had returned to the UK within the period of the study.[175] This is illustrated in Figure 4.8 below:

[174] Canberra Manual, OECD.

[175] Where do EPSRC students go?, Martin Dunn, EPSRC, September 2000.

Figure 4.8: Location of first and current jobs of EPSRC postgraduates



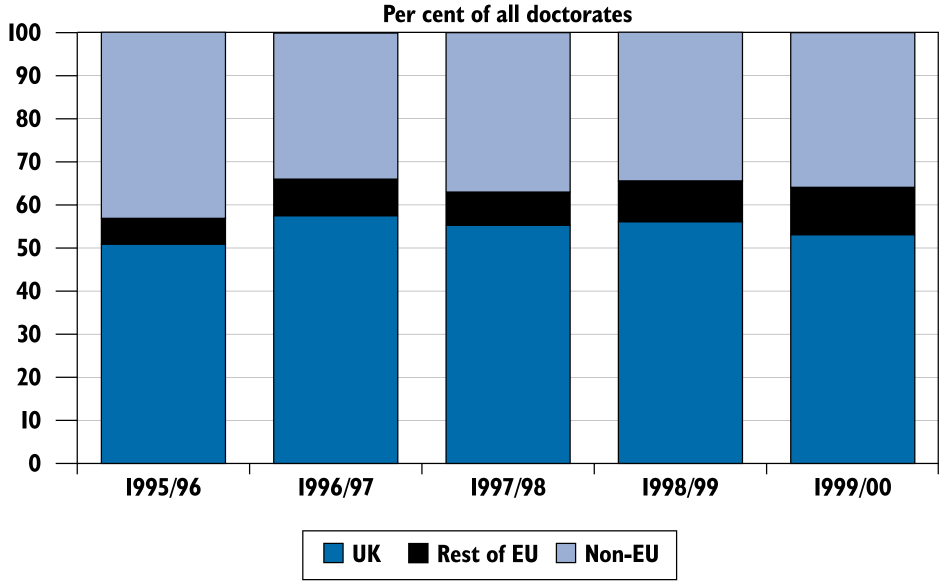
Source: Where do EPSRC students go?, Martin Dunn, EPSRC, September 2000.

Non-UK PhD students studying in the UK

4.75 In the UK, the greatest proportion of students from outside the UK is found on engineering courses. Figure 4.9 illustrates that typically 40 per cent to 50 per cent of engineering PhD students in the UK are not of UK origin. This level of participation by non-nationals is not exclusive to the UK; in 1995, 40 per cent of all US science and engineering doctorates were gained by citizens of foreign countries (up from 27 per cent ten years previously) and 56 per cent of engineering doctorates awarded in 1991-1995 were gained by non-US nationals.[176] A recent report in Physics Today (May 2001) noted that over half of the pool of US PhD students in physics were foreign.

[176] National Science Foundation/SRS, Survey of earned doctorates for the years 1991-95.

Figure 4.9: Proportion of UK doctorates in engineering by student origin, 1995/96 to 1999/00



Source: HESA Student Returns (unpublished DfES data) – excludes students gaining doctoral qualifications from dormant status (i.e. those who were not students immediately prior to award and whose origin was therefore unknown).

4.76 It is not immediately obvious whether high numbers of overseas students represent a problem for the UK or a benefit. From a UK skills perspective, too high a proportion of non-UK students may cause difficulties. The global market for scientists and engineers notwithstanding, there is a tendency for even the highly skilled to remain in or return to their country of origin. Researchers of other nationalities actively value the opportunity to hone their scientific English and hence seek out opportunities to study in anglophone countries such as the UK, but will often return to their country of origin within a few years. If too many students from outside the UK occupy PhD places which would otherwise have been taken by able UK students, there will be a skills cost to the UK, as those non-UK students are more prone to leave the UK than 'home' students.

4.77 However, if most of the students coming to the UK are self-funded or are filling places which UK students would not fill (because demand from potential students is low, and/or good candidates are not available) then the UK benefits. Not only does it gain from the students' research outputs while they remain in the UK, but the introduction of individuals with a different set of skills and approaches from UK students will lead to beneficial cross-fertilisation of ideas and approaches and strengthen both UK research and UK research training. The presence of non-UK students may also lead to longer-term benefits of international networking between former PhD students. Furthermore, non-EU students are net contributors to an HEI's income, and may help maintain the viability of a university department that might otherwise close.

4.78 In conclusion, the presence of non-UK students in the UK is almost wholly beneficial, as long as there is a sufficient supply of UK scientists and engineers (or of scientists and engineers wishing to work in the UK). The Review has not found evidence that the presence of large numbers of non-UK students indicates anything other than the weak demand from the most able UK students to study for a PhD, and so the Review believes that action to render PhDs more attractive to UK students is more important than the origins of non-UK PhD students. However, it is important that the situation should be monitored to ensure that enough good-quality PhD students from the UK are trained in the UK and that non-UK students are encouraged to remain and enabled to do so by the work permit system. Chapter 6 deals with the issue of work permits in more detail.

4.79 This argument deals only with supply direct from higher education. Once researchers are in the labour market, the responsibility to recruit and retain them in R&D posts must lie with the employers – in both HE and business – collectively. Employers also have a shared responsibility with the researchers they employ for the continuing professional development (CPD) of those researchers.

Maintenance awards for EU postgraduates

4.80 Many universities interviewed by the Review Team or which responded to the consultation said that a lack of sufficiently high-quality UK students wishing to do PhDs encouraged them to recruit students from overseas. EU students often wished to undertake postgraduate training in the UK, but Research Council grants would pay university fees but no maintenance support (stipend). Universities have therefore found themselves either leaving studentships unfilled or having to pay EU research students maintenance from other resources.

4.81 In order to allow HEIs to attract top EU students, it has been suggested that the Research Councils should be given the freedom to pay maintenance awards to PhD students from elsewhere in Europe. One possible concern is that additional expenditure on EU students would reduce the number of studentships Research Councils can offer, and/or increase the flow of EU students at the expense of (possibly less-qualified) UK students. It is important that any change to Research Councils' practice should not reduce the supply of PhD holders in the UK workforce.

Recommendation 4.4: EU PhD students

The Review would welcome the extension of PhD maintenance awards to EU students by the Research Councils as a means of maintaining and improving the quality of research in the UK. The effect of this on the number and quality of UK PhD students should be closely monitored in order to ensure sufficient supply of PhD holders for the needs of the UK economy.

5 EMPLOYMENT IN HIGHER EDUCATION

Summary of issues

Higher education (HE) staff in science and engineering departments are at the forefront of scientific and technical research efforts, and are also central to the education and development of science and engineering students and future researchers. Ensuring that universities are able to recruit and retain quality staff is therefore vital to the UK's future supply of highly-skilled scientists and engineers. However, problems have been identified with the quality of some taking up employment as postdoctoral researchers and then as permanent members of academic staff. It appears that this is not an attractive career path for many of the brightest PhD graduates. This is both harming the UK's research base and causing recruitment and retention difficulties for universities.

The problems affecting postdoctoral and other contract research staff (CRS) are:

- **lack of a clear career structure and uncertain career prospects** associated with work on a short-term contractual basis is a major barrier to the recruitment and development of postdoctoral researchers;
- **unsatisfactory training** in the skills required either in an academic career or in a business research environment means that CRS are poorly prepared for potential careers; and
- **increasingly uncompetitive salaries** act as a disincentive to work as a contract researcher.

Furthermore, **low levels of pay and consequent recruitment and retention problems for permanent academic staff**, coupled with an ageing cohort of academic staff in some disciplines and reports of a decline in the quality of applicants for academic jobs, are also of concern.

This chapter proposes that the recruitment, retention and development of skilled scientists and engineers within HE should be supported through:

- the development of **a range of career trajectories and clear career structures** for those employed as CRS, including greater use of permanent contracts for researchers;
- the inclusion of **earmarked funding for training and professional development** in all grants or contracts that provide for the employment of CRS;
- **enhanced salaries for CRS** funded by Research Councils, particularly in disciplines where there are shortages due to high market demand, and greater possibilities for salary progression within contract research; and
- **more market-related salaries for key academic staff**, which should benefit scientists and engineers, particularly those engaged in research of international quality.

Higher education staff

5.1 Scientists and engineers play a wide range of roles in Higher Education. Those employed in a teaching or research capacity can be broadly divided into:

- academic staff, who may be involved primarily with research, teaching or a combination of the two;
- academic-related staff, typically involved in research work on a short-term contractual basis, and commonly referred to as Contract Research Staff (CRS) or – for those CRS with doctorates – postdoctoral researchers.

5.2 There are around 100,000 full-time and over 14,000 part-time academic staff in UK Higher Education Institutions (HEIs), and around 37,000 researchers, of whom 30,000 or so are CRS and approximately half work in science, engineering and technology (SET).[177] A range of factors currently operate to inhibit the recruitment, retention and development of both CRS and academic staff. The sections below analyse these factors and make recommendations for action.

The funding of research in higher education

Research in Higher Education is funded through two routes, the 'dual support system'. One route for funding is the Quality Related (QR) system, the amount of which is related to institutions' RAE (Research Assessment Exercise) research quality ratings. The second funding route is through research funding from the Research Councils and other Government, charity and private sector sources. Such research funding tends to be awarded on the basis of competitive processes which often include peer review. In a top research-intensive university, funding from Government is approximately a 50:50 mix of Funding Council and Research Council/project funding.

Contract research staff

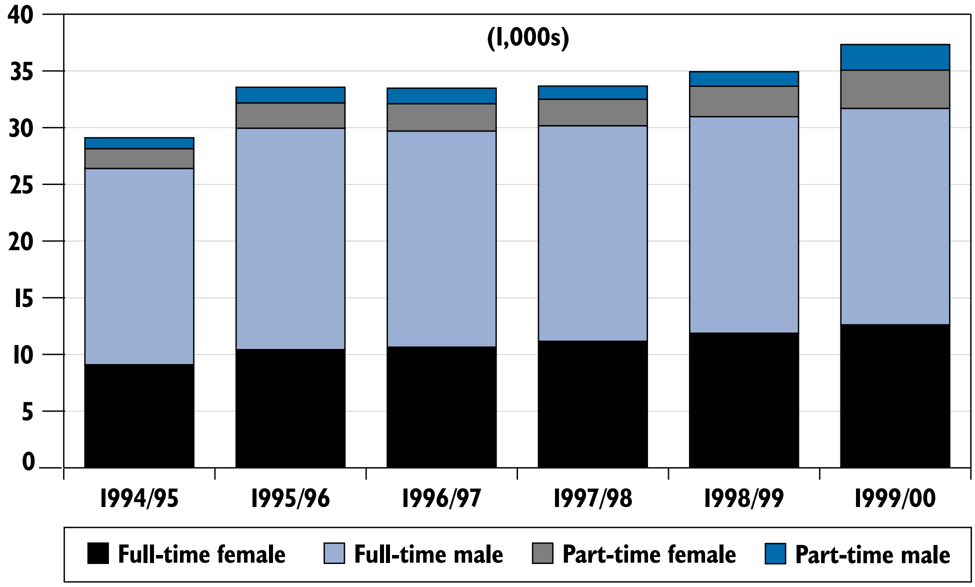
5.3 The Review is principally concerned with the high-level research skills possessed by postdoctoral researchers ('postdocs'), but this chapter also considers some issues associated with CRS more generally. In SET subjects, the overwhelming majority of academic staff have doctoral qualifications such as a PhD and worked as a postdoc before becoming a permanent member of staff.

[177] including mathematics.

5.4 A typical university research group consists of one or more Principal Investigators (usually a member of academic staff who leads the research and co-ordinates the activities of the group), one or more postdocs, and a number of PhD students. Within this group, the postdocs would conduct research on a specific topic under the supervision and direction of the Principal Investigator, and would often be involved in informal mentoring and instruction of PhD students or undergraduate project students working within the group. Many also have a role in university teaching, for example as demonstrators (assistants and safety monitors) in laboratory classes, for which they are paid separately.

5.5 The reduction in the number and size of UK corporate research laboratories, paralleled by a rise in the amount of contract research undertaken in universities, has led to a significant increase in the number of contract researchers. Figure 5.1 shows the rise in the number of researchers employed by HEIs in recent years, as well as a shift towards greater female employment: an increasing proportion of women are employed as CRS by all groups of subject funders, and the majority of CRS funded by UK-based charities, government bodies and health & hospital authorities are women.

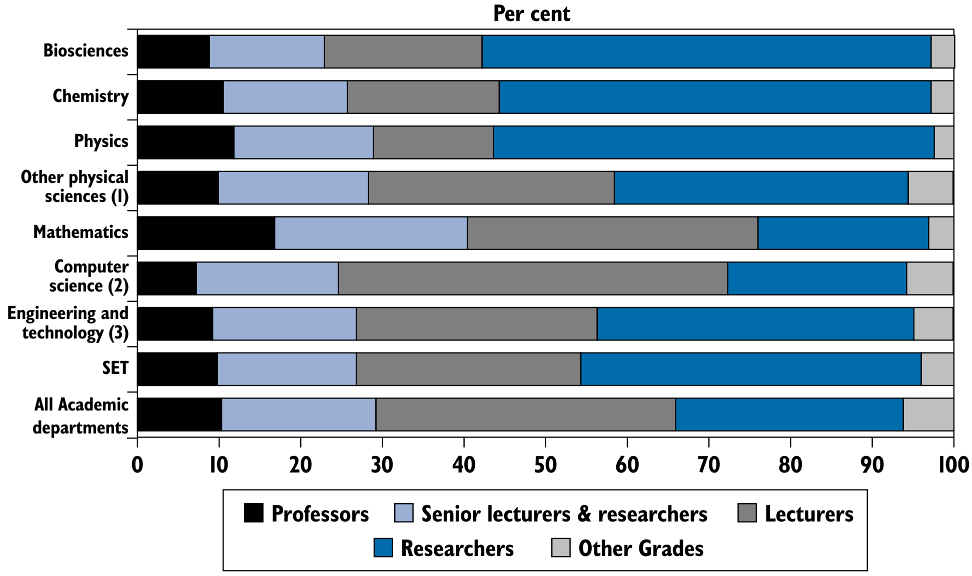
Figure 5.1: Full-time and part-time researchers by gender, 1994/95 to 1999/00



Source: HESA (various years) Resources of Higher Education Institutions.

5.6 Figure 5.2 shows that contract researchers across all disciplines represent 28 per cent of full time staff, but for SET subjects, this rises to 42 per cent. The proportions are particularly high for biosciences (55 per cent) and physics (54 per cent).

Figure 5.2: Percentage breakdown of full-time staff by grade and SET discipline, 1999/00



Source: HESA Cost Centre data in HESA (2001) Resources of Higher Education Institutions 1999/00.

Notes:
(1) a combination of 'Earth, marine & environmental sciences' and 'General sciences'.
(2) a combination of 'Information technology and systems science' and 'Computer software engineering'.
(3) a combination of 'General engineering', 'Chemical engineering', 'Mineral, metallurgy & materials engineering', 'Civil engineering', 'Electrical, electronic and computer engineering', 'Mechanical, aero & production engineering' and 'Other technologies'.

5.7 Contract research offers a number of key advantages. In particular, the project-based nature of contract research means that staff resources can be better directed towards topics of current relevance and importance, as identified by the Research Councils and other funders. The system is important in providing staffing flexibility in the university system. The national and international mobility encouraged by the range of short term positions on offer facilitates cross-fertilization of ideas and the development of innovative approaches and team working skills.

5.8 Despite these advantages and the rising numbers of CRS employed by the HE sector, the Review's consultation process revealed a range of concerns affecting the recruitment, retention and development of CRS, particularly postdoctoral researchers. The process of entering an indefinitely long series of postdoctoral research positions in order to pursue an academic career was seen as particularly unattractive for many of the best PhD graduates. Key issues identified include:

- **a lack of a clear career structure**, together with the uncertain prospects associated with work on a short-term contractual basis. This stems largely from the fact that the roles and numbers of contract researchers today no longer reflect their origins as a small elite group of post-doctoral Fellows. A consequent lack of a coherent career trajectory – both for individuals pursuing future careers in academia and those who move across to industry – is a major barrier to the recruitment and development of many skilled scientists and engineers;

- **inadequate training** for individual CRS. The immediate pressure of conducting research often means that training is not funded by research sponsors, provided by research institutions and/or taken up by individual researchers. This, combined with a lack of training in the skills required either in an academic teaching career or in a corporate research environment, means that CRS are poorly prepared for potential careers; and

- increasingly **uncompetitive salaries**. As well as acting as a disincentive to work as a contract researcher, low salaries may also act as a downward influence on salaries offered to newly qualified SET postgraduates in the private sector. Together, the low salaries offered to CRS and the consequentially lower salaries offered by the private sector may in turn provide a disincentive to study for a PhD and to pursue a research career.

Career structure

5.9 The Review's consultation process indicated significant concern with the lack of any clear career structure associated with contract research. This both acts as a disincentive to employment as a contract researcher and means that those involved in contract research are often ill-prepared for future employment, both within and outside academia.

5.10 Of the 30,000 contract research staff in UK universities, approximately one third are under the age of 30, one third aged 30-34 and one third aged 35 or over. Around 45 per cent of CRS have held other fixed term contracts (i.e. their previous work was as a contract researcher) and about one third of CRS enter contract research directly from a PhD.

The Research Careers Initiative

In 1996 representatives of institutions and the principal funders of research in the UK agreed a Concordat on Contract Research Staff concerning the management of staff appointed on fixed term contracts to carry out research in UK universities and colleges. The Research Careers Initiative (RCI) was subsequently set up to monitor progress towards meeting the commitments of the Concordat, under the chairmanship of Professor Sir Gareth Roberts FRS, then Vice-Chancellor of the University of Sheffield and now President of Wolfson College, Oxford and responsible for this Review.

The RCI identifies and encourages good practice in the career management and development of contract research staff. The secretariat of the Research Careers Initiative is shared between OST (for the funders) and Universities UK (for institutions). The RCI has issued a series of reports and good practice guidelines concerning contract researchers. This has led most universities to review and to some extent improve their procedures and their pattern of employment of CRS.[178]

[178] Further information on the Research Careers Initiative (RCI) is available from http://www.universitiesuk.ac.uk/activities/rci.asp

5.11 Individuals working as contract researchers have many different career aspirations and needs. Drawing on the Academic Research Careers in Scotland (ARCS) survey,[179] the Third Report of the Research Careers Initiative identifies three broad types of CRS:

- **career starters**, typically in their first or second contract, who enter contract research to gain experience leading to a continuing academic position or a more permanent research career, and typically stay as CRS for only a short period;
- **career researchers**, who have worked as CRS over a longer period and wish to remain in research, ideally in an academic environment; and
- **job entrants**, who may enter contract research as a job, but not explicitly to make a career in research, and who may or may not remain in research or in related academic work.

5.12 Other groupings are also possible. The most able postdoctoral researchers who aim at academic jobs often use the short-term contract system to arrange a series of short, often international posts which duplicates in an ad hoc way the more formal job rotation often found on graduate training schemes. This group of CRS can be thought of as 'high fliers' who aim at careers in academia (or, sometimes, business R&D), and is a subset of the 'career starters' group described above. Career starters who do not meet their own aims for contract research can often become career researchers, and it is important to distinguish between the 'willing' career researcher who actively embraces the contract research ethos and the 'unwilling' who regard contract research as second best to a desired career in academia or in business.

5.13 Surveys for the Research Careers Initiative suggest that "a large proportion of research staff remain intent solely on academic research careers", while "a proportion" (particularly in some, unspecified, subject areas) intend to move out of HE in due course. The academic career expectation in SET is that a good postdoctoral researcher will fill a couple of postdoc positions (ideally in prestigious research groups, and preferably at least one outside the UK) and then take up a lectureship at a research-intensive university. Postdocs or other CRS not following this career trajectory (those who are not 'career starters' in the terminology above) often believe they are treated as 'inferior' by the HE system, where most academic staff in SET are the product of precisely such a career path. It is undoubtedly true that many long-term contract researchers have tried and failed to obtain appointments as academic staff. However, other CRS see their roles as skilled research workers, and have no desire to teach or to fulfil any of the other obligations of the typical academic. Both groups are concerned that their research is not perceived as valuable, and that they are marginalized and expendable. Perhaps as a result, a number become disillusioned with research as a career.

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[179] For details of the project and initial results see http://www.warwick.ac.uk/ier/shefc/shefcpub.html

5.14 These uncertainties are magnified by the series of short term contracts often (but not necessarily) associated with contract research funding. The Bett Report[180] recommended that the sector's dependence on these short-term contracts be reduced. A joint working group of employers, via the Universities and Colleges Employers' Association (UCEA), and trade unions has developed a good practice guide covering this issue,[181] although this report simply refers to the RCI when talking about contract researchers. The Academy of Medical Sciences has also made recommendations on good practice.[182] In addition, the Government will shortly be implementing the EC Directive on Fixed Term Work, which will limit the number and extent of repeat short-term contracts, although the exact nature of the UK regulations is still out for consultation.[183]

5.15 Reflecting these factors, this Review believes that contract research posts should generally be seen as having a transitional rather than semi-permanent status; in other words, people usually should not remain on a series of short-term research contracts for a long period of time, particularly within a single institution. The Review concludes that three different career trajectories for contract researchers subsequent to their initial postdoctoral position should be encouraged. The researcher's manager and/or supervisor should discuss the researcher's most probable future trajectory as part of his or her regular staff appraisal. Once the probable trajectory has been established, this should be used to determine the types of training and careers opportunities that are taken up by the individual. These trajectories reflect the differing types of CRS identified in the Academic Research Careers in Scotland (ARCS) survey; each will have differing contractual status and expected career outcomes.

- **The Industrial trajectory** – contract research, especially that funded by business, potentially involves broader or more applied research than that involved in a PhD, thus providing a better preparation for a corporate research career. At the same time the current dominant aspirations and training provision amongst CRS are focussed on a career within the HE sector. The industrial trajectory would require awareness-raising by institutions and potential employers, and extra training in skills relevant to potential employers including the provision of supervisory and managerial experience. Those choosing to follow this trajectory would probably be employed on short-term contracts for a short period of time, then move into employment in industry. In time this, rather than the Research Associate trajectory, should come to be regarded as the 'default option' by CRS. Here schemes such as RAIS (Research Assistants Industrial Secondments) may provide a useful model.[184]

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[180] Independent review of higher education pay and conditions: Report of a committee chaired by Sir Michael Bett, Stationery Office, May 1999.

[181] Fixed-term and Casual Employment in HE a Guide to Good Practice, UCEA (2000).

[182] Non-Clinical Scientists on Short Term Contracts in Medical Research: A report on career propsects and recommendations for change, The Academy of Medical Sciences, February 2002.

[183] DTI (2002) Final Consultation on the Draft Fixed Term Employees (Prevention of Less Favourable Treatment) Regulations 2002; closing date for the consultation is 15 April 2002.

[184] RAIS aims to encourage the transfer of knowledge gained by Research Assistants working on existing research grants and provides training in an industrial environment. There are two variants to the funding scheme: one follows on from a collaborative grant, while the second involves a start-up company set up by a university to exploit EPSRC funded research. In both cases the scheme covers the salary costs of the RA for 12 months.

- **The Academic trajectory** – although a research-active teaching role is the desired career objective of many (though by no means all) postdoctoral researchers, only a minority actually achieve this goal. Better appraisals and career advice early on in a researcher's career should be aimed at identifying those with the potential for an academic career. This trajectory may require institutions to underwrite the salaries of those so identified in order to recruit or retain them, but the basis of employment should remain the short-term contract, to match the needs of research funders and encourage the mobility of potential academics.

- **The Research Associate trajectory** – there are a group of contract researchers who want to continue with a research career and do not want to pursue an academic career. This track would principally apply to those who have developed specialist knowledge of specific research equipment or methodologies (e.g. mass spectrometry or NMR) and provide an ongoing support/enabling function within a research group or groups. Importantly this trajectory should not been seen as the default, and entry should be highly selective. Here the emphasis would be on the provision of permanent contracts underwritten by research contracts being held by university departments, which could in some cases assign individuals to other research projects if a particular line of funding were to cease.

5.16 Achieving this vision for all these trajectories will require better training and development, a greater range of salaries and a clearer career progression for CRS, in line with the recommendations made below. Contract research should not become a permanent career option, but a preparation for a range of careers that reflect the skills possessed by contract researchers.

5.17 A number of the CRS interviewed by the Review Team were strongly in favour of a career track for all researchers, which ran in parallel to the established academic career track. The benefits of such a system would be a greater degree of transparency about future career and a better-defined salary progression, thus rendering contract research more attractive to new entrants and more secure for long-term CRS. A typical aspiration of someone arguing for a parallel research career track was to continue doing research without being burdened by administrative or teaching responsibilities.

5.18 While the Review is in sympathy with these aims, clearly there are a number of difficulties with the establishment of a 'parallel track' for all CRS:

- the intrinsic variability of contract research income and topic, although it can be compensated for to some extent by institutions, would make it very difficult to establish all or most current CRS on permanent contracts,[185] and doing so would reduce the responsiveness of the UK's research capability to new and emerging areas of interest;
- the existence of a career structure would therefore lead to informal expectations of continued employment which will not be realisable for all staff. As the RCI's best practice guidance on the employment of CRS warns: "That false expectation is much more unfair to all CRS in the long run than facing up to hard choices for individuals in the short run. It will inevitably lead to researchers leaving HE employment feeling, to a degree, disenchanted and less likely to carry their research skills into the wider economy"; and
- although many institutions employ a few research-only academic staff (Research Fellows, Readers etc.), it appears that many of these are drawn from the 'career starters' or academic trajectory rather than from current long-term CRS, so a career progression based on similar posts might not be of value to many CRS.

5.19 As outlined above, the Review is firmly in favour of a more permanent career structure for what have been termed 'Research Associates', long-term CRS who play a valuable role in supporting and enabling the UK's research. The case that this need extends to all current CRS is less convincing; anything which de-emphasises preparation for jobs outside academia would be a retrograde step. However, HEIs should consider whether offering more academic posts with a strong or exclusive research orientation might be appropriate. For those CRS who have the desire and the potential to enter academic careers, there is a case for better development into academic roles. One possible way to assist this is by developing new research or academic Fellowships.

5.20 As part of developing the academic trajectory a clearer path into academic lectureships should be developed, along similar lines to the US tenure track system or the former Assistant Lecturer scheme in this country.[186] There is value in using the postdoctoral system to gain a wide range of international research experience, but clear paths need to be marked out and advertised for movement from undergraduate or postgraduate study to employment as a member of academic staff. One tool for achieving this would be the establishment of more five-year Research Fellowships, like those offered by the Royal Society and the Wellcome Trust, and/or junior academic posts that give holders the opportunity to build their expertise and reputation in teaching, research and other relevant activities such as knowledge transfer.

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185 In larger departments and institutions the overall level of research grant income is relatively stable, which makes it easier for the institution to employ a core of 'research associates'. The constraint in this situation is whether the research associates are able to apply their skills effectively across a range of research topics and fields, as the portfolio of grant-supported work changes.

186 The German Bundestag and Bundesrat recently agreed to establish up to 3,000 three-year junior professorships with €60,000 each, predominantly aimed at people in their early thirties (i.e. the same age as many UK postdoctoral researchers). Detailed information is available (in German only) at http://www.bmbf.de/3992_4066.html.

Recommendation 5.1: Academic Fellowships

The Review believes that there should be a clearer path for those who have completed PhDs into academic lectureships. This should be achieved through creating Fellowships that allow those involved to move from principally research-based work towards the role of lecturer, with an added role of reach-out to schools (for example, becoming a Science and Engineering Ambassador) and helping to widen access to higher education. The Review therefore recommends that the Government provide funds to establish a significant number (the Review believes 200 a year) of prestigious academic Fellowships to be administered by the Research Councils. The Fellowships should last for five years and should be designed to prepare people explicitly for an academic career, to be distributed and awarded on the basis of academic excellence across the range of subjects considered in this Review. The Research Councils should work with the funders of similar schemes (for example, The Royal Society and the Wellcome Trust) in introducing these Fellowships.

A possible model for prestigious academic Fellowships

Fellows would serve a probationary period of two or three years, on satisfactory completion of which the HEI would be obliged to offer a permanent academic post to the Fellow at the end of the Fellowship (as occurs with Wellcome Trust-sponsored Fellows). Over the five year period, the Fellows would progressively move from primarily conducting research to take on the teaching and PhD supervisory roles associated with a lecturer. All Fellows would, as part of their role, be involved in reaching into schools and widening access to higher education in SET and all should qualify to be Science and Engineering Ambassadors.

5.21 To reinforce the parallel industrial and research trajectories, similar initiatives to the academic Fellows should be developed in these areas.

Recommendation 5.2: Industry secondments for postdoctoral researchers

The Review recommends that HEFCE and the Research Councils evaluate schemes such as the Research Assistants Industry Secondments run by the EPSRC as the basis for a wider mechanism for encouraging postdoctoral researchers into industrial careers, and as a mechanism for knowledge transfer.

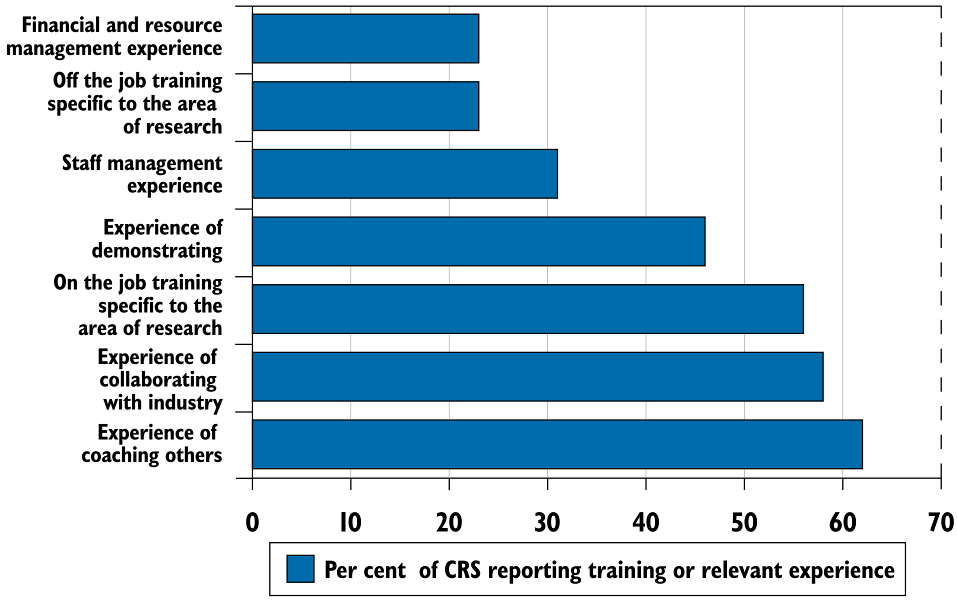
Training for Postdoctoral Researchers

5.22 The consultation revealed significant concern about the level of training provision for contract researchers. From the perspective of HEIs, the principal desired output of a postdoctoral researcher is research, primarily in the form of (joint) publications. However, this near-exclusive focus on research output generally leads to an under-emphasis on training and continuing professional development (CPD) for and by postdoctoral researchers.

5.23 There is evidence from the Research Careers Initiative that postdoctoral researchers do not tend to develop the full range of skills needed to be effective academics or to obtain jobs in R&D. In fact, postdoctoral experience, unless it is in a directly relevant field, seems to be a barrier to employment. Employers generally regard postdocs as likely to have been 'captured' by the ethos of 'pure' curiosity-driven research, in the negative sense that they are either unaware or actively unsympathetic to commercial constraints and directions on research.

5.24 The third RCI report concludes, on the basis of surveys of CRS (the results of which are set out in Annex 4 of the RCI report), that only a little over half of CRS (56 per cent) received on-the-job training specific to their research topic in 2000, and only 20-25 per cent received off-the-job training. This is despite the RCI guide to best practice, which states that funders should contribute to long-term research training of CRS.[187] Two-thirds of CRS survey respondents had not received any staff management experience, although 60 per cent or more had experience of coaching others. Nearly 50 per cent had experience of demonstrating (helping run laboratory classes for students) and around 45 per cent had experience in explaining their work to non-scientists. Similarly, a decreasing proportion of CRS (29 per cent in 1997, 23 per cent in 2000) gained experience of financial and resource management during their contract, and the proportion experiencing collaboration with industry also declined slightly, from 32 per cent in 1997 to 28 per cent in 2000. Despite this, around 60 per cent of respondents thought that collaboration with industry was "very useful".

Figure 5.3: Training or relevant experience reported by CRS in 2000



Source: September 2001 RCI report, Annex 4.

[187] Report from RCI Group on Career Management and Career Structure of Contract Research Staff: A Guide to Good Practice. RCI Working Group on Career Management, 1998.

5.25 While the proportion of CRS receiving training has remained low and even declined, the availability of training has increased dramatically over the period covered by the surveys. Training in communication skills was available to 22 per cent of respondents in 1997 and to 42 per cent in 2000, although only 58 per cent of those to whom it was available in 2000 took part. Similarly, the availability of supported learning on intellectual property rights had grown from 6 per cent of respondents in 1997 to 16 per cent in 2000, with non-take-up of 44 per cent in 2000. These figures are illustrated in Table 5.1 below.

Table 5.1: Training provision and uptake by CRS

Training type	Availability (per cent)	Uptake (per cent)	Proportion with training (per cent)
Communication skills	42	58	24
Intellectual property rights	16	56	9
Teaching in HE	31	64	20
Project/finance management	18	49	9
IT training	50	69	35

Source: Research Careers Initiative, 2001.

5.26 A major constraint on training is finance. Some research funders are apparently unwilling to count training and development as legitimate uses of project funds. Only half of survey respondents received a regular (at least annual) appraisal of their work and personal development, although those who did almost always found them 'very useful' (39 per cent in 2000) or 'moderately useful' (44 per cent).

5.27 The RCI and the Bett Review of higher education pay and conditions[188] both recommended an increase in training and appraisal for CRS. This Review fully endorses and supports these recommendations. However, despite the improvements noted above, much more must be done to ensure that all CRS receive appropriate training and appraisal. Funders of CRS need to take this requirement fully on board in providing resources for research projects.

Recommendation 5.3: A vision for postdoctoral researchers

It is important for postdoctoral researchers to be able to develop individual career paths, reflecting the different career destinations – Industrial, Academic and Research Associate – open to them, and that funding arrangements reflect the development of these career paths. The Review believes that enabling the individual to establish a clear career path, and a development plan to take them along it, is critical to improving the attractiveness of postdoctoral research. The Review therefore recommends that HEIs take responsibility for ensuring that all their postdoctoral researchers have a clear career development plan and have access to appropriate training opportunities – for example, of at least two weeks per year. The Review further recommends that all relevant funding from HEFCE and the Research Councils be made conditional on HEIs implementing these recommendations.

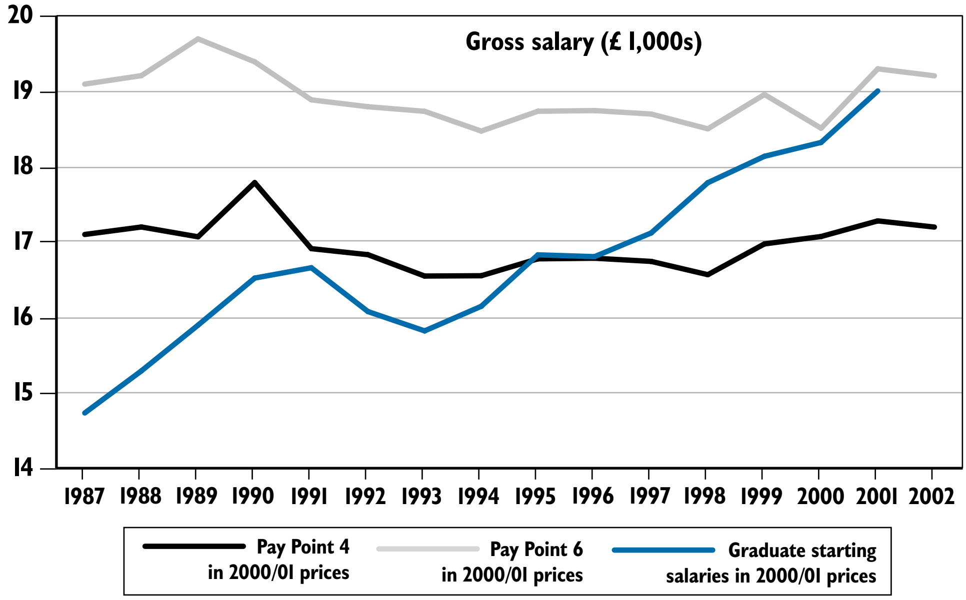
[188] Independent review of higher education pay and conditions: Report of a committee chaired by Sir Michael Bett, Stationery Office, May 1999.

Salaries for Contract Research Staff

5.28 A further issue highlighted by the Review's consultation process was the relatively low salaries paid to CRS. Although the overall attractiveness of CRS jobs depends on a wide range of factors, including conditions of work, availability of training and work satisfaction, salary levels are an important factor in attracting sufficient numbers of able graduates to CRS posts.

5.29 Declining salary levels for CRS are illustrated in Figure 5.4. This shows salaries paid to researchers on spinal point 4 (the minimum appointment level for a PhD) and spinal point 6 (the minimum point for a 27 year old), against starting salaries for new graduates with a 2:1 or above offered by the Association of Graduate Recruiters companies. Salaries at both spinal points 4 and 6 fell in real terms during the early 1990s, as did graduate starting salaries. However, during the later 1990s CRS salaries remained static in real terms, while graduate starting salaries rapidly rose. By 2001, graduate starting salaries were virtually equivalent to salaries offered to 27 year old researchers.

Figure 5.4: Comparison in real terms of spinal point 4 and 6 with graduate starting salaries



Source: Review Team and Association of Graduate Recruiters.

5.30 Falling real salary rates have a number of detrimental effects. Most significantly, fewer of the best PhD graduates are attracted to postdoctoral research posts as salaries fall relative to those available elsewhere. Additionally, although there is evidence that newly qualified PhDs are willing to take lower salaries from employers who allow them to continue some curiosity driven research and academic publishing,[189] lower salaries may also be depressing private sector salary offers and thus reducing the overall attractiveness of undertaking a PhD.

189 Do scientists pay to be scientists?, S Stern, NBER working paper 7410, October 1999.

Recommendation 5.4: Postdoctoral researchers' salaries

In addition to establishing clearer career progression, the Review recommends that Research Councils should significantly increase salaries – particularly starting salaries – for the science and engineering postdoctoral researchers it funds, and sponsors of research in HEIs and PSREs should expect to follow suit. The Review considers that the starting salary for postdoctoral researchers should move in the near future to at least £20,000, and that further increases should be available to solve recruitment and retention problems in disciplines where there are shortages due to high market demand (for example, mathematics).

Permanent academic staff

5.31 Academic staff are largely responsible for training the next generation of students at undergraduate and postgraduate level. The quantity and quality of academic staff employed by HEIs is therefore critical to the future supply of highly qualified scientists and engineers. In addition, those supervising and conducting research play an important role in supporting successful innovation within the UK.

5.32 The Review's consultation process revealed a range of concerns affecting the recruitment, retention and development of academic staff. Besides the disincentive to embarking on a university career created by the prevalence of short-term contract research work – addressed in the previous section – and other problems with the education supply chain addressed in previous chapters, key issues identified include:

- a **shortage of quality applicants** for many academic jobs;
- an **ageing demographic profile of academic staff** in SET – with many older staff in physical sciences and mathematics in particular; and
- **low academic salary levels**, operating to inhibit the recruitment and retention of scientists and engineers, particularly in areas with high housing and living costs.

5.33 It appears that HEIs have difficulty recruiting and retaining top-quality scientists and engineers, a problem which is exacerbated by the demographic profile of academic staff in these subjects (a large proportion of staff are over the age of 55) and in part caused by paying salaries which cannot compete with those on offer in some other countries (notably the US and Canada) and jobs outside the higher education sector.

Quality of applicants

5.34 The Review's consultation process identified a decline in the quality of new applicants for academic jobs, as perceived by universities. Measuring this is extremely problematic. Possible indicators include salary level, number of applicants per post, level of qualification and, for academic researchers, publication record.[190] Quantitative data on most of these indicators are not available, while salary level is not useful because UK pay scales are set through national bargaining. However, a number of surveys[191] suggest that academics have been increasingly forced to appoint people of a lower standard than normal or to leave posts unfilled. Reports of problems appear to be particularly widespread in IT,[192] engineering,[193] medicine, economics, law and business studies. Some of these surveys also indicate concern within universities at the ability of newly-appointed academic staff, in comparison with staff in other countries.

5.35 This largely anecdotal information, coupled with the evidence of rising demand in the physical sciences and engineering presented in Chapter 1 and the divergence between graduate salaries and CRS salaries (Figure 5.4) is consistent with the idea that the quality of new academic staff has fallen slightly. It is difficult to make any firmer statement than this on the basis of available information.

Demographic profile of academic staff

5.36 The consultation process indicated that an ageing demographic profile among academic staff is an area of significant concern. This changing profile has the potential to create major staffing difficulties in future years, particularly if SET subjects are to expand as part of reaching the Government's target of 50 per cent participation in HE.

5.37 The average age of institutionally-funded academic staff is increasing, with 16 per cent due to retire within the next 10 years in 1999/00, compared with 14 per cent in 1994/95. The change in age structure has been most noticeable in mathematics, where the percentage aged 55 and over has risen from 18 per cent to 25 per cent. In chemistry, the proportion of academic staff aged 55 and over has fallen slightly, although staff in this age group still represent a quarter of wholly institutionally funded academic chemistry staff. The proportion of female academic staff is projected to increase in all SET subjects in the next 10 years.

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[190] e.g. in the sense measured by the Research Assessment Exercise (RAE), which includes patent activity.

[191] Recruitment and Retention of Academic Staff in Engineering Faculties; Radio 4 Today Programme survey of Russell Group Vice Chancellors, 19th January 2002; Staffing University Computing Faculties, BCS, January 2002.

[192] A survey by Metra Martech for the British Computer Society indicated that 13 per cent of computing departments had 20 per cent or more posts unfilled, with the major cause of shortages reported to be salary differentials between HEIs and industry.

[193] Recruitment and Retention of Academic Staff in Engineering Faculties, AE Long and A Toman, Institution of Civil Engineers, August 2001.

Table 5.2: Percentage of wholly institutionally funded staff aged 55+ in 1994/95 and 1999/00

	1994/95 (per cent)	1999/00 (per cent)
Medicine & dentistry	11.4	14.7
Subjects allied to medicine	9.2	11.0
Biological sciences	15.4	17.7
Chemistry	27.1	25.0
Physics	27.3	29.0
Other physical sciences	14.6	15.8
Mathematics	17.6	25.4
Computer science	8.2	12.0
Engineering	17.8	19.3
Business & administrative studies	10.5	13.6
All academic departments	13.8	16.3

Source: Based on HESA cost centre data in Resources of Higher Education Institutions.

A model of academic staff flows

5.38 To estimate the potential future impact of this changing profile, the Review worked with HEFCE to develop a model of the stocks and flows of academic staff in UK HEIs. The model was based on 1998 stock data for permanent academic staff who were either full-time or part-time and employed for over two days a week. The model also used data, collected over several years by HESA, which allows the tracking of individuals' academic careers. These data were then used to generate age-, gender-, grade- and discipline-specific profiles of recruits to and leavers from the system.[194]

5.39 The model worked on an iterative basis: first it aged the population by one year, then modelled the outflows, then promotions and finally calculated the necessary inflows before starting again with the next year. The primary constraints on the model were the maintenance of the numbers with each subject of highest qualification. There were no constraints on the numbers in each grade. This meant that if the proportions in each grade were changing as a result of the flows prior to 1998, this pattern was sustained in the forecasts.[195]

5.40 The expanding number of students in higher education needed to meet the Government's target of 50 per cent participation will have an impact on the number of academic staff required. However, the relationship between student numbers and number of academic staff is not simple, particularly as some

[194] Additionally information as to whether the staff were in a department with a RAE score of 3 and above in 1996 was used to examine the difference between research and non-research intensive staff. Individuals were classified on the basis of the discipline of their highest qualification, for ease of comparison between existing staff and postgraduates who could one day fill academic posts. The extent of transfers between disciplines, apart from transfers in and out of 'unknown', were rare, and the net flows were negligible, and it was decided not to model these flows.

[195] Further details of the modelling methodology and its results can be found in the forthcoming HEFCE publication Academic staff in higher education: trends and projections.

subjects will grow faster than others. Naturally, if all subjects grow at the same rate than the disciplines where the greatest number of staff are needed, identified in Table 5.3 below, would be under most pressure.

Results of the demographic model

5.41 Table 5.3 compares the inflows required to maintain 1998 numbers of staff to actual inflows in 1998. The modelling predicts a significant shortfall in the number of academics with an engineering qualification: the predicted necessary inflow in 2010 is 22 per cent greater than the actual inflow in 1998. In part this can be ascribed to the age profile of the 1998 stock – nearly 20 per cent of engineering staff were over the age of 55. However, the recent pattern of recruitment reflects relatively static student numbers, leading to recruitment levels below that necessary to sustain the stock of staff. Other factors are also at work. Engineers tend to enter the academic profession at a later stage than average (probably due to work in industry and/or greater postdoctoral research opportunities) and tend to retire earlier than average (probably due to the greater range of alternative employment available).

5.42 The modelling also suggests that about 33 per cent more mathematicians will be needed in 2010 to maintain the 1998 numbers. Here the essential problem appears to be the relatively low inflows prior to 1998, which were below replacement levels.

Table 5.3: Actual and forecast inflows by SET discipline 1998, 2005 and 2010

	Actual 1998 inflow	Forecast need in 2005	Percentage change 1998-2005 %	Forecast need in 2010	Percentage change 1998-2010 %
Biological sciences	511	407	-20	415	-19
Chemistry	133	143	8	129	-3
Physics	124	153	23	140	13
Other physical sciences	169	118	-30	128	-24
Mathematical sciences	144	213	48	192	33
Computer science	361	302	-16	314	-13
Engineering	498	632	27	610	22
Total	5,871	5,271	-4	5,337	-3

Source: HEFCE (forthcoming) Academic staff in higher education: trends and projections.

5.43 The model therefore suggests that greater inflows of academic staff in certain key areas will be required to maintain current levels. If student demand in these areas increases as a result of the actions recommended in this report, and the Government's work on achieving its 50 per cent target for participation in higher education, this need will be greater still. To analyse whether estimated necessary inflows are achievable, it is useful to compare these estimates with current numbers of doctoral graduates. It is recognised that in general not all academic staff have (or need to have) a doctoral qualification, and not all PhDs enter an academic career. Within SET, however, a doctorate is almost always a pre-requisite for appointment to an academic post. One possible exception is computer science, where non-doctoral postgraduate qualifications are more common, which appears to require a large proportion of its PhD output as replacement academic staff. It may be that the pattern of qualifications for computer science staff either has changed or needs to change, with more academic staff being drawn from industry with non-doctoral backgrounds.[196]

5.44 Table 5.4 shows that a higher proportion of both mathematics and engineering post-graduates will need to be recruited as academic staff in order to meet estimated necessary inflows.

Table 5.4: Comparison of modelled inflows and PhD output

Subject area	Actual 1998 inflow	PhD output 1998/99	Actual recruitment as percent of PhD output	Forecast need in 2010	Forcast 2010 recruitment as percent of 1998/99 PhD output
Biological sciences	511	1,706	30.0	415	24.3
Chemistry	133	873	15.2	129	14.8
Physics	124	555	22.3	140	25.2
Other physical sciences	169	480	35.2	128	26.7
Mathematical sciences	144	379	38.0	192	50.7
Computer science	361	301	119.9	314	104.3
Engineering	498	1,805	27.6	610	33.8
Total	5,871	11,338	51.8	5,337	47.1

Source: HEFCE (forthcoming) Academic staff in higher education: trends and projections.

5.45 These forecasts strengthen the case for improving the attractiveness both of PhD training (as discussed in Chapter 4) and an academic career, particularly as they affect certain key disciplines.

Academic salaries

5.46 The consultation process indicated growing concern at salary levels of academic staff, contributing to problems of recruitment and retention, which will be exacerbated by the increasingly international nature of the labour market.

5.47 International comparisons of the spending power of average UK academic salaries, calculated using a method developed by the National Association of Teachers in Further and Higher Education (NATFHE) based on OECD data, are presented in Table 5.5. They indicate that although UK academics are not paid as well as their counterparts in the US and Canada, they are – as a whole – neither particularly well off nor particularly badly off, with salaries

[196] The apparent lack of preference for PhDs shown by employers of computer scientists, mentioned in Chapter 4, is also a factor here.

falling between those of French and of German academics. Other studies[197] tend to present a similar picture, with academic staff in the UK earning around the same as or slightly less than their counterparts elsewhere in Europe, but somewhat less than equivalent staff in the US. However, these data do not distinguish between disciplines or between grades and quality of staff.

Table 5.5: International comparisons of average academic salary spending power, 1998

Country	Average annual salary spending power, 1998 (£)
Canada	58,289
United States	52,300
Finland	42,939
France	33,647
United Kingdom	31,210
Norway	30,511
Australia	28,654
Spain	23,365
Germany	23,005
Japan	15,481

Source: Based on work by NATFHE, using Education At A Glance 2001 (OECD) and underlying data from www.oecd.org. The OECD Purchasing Price index, which takes benefits, taxes, exchange rates and living costs into account, was used to convert the average "compensation" of teaching and teaching/research staff in tertiary level institutions (which includes pension and other social benefits such as health care) into UK equivalents. The low placing of Japan may be due to them reporting headcount figures rather than full-time equivalents.

5.48 The Bett Review of UK higher education pay and conditions[198] found that pay for the most junior and most senior academic staff was low relative to comparable jobs in other sectors, and predicted recruitment and retention difficulties if pay for some groups of HE staff continued to be significantly below earnings from comparable jobs. There are similar problems in Germany.[199] In the case of SET and other disciplines linked to high-earning professions such as law and economics[200] this differential is likely to be much greater.

5.49 There is evidence that HEIs are promoting a greater proportion – relative to most other disciplines and relative to previous levels in SET – of scientists and engineers to professorships and other senior posts in order to recruit and retain academic staff. Pressure for this 'grade drift' is created by the fact that UK universities, with few exceptions, operate a collective bargaining system for pay. This, in effect, sets out a common pay scale for all academic staff

[197] e.g. Science Polices for the next Parliament: Agenda for the next five years, Save British Science Society, February 2001.

[198] Independent review of higher education pay and conditions: Report of a committee chaired by Sir Michael Bett, Stationery Office, May 1999.

[199] The remuneration system for university professors in Germany has recently been reformed (including the removal of a salary maximum) to improve the international competitiveness of German HEIs for excellent academic staff and for experts from industry. Details are available (in German only) from http://www.bmbf.de/3992_4066.html.

[200] The British Academy's Review of Graduate Studies in the Humanities and the Social Sciences (2001) noted concerns over the recruitment of academic staff in business studies, economics, psychology, law and education.

(professors excepted) across almost all disciplines.[201] As a result, the rate of promotion is the central way in which market forces operate on academic pay levels, which creates rigidity in HE reward mechanisms and suppresses salary differentials within and between institutions, disciplines and individuals.

5.50 A similar process operates to some extent in the private sector. The Mason report on the labour market for engineering, science and IT graduates,[202] for example, explored the question of why the perceived shortage of scientists and engineers had not led to increased salaries across the economy as a whole. The report concluded that many scientists and engineers work for companies that "operate 'internal labour markets' with a preference for stable salary differentials and for internal promotion within each firm to fill senior jobs. Such employers are reluctant to respond to recruitment difficulties by raising salaries for new recruits and thus disturbing existing salary structures".

5.51 The extent of grade drift is illustrated in Table 5.6, which shows the percentage of staff in UK HEIs in Senior Lecturer and Professorial grades (or their equivalents) rising rapidly between 1995 and 2000. Table 5.7 presents this increase in percentage terms. The tables show particularly large increases in the number of professors in physics, chemistry, biology and mathematics, as well as social, political and economic studies (which is outside the scope of this Review). This is not simply a function of age: comparison with Table 5.2 shows that the large increase in chemistry professors coincided with a reduction in the proportion of staff over the age of 55.

Table 5.6: Grade drift in UK HEIs between 1995 and 2000 by subject of highest qualification

Subject	Percentage of staff in grade 1995			Percentage of staff in grade 2000		
	Lecturers	Senior lecturers & readers	Professors	Lecturers	Senior lecturers & readers	Professors
Biology	49.9	33.4	16.7	41.8	33.7	24.6
Chemistry	45.3	35.6	19.1	37.6	35.3	27.1
Physics	44.7	35.6	19.7	33.9	37.5	28.6
Mathematical science	53.8	29.5	16.7	42.8	32.6	24.6
Other physical sciences	54.2	30.2	15.6	46.2	30.8	23.0
Computer science, librarianship & info science	72.4	21.0	6.6	66.3	23.6	10.1
Engineering, technology, building and architecture	60.1	27.4	12.6	50.5	31.3	18.2
Social political and economic studies	58.5	28.1	13.4	50.6	28.7	20.7

Source: HEFCE (forthcoming) Academic staff in higher education: trends and projections.

[201] There is a London weighting, and there are separate arrangements for clinical academic staff.

[202] The labour market for engineering science and IT graduates: are there mismatches between supply and demand?, G Mason, National Institute of Economic and Social Research, March 1999.

Table 5.7: Increase in senior lecturer and professorial grades in UK HEIs, 1998 to 2000

Subject	Percentage increase in senior lecturer grades	Percentage increase in professorial grades
Physics	1.9	8.9
Chemistry	–0.3	8.0
Biology	0.3	7.9
Mathematical sciences	3.1	7.9
Other physical sciences	0.6	7.4
Social political and economics studies	0.6	7.3
Engineering and technology	3.9	5.6
Humanities	5.0	3.9
Computer science, librarianship and information sciences	2.6	3.5

Source: HEFCE (forthcoming) Academic staff in higher education: trends and projections.

5.52 The data presented in Table 5.6 and Table 5.7 indicate that universities are using promotion as a method of recruiting and retaining staff in certain disciplines, particularly at senior levels where international competition is most visible. It is less clear that HEIs are dealing with the issues of low pay for the most junior academic staff highlighted by Bett and with the competition for staff at that level.

Conclusions on academic pay

5.53 The Review's evidence points to the following conclusions:

- There is a significant mismatch between academic salaries and those in other occupations for particular scientific and engineering-related disciplines, such as physics and computer science. This mismatch is worse than for academic pay in general. Similar mismatches are believed to exist in other disciplines beyond the scope of this review, such as law and economics. Salary and grade structures are being manipulated to alleviate the problem, causing grade drift.

- There is need to improve financial rewards in order to maintain or improve the quality and numbers of the best researchers and educators of researchers in the UK. This is especially the case in engineering, computer science and mathematics, where the demographics indicate a need for increased recruitment, but also in biology, physics and chemistry, where grade drift is most marked. These people are long-term contributors to UK productivity through original research and the training of skilled researchers.

- HEIs, aside from creating additional professorships, have not managed to deal with this situation. There are financial and cultural barriers to delivering improvements in terms and conditions targetted on these disciplines and individuals where recruitment and retention pressures are greatest. HEFCE's human resources strategy fund has provided some resources, which have mainly been used to establish institutional HR strategies.[203]

- Revenues from knowledge transfer (KT) activity have improved the situation for a few but certainly not all scientists and engineers in HE, and mechanisms for promoting KT and revenue sharing from KT activity vary noticeably across all institutions.

- Additional funding for scientists' and engineers' pay is needed, particularly for the most junior and most senior staff and those engaged in research of international quality, but the need is not uniform across disciplines (or across SET disciplines) or across institutions. Instead, there is a case for greater differentiation between and within disciplines and institutions. However, it is vital that institutions do not unfairly discriminate against women or ethnic minorities in competing for staff on the basis of salary.

Recommendation 5.5: Academic salaries

As with contract researchers, there is a need for universities to improve salaries – particularly starting salaries – for many scientists and engineers. The Review is clear that universities must use all the flexibility at their disposal differentially to increase salaries, especially for those engaged in research of international quality, where market conditions make it necessary for recruitment and retention purposes. The Government should assist by providing additional funding to permit universities to respond to market pressures. As a first step, the HEFCE funding currently dedicated to the human resources strategy should be made permanent. Further additional funding for recruitment and retention, which will vary between institutions, should initially be part of a separate stream linked to the existing human resources strategy fund and appropriately focussed towards research excellence. However, once more market-based systems have been embedded, the funds should be incorporated into core funding for research and also into revised subject teaching premia.

203 See also Rewarding and developing staff in higher education: Good practice in setting HR strategies, HEFCE 02/14, March 2002, http://www.hefce.ac.uk/Pubs/hefce/2002/02_14.htm#exec.

6 SCIENTISTS AND ENGINEERS IN R&D

Summary of issues

Scientists and engineers make vital contributions to many sectors of the economy, not just through working in R&D. Their increasing attractiveness to a wide range of employers means that those seeking to employ the best scientists and engineers to work in R&D must compete more fiercely for their talents.

However, many R&D employers' packages are not competitive with what the best scientists and engineers can earn elsewhere. There are a number of areas in which action is needed if R&D employers are to attract the best scientists and engineers, including:

- **Salaries** – initial starting salaries and salary progression for scientists and engineers working in R&D are often worse than elsewhere. For example, the best scientists and engineers in industrial R&D earn less than two-thirds what their counterparts in the financial services sector earn.
- **Career structure and job design** – it is essential that scientists and engineers have both attractive initial posts and suitable career progression within the organisation.
- **Continuing Professional Development** – many scientists and engineers choose to work in research primarily due to their interest in the scientific or technical discipline, yet many R&D employers do not provide the time or resources needed to help them to stay abreast of the latest developments in their field.

The Review found that outdated employment practices were often representative of employer attitudes to R&D more generally, which is seen by too many as a short-term drain on profits and 'optional', in a way that other areas of the business are not.

The Review concludes that there is a significant challenge facing the community of employers which seeks scientists and engineers to work on R&D, but one that must be taken up if the supply of high-level SET skills to these businesses and organisations is to be improved.

The Review also identifies ways in which the supply of suitably skilled scientists and engineers could be improved through better skills planning by employers, and more coherent dialogue and collaboration in training and research between employers and universities.

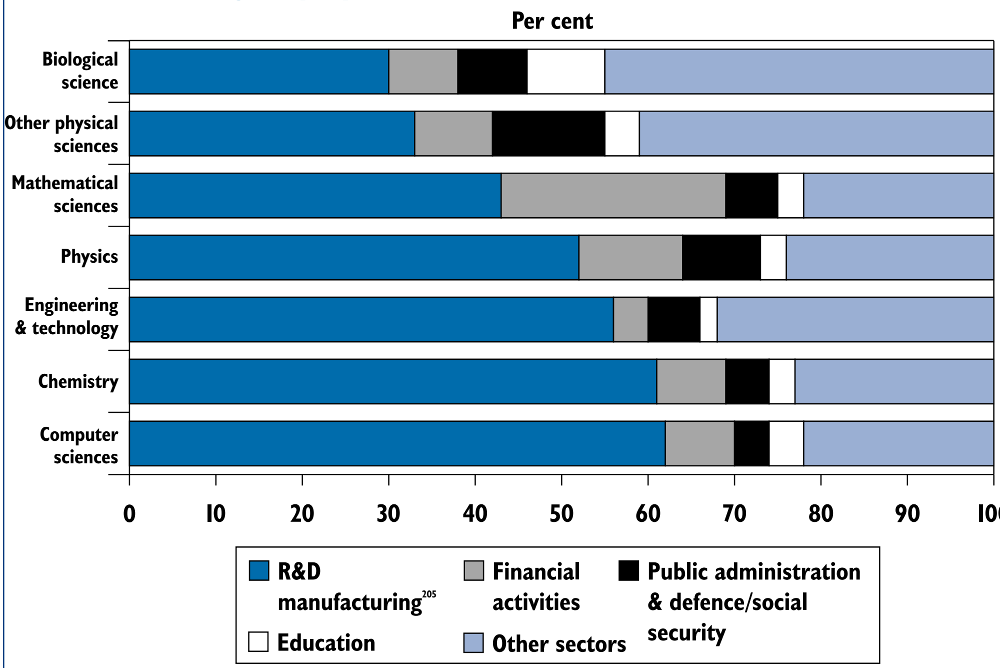
This chapter concludes by considering the issue of international mobility of scientists and engineers, and investigates (in particular) the arguments around whether the UK is suffering from a 'brain drain' in SET skills. Some evidence for this is found, although its extent is often overstated (indeed, more scientists and engineers locate to the UK than move abroad). Finally, the review recommends action aimed at improving the capacity of UK businesses to draw upon scientific expertise and talent from other countries in driving forward their R&D activities.

Employment of scientists and engineers

6.1 The demand for scientists and engineers in fields beyond their traditional employment in industry and higher education is rising. Employers in a wide range of sectors are attracted to scientists and engineers primarily for their numerical and analytical skills but also for their problem-solving abilities, computer literacy and ability to deal with large quantities of information. These skills are particularly useful in fields such as finance, accounting, consulting and IT. This increasing demand is set to continue and is welcome, since the contribution that scientists and engineers make in these fields is vital to the growth and success of these sectors. The importance of scientists and engineers to productivity growth is underlined by recent research[204] by Haskel. This finds a broadly positive relationship between the proportion of firms employees who are qualified scientists and engineers (irrespective of their present functions) and firms' productivity growth.

6.2 The demand for scientists and engineers across a range of sectors is illustrated in Figure 6.1, which shows that over half of all physics, chemistry, engineering and computer science graduates work in what is loosely described as 'R&D manufacturing'. It also shows, however, that financial services are an important employer for graduates in the mathematical sciences and physics, due to the high-level numerical skills they will have picked up during their course. The education sector and public sector organisations such as the NHS, Public Sector Research Establishments and Goverment departments are also significant employers of scientists and enginners.

Figure 6.1: First destination for first degree graduates entering employment 1999/00



Source: HESA.

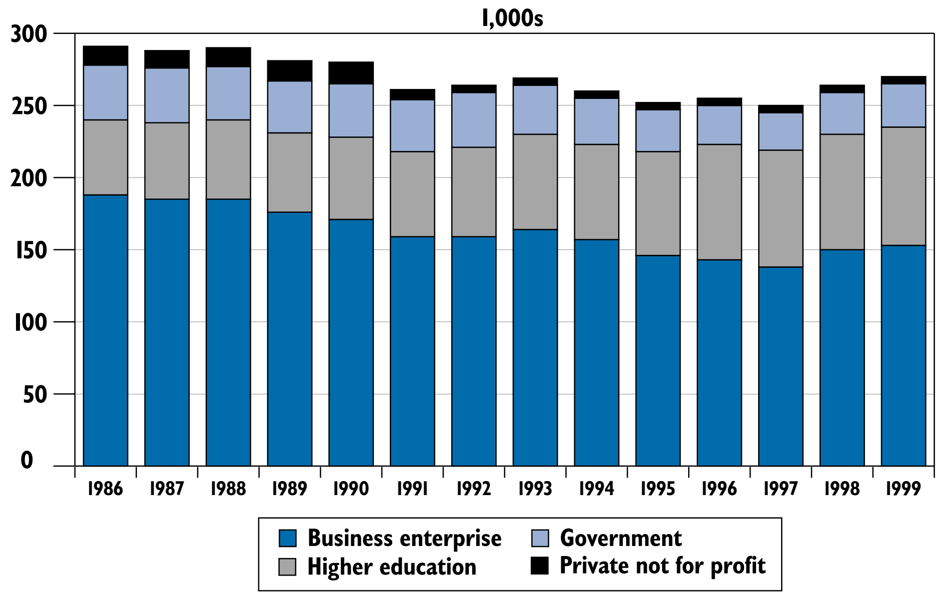
[204] UK Manufacturing Productivity in the 1980s and 1990s, Haskel, 2002.

[205] R&D manufacturing is the combination of SIC group D (manufacturing) and SIC group K (property development, rental and R&D) - in this case primarily R&D.

6.3 Figure 1.1 in Chapter 1 demonstrated that the UK's R&D performance in the 1980s and early 1990s was poor, with the UK spending less on R&D as a proportion of GDP in 1999 than it did in 1981. Together with the increasing 'capital-intensity' of R&D (the need for more sophisticated and expensive equipment per worker), this poor performance in overall R&D has led to a declining number of staff employed in R&D.

6.4 Figure 6.2 shows that the number of full-time R&D staff fell by over 10 per cent between 1986 and 1997, from nearly 300,000 to around 260,000. The main cause of this fall was a reduction in the number of R&D staff in business (and, to a lesser extent, the public sector), which is offset somewhat by a rise in the number of research staff in higher education. The increase in the number of researchers in 1998 and 1999 suggests an upturn in the level of business R&D activity in recent years[206].

Figure 6.2: Full-time staff employed in R&D, 1986 to 1999



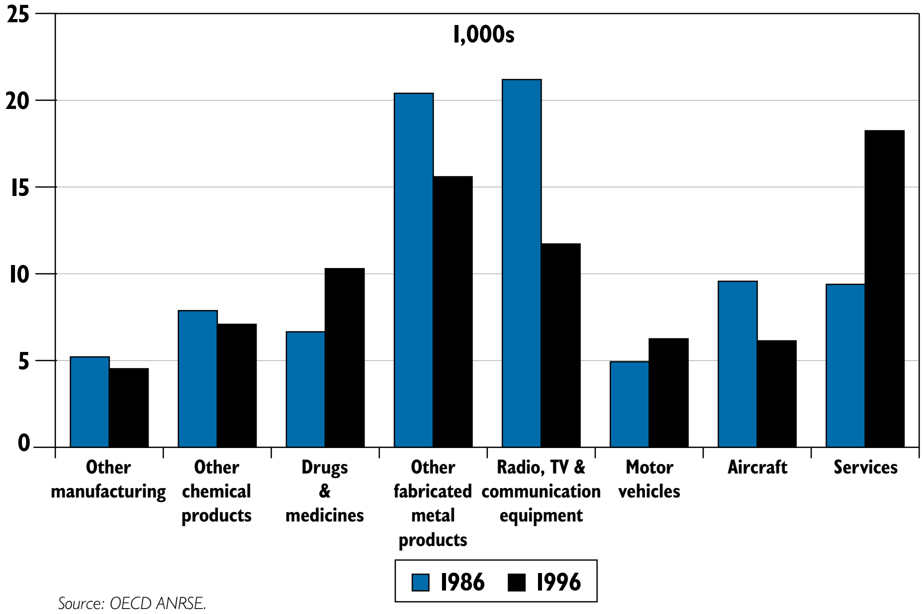
Source: OECD & OST.

Note: private not for profit numbers estimated from 1994 onwards.

6.5 Within the overall fall in employment in R&D between the mid 1980s and mid 1990s, there have been some substantial differences in the trends in individual sectors. Figure 6.3 presents some of the changes in the key sectors. It should be noted that the main driver in these changes is the overall strength and health of the sector and the economy, and the changes do not necessarily represent an increase or decrease in the sector's commitment to R&D.

[206] Although, as with the spend on R&D, this positive trend appears not to have continued into 2000.

Figure 6.3: Employment of professional scientists and engineers in business enterprise research sectors, 1986 and 1996



Source: OECD ANRSE.

6.6 The chart shows that although the number of scientists and engineers has fallen in many sectors (consistent with the overall trend), the numbers employed in the pharmaceuticals and service sectors have increased significantly. This underlines the growing importance of 'new' sectors as well as 'traditional' industrial R&D as employers of scientists and engineers.

SET and the City: Employment of scientists and engineers in the financial services sector

Financial services businesses in the City of London are important employers of highly-skilled science and engineering graduates and PhD holders. Nearly 10 per cent of all SET students' first jobs are in the financial services sector, and this figure rises to a quarter when considering mathematical sciences graduates. Graduates in mathematics and physics in particular are attractive to the City because they often have good problem-solving and very strong numerical skills, which are important in dealing with financial data. City firms acknowledge a preference for SET graduates (and financial and economics graduates) over other disciplines, although this is not the only criteria against which applicants are judged.

In highly mathematical areas such as risk analysis, options pricing and computer modelling there is a growing demand for exceptionally numerate and skilled graduates and, in particular, PhD holders. Demand from financial companies for these skills has grown since the deregulation of the UK financial system began in the 1970s. The subsequent growth in complex and 'exotic' financial products such as options and derivatives led to a demand for people who were familiar with solving partial differential equations used in pricing options as well as other highly quantitative modelling techniques involved in risk analysis. In many cases, only mathematics graduates and postgraduates (and other science, engineering, finance and economics graduates and postgraduates who have specialised in strongly mathematical-related areas) are able to deal with the complexities in the analysis of such financial instruments.

The attractiveness of work in R&D

6.7 Given the increasing demand for highly-skilled scientists and engineers from a range of sectors, employers wishing to recruit and retain the best scientists and engineers to work in R&D will have to offer 'packages' that compete with the best offers available elsewhere.

6.8 However, discussion with students, employers and university academic staff, and responses to the Review's consultation, revealed that highly-skilled scientists and engineers are increasingly viewing the packages offered by many R&D employers as uncompetitive. This contributes to the recruitment difficulties experienced by R&D employers discussed in Chapter 1[207].

Salaries for scientists and engineers

6.9 An attractive starting salary and salary progression are widely acknowledged to be increasingly important factors in graduates' career choices. This is partly due to the increasing levels of debt that students incur during their time in higher education. In addition, students are being taught – at the request of employers – more about enterprise and commercial awareness during their education, and therefore often apply these principles when choosing employment themselves.

6.10 However, the salaries paid to scientists and engineers working in R&D are increasingly uncompetitive with what their counterparts in other sectors are earning. Data from the Labour Force Survey suggests that science and engineering graduates working in a 'professional' capacity earn around 10 per cent less than qualified scientists and engineers working in other areas.

6.11 This is backed up by a survey carried out for the Mason report[208], which found that technical graduates working in the financial services and computer services sectors earned more than their counterparts in the electronics, machinery, pharmaceuticals and R&D services sectors.

6.12 Interestingly, the salary differences were greater at the top end of the income spectrum. Although there was little difference in the median starting salaries between these sectors, those around the top quartile in the financial services sector earned around 5-10 per cent more than their counterparts in the electronics, machinery, pharmaceuticals and R&D services sectors. This gap grew to around 20 per cent for those around the top decile, which suggests that financial services companies are targeting their rewards to attract the best people more so than companies in other sectors.

[207] Econometric evidence presented in the paper Technology, Wages and Skill Shortages: Evidence from UK Micro Data, Jonathan Haskel (Queen Mary and Westfield College), Christopher Martin (Brunel University), November 1998, found that, as theory would suggest, recruitment difficulties are inversely related to the relative wage.

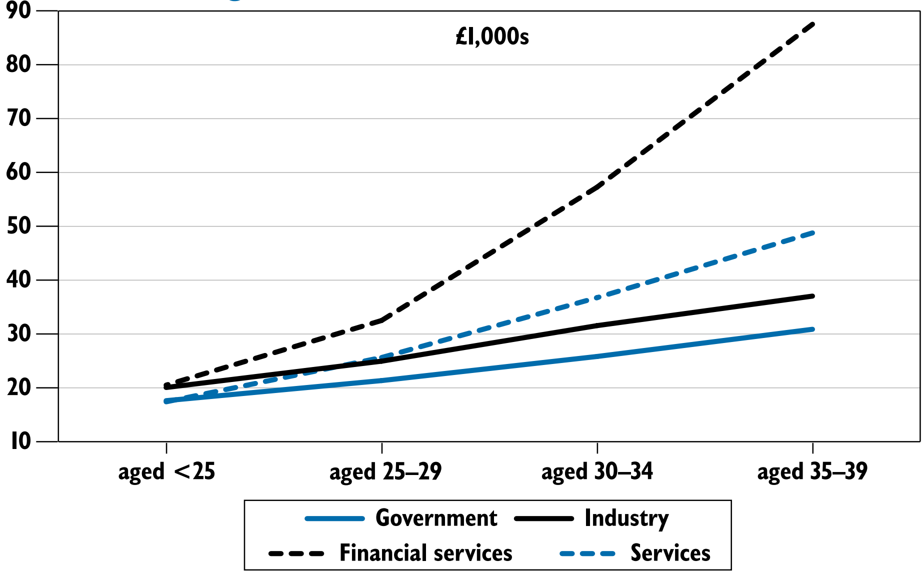
[208] The labour market for engineering, science and IT graduates: are there mismatches between supply and demand? G Mason, National Institute of Economic and Social Research, March 1999.

6.13 The gaps in salaries between these sectors were also shown to grow substantially with experience. After five years' experience, the median salary of those in the financial services sector was around 5-10 per cent higher than for those in industrial R&D, with the gaps between the upper quartile salaries being around 25 per cent and the gaps between the top decile salaries being around 50 per cent.

6.14 This suggests that although businesses in the financial services and similar sectors may not give a substantially higher starting salary to the average graduate, they will pay considerably more for a highly-skilled graduate than R&D businesses. Furthermore, the salary progression is far more rapid in the financial services sector than in industrial R&D.

6.15 The findings from this survey are supported by data provided by the Institute of Physics, which show that although there is relatively little discrepancy in the starting salaries of their members working in industry, services and the financial services sector, substantial differences soon emerge. This is illustrated in Figure 6.4.

Figure 6.4: Median salaries of male physics graduates by sector and age, 2001

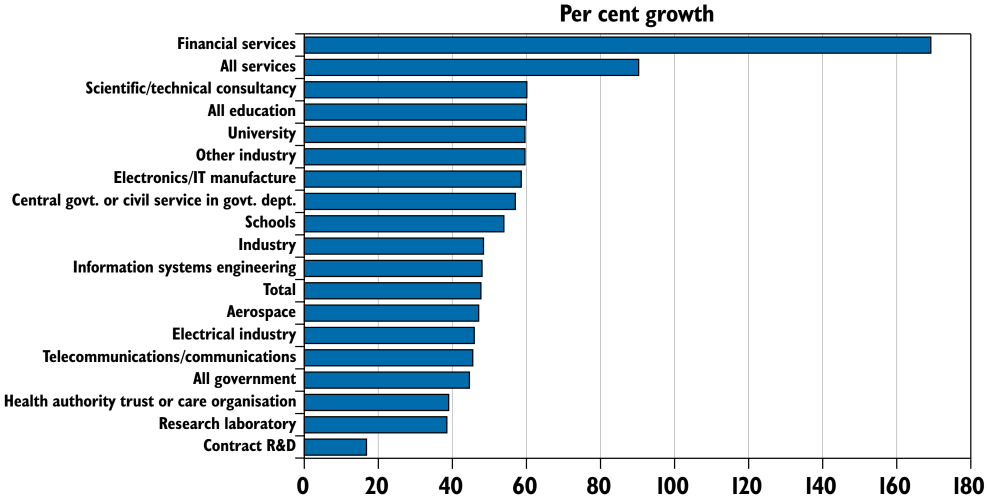


Source: Institute of Physics (unpublished data). [Data for women have been removed since data are relatively volatile].

6.16 Figure 6.5 shows that male physics graduates[209] employed in financial services and in the service sector generally received significantly larger salary increases between their late 20s and their late 30s than did their counterparts in industry.

[209] Members of the Institute of Physics typically possess a physics degree.

Figure 6.5: Growth in median salaries of male members of the Institute of Physics in various careers, between ages of 25-29 and 35-39



Source: Institute of Physics (unpublished data). [Data for women have been removed since data are relatively volatile].

Salary competition for scientists and engineers

Discussions with businesses and others as part of the Review's consultation revealed a number of reasons why R&D businesses often do not compete more vigorously on salaries for the best scientists and engineers.

Attitudes to R&D – Regrettably, some businesses tend to view R&D more as an optional extra than as a core part of their business plan. As a result, if they cannot recruit a scientist or engineer at a particular salary to work on an R&D project, they will often choose not to undertake the project rather than increase the salary offered.

Salary rigidities – Some R&D businesses choose not to compete on salaries for fear of disturbing the salary structures that already exist in a company (for example, to stop a new recruit earning as much as, if not more than, an existing employee).

Alternatives to raising salaries – In response to a recruitment difficulty some businesses choose to retrain their existing staff or improve their advertising strategy. They may also use 'hidden' financial rewards (e.g. subsidised mortgages) that will not show up in salary data. In some cases, larger companies may take short-term action by recruiting contract staff, although this can be very expensive and is probably a last-resort measure. In the survey of firms carried out for the Mason report, most firms appeared to prefer these methods of dealing with recruitment problems rather than competing on salaries.

Uncertainty – Business can be discouraged from increasing their starting salaries through uncertainty as to how well the new recruit will perform in R&D. In particular, businesses can find it difficult to assess before appointing someone whether an individual has an 'innovative spark'.

'Choosing the competition' – Many R&D businesses choose not to compete with service sector companies on pay, but instead seek to compete for those scientists and engineers for whom the wish to work in research outweighs salary considerations. In particular, some businesses look to the public and higher education sectors (the largest employers of scientists and engineers working in research) who tend to pay lower rates than the private sector generally. Public and university pay scales are often inflexible and relatively immune to market pressures in the short to medium term and are therefore poorly correlated with demand for scientists and engineers. Some R&D businesses see university research salaries as a benchmark against which they need only offer slightly higher salaries to attract researchers. However, as referred to previously, this approach is likely to lead to R&D businesses being unable to recruit graduates and postgraduates with entrepreneurial and commercial awareness, who are more likely to choose better paid careers in other sectors.

Economic conditions – There are also arguments that because R&D businesses are primarily in the manufacturing sector they face stronger cost pressures than their counterparts in the service sector, and that their ability to pay scientists and engineers more has been limited by conditions in manufacturing more generally.

Non-salary factors in recruiting and retaining scientists and engineers

6.17 Through discussion with scientists and engineers, the Review identified a range of factors other than salary as important in providing an attractive package, including:

- an attractive career structure, with sufficient responsibilities and challenges; and
- good prospects for training and development, and intellectual rewards.

6.18 Career structure is important to many science and engineering graduates. The Review found that in too many cases R&D businesses were not doing enough to provide an attractive and rewarding job and career in R&D. A number of practices that reduce the attractiveness of careers in R&D were identified:

- **Poor job design**, with many highly-qualified researchers feeling that their skills were being under-utilised. One reason for this is that the majority of graduate recruiters[210] do not have a separate recruitment process for postgraduates. Postgraduates therefore enter the same jobs as first-degree entrants, which they find unchallenging and unrewarding. A further example of this under-utilisation of skills comes from the Mason report,[211] which found that just over one in four recruiters had filled previously non-graduate jobs with graduates in the previous three years. Better job design could also allow more flexible working, which would encourage more qualified women into (and back into) R&D.

[210] Evidence from a survey of 80 employers published in November 2000 in Survey of Employer Attitudes to Postgraduates and Contract Researchers, S Wright, AGCAS, November 2000.

[211] The labour market for engineering science and IT graduates: are there mismatches between supply and demand?, G Mason, National Institute of Economic and Social Research, March 1999.

- A new study for the DTI on the biotechnology sector found that **companies, particularly SMEs, needed to structure and pre-plan the induction of new employees better**, in order to integrate new staff into the firm's work patterns and processes – and hence make them productive – more quickly.
- R&D businesses seem in many cases reluctant to give as much **responsibility** to new graduates as do businesses in the services sector – for example, meeting clients or customers.
- **Poor job security**: some businesses appoint scientists and engineers on successive short-term contracts, coinciding with the duration of R&D projects. This makes career planning very difficult; as a result, short-term contracts can be a significant factor in discouraging women, in particular, from entering scientific careers. The Fixed Term Work Directive, due to be implemented in the UK later this year, should help to reduce unfair use of successive short-term contracts.

6.19 **Training and continuing professional development** (CPD) are vital to staff in fast-moving scientific disciplines, and act as an important retention mechanism. However, science and engineering graduates are offered less job-related training than those from other disciplines.[212]

- The non-monetary rewards of developing and contributing to scientific understanding are important to many scientists and engineers. Some scientists are willing to forgo improved earnings in order to work in an environment where they can publish and continue to contribute to the broader body of knowledge.[213] CPD can likewise help motivate and retain such staff.
- Trade associations and professional bodies should advise companies on effective induction and training processes, and can help engage HEIs and other providers to deliver high-quality, high-level CPD to businesses. The DTI study of the biotechnology sector indicates that, given the timescales that can be involved in changing undergraduate and postgraduate courses in HE, companies needed to make much greater use of CPD in tackling their skills needs.

6.20 R&D businesses must also employ sophisticated **recruitment techniques** to be able to compete for science and engineering graduates with other sectors. The financial services industry, for example, uses a wide range of media and events to attract students, from poster advertising to targeting of key HEIs and courses. This involves marketing of the sector and the firm as well as advertising particular jobs. The DTI study of the biotechnology sector reveals that normally more than one recruitment method is used in a successful recruitment exercise. Taking sandwich year or vacation students is also a valuable tool for recruitment.

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[212] Evidence from the Institute of Employment Studies in *The Graduate Review 2001* by Sarah Perryman and Richard Pearson, showed that science and engineering graduates were less likely to have participated in training at work compared to other graduates.

[213] *Do scientists pay to be scientists?*, Stern, NBER Working Paper 7410, October 1999.

Recommendation 6.1: Attractiveness of careers in R&D

Responding to the challenge of improving the attractiveness of jobs in R&D to match or surpass all other opportunities open to the best science and engineering graduates and postgraduates is crucial to individual businesses' future success – since their R&D underpins their future products, services and, ultimately, their future sales and profits.

Through consultation with businesses and scientists and engineers themselves, the Review has identified a number of issues related to work in R&D that employers must address in order to be able to attract the best science and engineering graduates and postgraduates.

- **Initial pay.** Starting salaries are an increasingly important factor in students' career choices, in part due to the effect of student debt and students' increasing commercial awareness. The starting salaries and bonuses paid to scientists and engineers working in R&D are often not as high as they could receive in other sectors or occupations. While it may not be necessary to match the highest salaries paid elsewhere, the Review is clear that businesses will ultimately need to raise the salaries and other financial rewards they offer if they are to compete for the best scientists and engineers (particularly those with an entrepreneurial spark or good commercial awareness). This goes hand-in-hand with the need for businesses to look at R&D not as a cost, but as an investment in their future survival and growth.

- **Salary progression.** Similarly, retention in an increasingly mobile workforce relies upon salary progression that compares well with the other opportunities available. Evidence suggests that the salary progression for scientists and engineers in R&D does not compare favourably with that for their counterparts in other sectors.

- **Career structure.** Science and engineering graduates and postgraduates can be put off entering R&D due to unattractive career structures – with short-term contracts, low levels of responsibility, few chances for progression within R&D and poor job design (e.g. jobs that do not use their skills to the full). It is clear from the Review's consultation that many employers can do more to improve the career structures of scientists and engineers, through addressing these and other influential factors.

- **Training and professional development.** Scientists and engineers working in research do so partly because of their interest in the subject, and it is therefore key that they can stay in touch with the latest developments in their field. Employers should do all they can to provide time and resources to allow them to do this, and partake in CPD activities, which will also bring benefits in terms of recruitment and retention. There is a role for the Government and for trades unions in helping to make sure that smaller businesses are able to provide sufficient training and CPD to research employees.

- **Recruitment mechanisms.** The Review believes that many R&D businesses must improve their recruitment mechanisms to compete better with other employers. For most R&D businesses, especially the smaller ones, increasing marketing efforts and taking opportunities to widen the number of students they make contact with should improve their ability to recruit the scientists and engineers they need. R&D businesses must also take responsibility for improving the perception of jobs in R&D.

The Review is clear that the response of R&D employers to these challenges is crucial in providing an adequate supply of scientists and engineers for R&D. Without improved and more attractive opportunities to work in R&D, the UK's best scientists and engineers will doubtless be tempted elsewhere, since the demand for their skills – and the rewards offered – will only grow over time.

Recommendation 6.2: The challenge to employers

The Review recommends that the Government should establish a group of R&D employers to support and monitor employers' responses to the challenge of improving the pay, career structures and working experiences for scientists and engineers in R&D. The group should include representatives from businesses (large, medium and small) and others that employ scientists and engineers in an R&D capacity.

The Review believes the group must act as a driving force in taking the recommendations in this report forward and should publish a report, before the next public spending review, setting out the response of employers to the challenges identified by this Review. The group might also play a key role in considering cross-regional and national R&D skills needs, referred to in Recommendation 6.4.

Communication and collaboration in research and training

6.21 The need for effective communication between businesses, the education sector and students has been highlighted throughout the report. The key messages have been that:

- the profusion of independent schemes aimed at enthusing and educating pupils in science and engineering is inhibiting the collective effect of these schemes, and the Government should establish SETNET as the single channel through which schools and colleges access these schemes (recommendation 2.12);
- R&D businesses must communicate better with HEIs to influence the skills that SET graduates and postgraduates develop;
- R&D businesses benefit from relationships with individual students in HEIs, who may be potential recruits; and
- research collaboration between R&D businesses and HEIs often aids recruitment.

6.22 Interactions between business, schools and Further Education colleges have been covered in Chapter 2. This chapter deals with the need for businesses to communicate better with the HE sector. Both businesses and HEIs have responsibilities for this and must be partners in improving the connections between science and engineering in higher education and the flow of SET graduates into R&D businesses. The Review is concerned that:

- businesses do not assess their future skills needs effectively;
- businesses do not (and often cannot) communicate their skills needs effectively to HEIs, and so do not readily develop effective partnerships; and
- more research collaboration between businesses and HEIs is needed.

Business assessment of skills needs

6.23 Although companies carrying out R&D often plan their research years in advance, skills needs are rarely assessed on the same timescale. The Review's discussions with firms in a variety of sectors indicate that while skills planning by large companies can be for 3-5 years ahead (often the length of the business planning cycle), SMEs and those companies in fast-moving industries such as ICT generally plan on a very short horizon (less than one year) if at all, preferring to recruit skilled labour from other businesses in the same field when need arises.

6.24 A recent study of the biotechnology sector by Angle Technology for the DTI[214] found that company business planning was typically on a 3-year cycle, but HR planning timescales were much shorter and in most cases planning for staff needs was sketchy. The HR brief was often held by a senior manager rather than a HR specialist, particularly in smaller companies.

6.25 Large companies tend to devote more resources to recruitment and skills planning than do SMEs; partly as a result, SMEs tend to face more recruitment difficulties. SMEs need to be supported and advised on their skills planning by trade associations, Sector Skills Councils, the Small Business Service or wherever else SMEs go to for help in their business planning. In some cases, regional or local business networks associated with clusters of SMEs[215] can allow collaboration on defining and planning for skill needs.

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[214] to be published April 2002.

[215] The south of England has a number of successful R&D clusters including the biotechnology industry in and around Oxford and Cambridge whereas regions such as the Midlands and Yorkshire have large manufacturing clusters.

Recommendation 6.3: Skills planning

It is clear that although many businesses may plan their R&D projects a number of years in advance, they often do not plan their skills needs for this research more than a year ahead. Although there are difficulties in detailed skills planning, the Review believes that R&D businesses must do more to establish what science and engineering skills they will need for future research projects in order for them to be able to recruit the skilled scientists and engineers they need with less difficulty.

HE-business collaboration in training and skills supply

6.26 The relationship between businesses and HEIs in meeting companies' skills needs must be a partnership. In too many cases, businesses have an inadequate grasp of their own skills requirements, and believe that HEIs should alter courses to meet their needs without reference to the other fields graduates might work in. Equally, as discussed in Chapter 3, universities and other HEIs often do not listen effectively to businesses, and have in many cases been insufficiently innovative in course design. One constraint on course design and adaptation has been the professional standards set by bodies like the Engineering and Technology Board which – in practice – largely determine the content of some courses and make them burdensome to alter. More flexibility from accreditation bodies is needed.

6.27 Partnerships between HE and business need to be rooted in the strengths of the two partners: businesses are best able to assess their current and near-future skills needs, while universities are expert educators and can – through their work at the forefront of new knowledge – teach students about areas which will grow to prominence in the future. They also must take account of the needs and relative weaknesses of the two: constraints of finance, the time lag between agreeing to develop course materials and offering the course, and so on.

6.28 HEIs have in the past responded to business skill needs by redesigning existing or designing new degree courses or modules, but this can be time-consuming and expensive. The Royal Academy of Engineering's Visiting Professorship Programmes aims to develop university teaching materials based on real-life business case studies and have been effective in fostering links between industry and academia. Communication between business and HE is currently too ad-hoc and varies widely in effectiveness. Large R&D businesses currently communicate with HEIs through Industrial Advisory Boards, careers services, or through sponsoring Chairs[216], but are not often actively involved in degree course design. SMEs are generally less proactive in communicating with HEIs, but clusters of SMEs and local or regional business networks tend to have better links with HEIs. More coherent skills messages are needed in order for HEIs to respond effectively. At the regional and sub-regional level, RDAs are vital to understanding labour markets and making HEIs aware of skills needs; this understanding must also be aggregated up to a national level, drawing on the work of trade associations, the Council for Science and Technology, Foresight and the new Sector Skills Councils.

[216] i.e. paying for a Professor in a particular field, almost always one relevant to the business.

6.29 Work placements and collaborative projects can be a good way of bringing HEIs and R&D businesses together, providing recruitment opportunities and reducing the search costs of recruitment for companies and potentially allowing staff to engage in CPD or to gain further qualifications. Existing schemes and mechanisms include:

- the **STEP**[217] (Shell Technology Enterprise Programme) scheme, which encourages SMEs to consider employing graduates (rather than non-graduates) and each year provides around 1,000 undergraduates with experience of working in a SME and encourages them to consider a career in a small company;

- **TCS** (formerly the Teaching Company Scheme), which aims to facilitate the transfer of technology between businesses and HEIs through providing business based training (for at least two years) for 'high quality' first SET degree graduates (at the beginning of 2002 there were more than 900 programmes in operation, predominantly in SMEs);

- the **CASE**[218] (Co-operative Awards in Science and Engineering) scheme, which aims to encourage communication and build links between universities, students and business employers in science and engineering (CASE allows research students to work on projects of one to three years in duration which are of direct relevance to a particular industry, jointly supervised by an academic supervisor and the company where the research student might be based); and

- HEI-run **sandwich courses** that enable students to gain valuable industrial and commercial experience during their programme of study. In the academic year 1999/2000 approximately 12,000 SET students graduated from sandwich courses[219]. The benefits of sandwich courses have been widely recognised; the Dearing Review in 1997 recommended that where possible every student should do a work placement. However, a survey of SET employers in the Mason report[220] found that only 38 per cent of all recruiting enterprises had recently been involved in providing placements for sandwich students, despite their widespread wish to recruit graduates with industrial experience; SMEs had particular difficulty in offering placements.

- The **Industrial Secondment Scheme** supported by the Royal Academy of Engineering provides engineering academics with the opportunity to learn of the latest developments in industry.

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[217] STEP (Shell Technology Enterprise Programme) is managed under contract to Shell International and is an undergraduate work experience scheme that is also funded by SBS and DTI.

[218] CASE projects are jointly devised and supervised by academic departments and co-operating bodies (industrial and commercial organisations in the public or private sectors, and local authorities and research council institutions and laboratories). The CASE award scheme has been successful in part because it has developed incentives for all parties (student, HEI and business) to be involved.

[219] Students in Higher Education Institutions, HESA.

[220] The labour market for engineering science and IT graduates: are there mismatches between supply and demand?, G Mason, National Institute of Economic and Social Research, March 1999.

Recommendation 6.4: Skills dialogue

The Review believes that the supply of skills to R&D businesses can be improved through more coherent skills dialogue between these businesses and universities. The Regional Development Agencies (RDAs) should take a leading role in the coordination of regional dialogue between businesses and HEIs through the new FRESAs (Frameworks for Regional Employment and Skills Action) to ensure that demand for higher level skills at a regional level can be met.

Furthermore, the Review recommends that the sector skills councils (which, the Review believes, should be represented in FRESAs) work with the Learning and Skills Council, trade associations and other business groups to identify – based on the regional skills discussions – evolving cross-regional and national R&D-related skills needs.

Recommendation 6.5: Business involvement in higher education

Although universities need to be proactive in ensuring that courses are as relevant to business as possible, the Review believes that businesses must become more actively involved in university course design. In particular, the Review recommends that employers' bodies – for example, the CBI and trade associations – and the Government work to encourage more R&D businesses to participate in providing work placements for SET graduates and postgraduates (for example, in sandwich year courses).

HE-business collaboration in research and development

6.30 Despite the clear commercial benefits to many businesses from research collaboration with HEIs[221] and the value of training SET undergraduates and postgraduates in a commercial research environment, very few businesses participate in innovation partnerships[222] with HEIs.

6.31 The Government already supports a number of industry-academic collaborations and centres, which involve the participation of businesses and universities and serve to encourage research collaboration[223] and hence communication between the parties involved. Some of these research initiatives also provide training for SET students/graduates and PhDs in an industrially orientated research environment, which helps to develop the skills required for working in business R&D:

- **Faraday Partnerships** have several objectives including improving the two-way flow of technology and skilled people between the science base and industry. Faradays create partnerships between industrially oriented research organizations, such as Research and Technology Organisations (RTOs), government agencies, private sector laboratories

[221] Studies suggest that there are significant benefits for companies if their scientists and engineers collaborate with university research teams. Collaborative research projects allow for a greater transfer of tacit knowledge which companies require to be able to commercialise the research and thus offset their commercial development costs. One such study is Commercialising knowledge: university science, knowledge capture, and firm performance in biotechnology, J Armstrong, M Darby, L Zucker, NBER Working Paper 8499, October 2001.

[222] The Community Innovation Survey 2001 (DTI) found that only 13 per cent of businesses had innovation partnerships with HEIs on a local level and 19 per cent on a national level.

[223] However, the Review is concerned that the research conducted in these collaborations is often too dominated by existing academic interests and funding and too little driven by business needs.

and the science and engineering base. The 18 Faraday Partnerships undertake core research to underpin product and process development at the same time as providing industrially relevant postgraduate training. (Three Industrial CASE studentships are allocated to each partnership every year.)

- At the end of 2001 the Engineering and Physical Science Research Council (EPSRC) established twelve **Innovative Manufacturing Research Centres** (IMRCs) at universities across the UK. The IMRCs cover several mainstream areas of manufacturing such as aerospace, defence, automotives and construction. The EPSRC has allocated £60m to the IMRCs over a five year period and expects that at the end of those five years third party funding will add another £45m. The aim of the IMRCs is to develop strong research links with industry and encourage collaborative research between universities and industry.
- There are a range of other **'Centres of Excellence'** in which universities and businesses collaborate to generate and apply knowledge to solve commercial problems, such as the Centre of Excellence in Advanced Telematics at the University of Birmingham and the Virtual Centre of Excellence in Mobile and Personal Communications led by the University of Surrey. The Engineering Design Centre (EDC) in Cambridge, also known as a 'Centre of Excellence', was recently identified as an IMRC by the EPSRC; the National Assembly for Wales recently established 20 Centres of Excellence for Technology and Industrial Collaboration; and the Ministry of Defence has recently launched a series of Defence Technology Centres designed to enhance UK defence capability.

6.32 These joint research organisations have an important role in preparing SET graduates with the appropriate skills needed for working in commercial R&D, and this should be given higher priority than at present. However, they need to do more to stimulate business investment in their research and R&D businesses should take a stronger role in leading their research.

Recommendation 6.6: Research collaboration between business and higher education

There are a number of Government sponsored schemes that act to encourage research collaboration between businesses and HEIs. However, the Review feels that the collective impact of these schemes is not as great as it should be. The Review therefore recommends that the Department of Trade and Industry, as part of its increased focus on innovation and skills, and more effective delivery of business support, should evaluate the success of existing initiatives in this area – in particular, paying attention to whether the training elements of these schemes are sufficiently supported and prioritised and the extent to which they play a strong role in employer-university communication and collaboration.

The need for better innovation partnerships

6.33 Business has been critical of the bias towards academic research of some of the existing research organisations in the UK and is often sceptical about the benefits of investing in more applied research itself. This not only leads to under-investment in collaborative research, but also reduces the opportunities for scientists and engineers in academia to gain experience of commercial work, and vice versa.

Overseas research organisations

The experience of a number of other countries in establishing joint-research initiatives between industry and academia can provide some relevant experience for the UK.

The Fraunhofer Institutes in Germany are applied research institutes that undertake contract research on behalf of industry, the service sector and government. Research is both industrially focused applied research as well as 'blue-skies' research. Applied research is directed at providing technical solutions to improve the competitiveness of industry. These Institutes have been able to provide commercial R&D experience for up to 10 per cent of German SET students/graduates. TNO (abbreviation of the Dutch name: toegepast-natuurwetenschappelijk onderzoek) in The Netherlands is also an applied research organisation, again connecting fundamental research with practical applications that can be commercially exploited by business. As with the Fraunhofer Institutes, up to 10 per cent of SET graduates and PhD students in The Netherlands undertake research in a TNO.

The Cooperative Research Centres (CRCs) in Australia aim to bring together research in universities, government laboratories and private industry and provide some training relevant for industry. There are currently 65 CRCs in Australia and Government funding for them has been approximately matched by business investment in the centres since their establishment in 1990. Approximately 250 companies are currently involved in the research being done in the CRCs.

The Cooperative Research Centres (CRCs) in Australia aim to bring together research in universities, government laboratories and private industry and provide some training relevant for industry. There are currently 65 CRCs in Australia and Government funding for them has been approximately matched by business investment in the centres since their establishment in 1990. Approximately 250 companies are currently involved in the research being done in the CRCs.

6.34 There is therefore a need for the Government to develop and part-fund innovation partnerships between businesses and HE, built on applied research that is directed by industry demand and learning from experience in other countries. The focus of such partnerships should be regional so that strong links can be made between local universities and business clusters in science and engineering.[224] A key aim should be for the partnerships to provide scientists and engineers from business and academia (including students) with skills training relevant to business R&D.

[224] Clusters are usually business-led but are underpinned by the local scientific base, including universities and research institutes, that endeavour to supply a suitably skilled pool of labour for the local companies.

6.35 The foundations for such partnerships are already being laid down in some regions. The North West Science Council, for example, brings together HEIs, the RDA and business to develop a long-term science strategy for the North West of England. One of its aims is to ensure that university research is focused on improving the performance of the region's businesses (such as the chemicals industry), helping to establish new products and processes and set up innovative new companies.

Recommendation 6.7: Innovation Partnerships for collaborative research

The Review recommends that the Government, while retaining successful initiatives, should develop stronger, more coherent and more substantial "Innovation Partnerships" to boost research collaboration between universities and businesses. The Review believes that these should incorporate the following principles:

- that the research be business-led and focused on commercially-oriented R&D;
- that the partnerships be based on clusters of businesses with particular research interests, either nationally or regionally;
- that the Government invest in each partnership alongside the prime funders (business, higher education and RDAs);
- that each partnership could be virtual or could have a physical centre, depending on the nature of the research and the participants in the partnership; and
- that each partnership should have an explicit, core aim of prioritising skills training for SET students and graduates, building a critical mass of SET students and graduates with experience in commercial R&D, and encouraging the interchange of people and technology between business and academia.

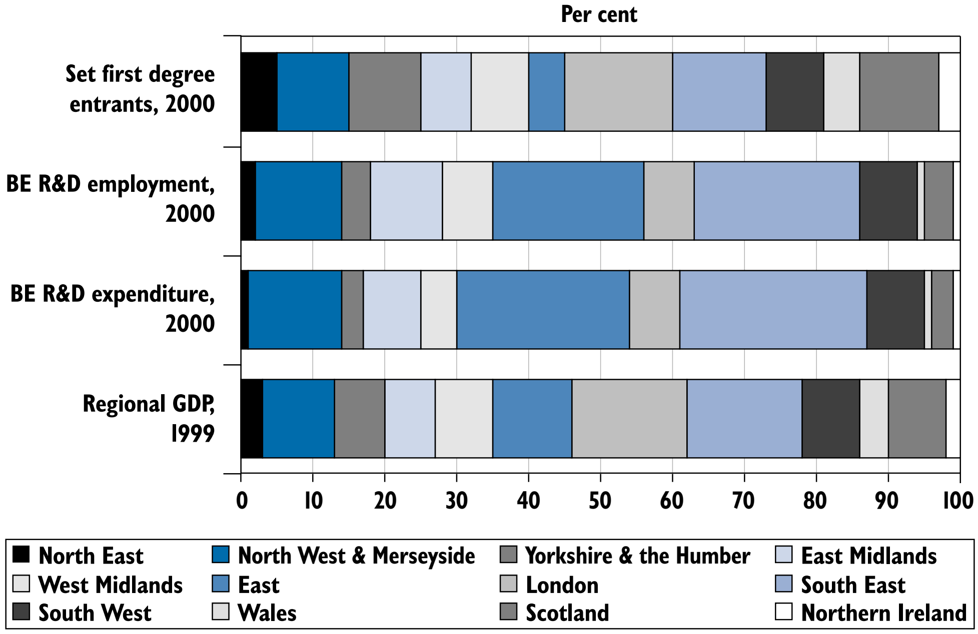
Regional supply and demand for scientists and engineers

6.36 The Review considered regional differences in the demand for, and supply of, scientists and engineers. The supply tends, naturally, to be heavily influenced by the number and type of HEIs in the region. However, demand is driven by the need for the skills of scientists and engineers from both businesses and universities in the region, as well as the public sector.

6.37 Figure 6.6 sets out the proportion of SET first degree graduates, business enterprise R&D expenditure, business enterprise R&D employment, and GDP, broken down by regions and countries. It shows that whereas London, the North East and Yorkshire and the Humber tend to generate a higher proportion of science and engineering graduates than the businesses in the region employ in R&D activities, the East and South East regions tend to have a higher proportion of R&D employment than their proportion of 'home-grown' scientists and engineers. This suggests a trend for some science and engineering students to migrate from universities in London, Yorkshire and the Humber and the North East, to jobs in the East and South East. (The level of R&D employment in a region tends to correlate closely with the level of R&D in that region, as might be expected.)

6.38 It is also interesting to note that Scotland's proportion of the UK's science and engineering graduates is higher than its proportion of UK R&D employment (in part because of its high participation rate in higher education). This supports a widely repeated view heard during the Review that the supply of SET skills in Scotland was more buoyant than elsewhere in the UK. To a lesser extent, the same was said in Wales and Northern Ireland.

Figure 6.6: Regional GDP, R&D activity and SET first degree entrants



Sources: HESA, OST and National Statistics.

6.39 That these differences occur is only natural, since graduates tend to be relatively mobile compared to non-graduates, and many graduates will study in a region and then choose to return to the area in which they went to school, or, indeed, elsewhere. However, a significant proportion will choose to work (or study further) close to their higher education institute.

6.40 Although graduates are highly mobile, higher education institutions nevertheless significantly influence the type of higher-level science and engineering skills available in a country/region. It is therefore important to the regional economy that the mix of science and engineering skills developed in the region's HEIs is suitable for its R&D base (and other employers). Regional Development Agencies therefore need to work with local employers and HEIs to consider the science and engineering skills needs of their region, to build the innovative capacity of the region. This will require the RDAs in England extending their expertise to match the experience of their counterparts in Wales, Northern Ireland and Scotland.

International mobility of scientists and engineers

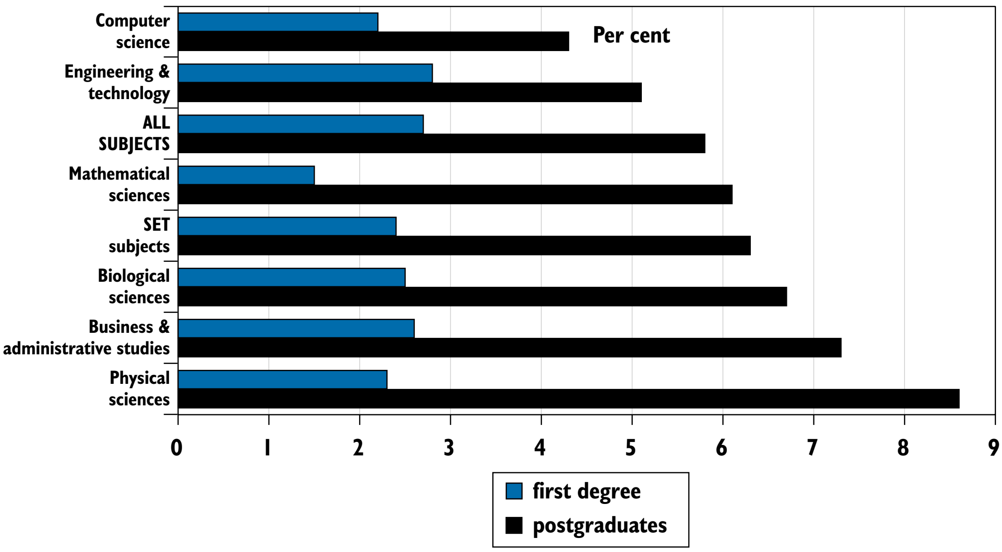
A 'brain-drain'?

6.41 A number of concerns have been expressed to the Review about a 'brain-drain': a net outflow of scientists and engineers from the UK, who carry out research abroad where financial and non-financial rewards for researchers are seen to be greater. The Review considered these concerns carefully.

6.42 There is some evidence supporting the view that increasing numbers of top scientists and engineers are leaving the UK.[225] Such evidence is usually on a micro level (for example, a survey of Royal Society Fellows which found that in 1969 only 16 per cent of Fellows worked outside the UK, 5.5 per cent in the US, while in 1999 26 per cent worked abroad and 12 per cent in the US[226]). These results are not unexpected, since the labour mobility generally has increased significantly in the last 30 years.

6.43 There is some evidence to suggest that the migration may be greater in science and engineering than in other areas. Figure 6.7 sets out the proportion of graduates taking employment abroad. This shows that SET graduates are more likely to move abroad for employment than graduates in general, which is consistent with the view that R&D employers recruit internationally to obtain the best.

Figure 6.7: Proportion of UK domiciled graduates and postgraduates taking employment abroad, 1999/00



Source: HESA, First Destinations of Students Leaving Higher Education Institutions 1999/00.

[225] Science policies for the next Parliament, agenda for the next five years, February 2001, Save British Science.

[226] Royal Society News Release, 27 January 2000.

6.44 However, other studies have concluded that this is not happening on a sufficient scale to contribute to a significant shortage in supply itself.[227] Furthermore, the UK attracts a large number of scientists and engineers from abroad – for example, in 2001 there was a net increase in the inflow of almost 5,000 scientists and engineers.[228] This suggests that the UK may actually enjoy a 'brain-gain' rather than a 'brain-drain'.

6.45 The Review concludes that there are undoubtedly a number of examples of top UK scientists and engineers being tempted to work abroad by better pay and conditions, particularly UK academics tempted by larger salaries overseas. However, the Review does not believe that there is sufficient evidence to suggest that the UK is suffering from a serious 'brain-drain' as such. Indeed, the UK appears to be a net beneficiary of the increasing migration of science and engineering talent.

6.46 Nevertheless, the Review acknowledges that both higher education and business must do more to recruit and retain the UK's best scientists and engineers. This is one of the underlying reasons for the recommendations made earlier in this chapter and in Chapter 5, which aim to improve the salaries and other working conditions of scientists and engineers in business and higher education respectively. In particular, in Chapter 5 the Review recommends that the Government provide additional funding for universities in order to enable them to pay differential amounts to recruit and retain their best academic staff. The Review believes that through such measures, and through businesses and other employers taking up the challenge to improve the attractiveness of jobs in R&D in the UK, it will be possible for the UK better to retain its top scientists and engineers.

Accessing scientific and technical talent from abroad

6.47 As discussed, the UK is at present a beneficiary of international inflows of professional scientists and engineers. The evidence on international flows of scientists and engineers shows that significant numbers of scientists and engineers enter the UK each year from abroad; ten per cent (6,626) of work permits granted in 2000 were for engineers and technologists.[229]

6.48 The UK is also an attractive place to study for science and engineering first degrees and postgraduate qualifications, and large numbers of overseas students study engineering in UK universities compared to other subjects (see Figure 6.8). This is in part due to the strong reputation of the UK, and in part because UK degrees tend to be shorter (and hence cheaper) than degrees elsewhere.

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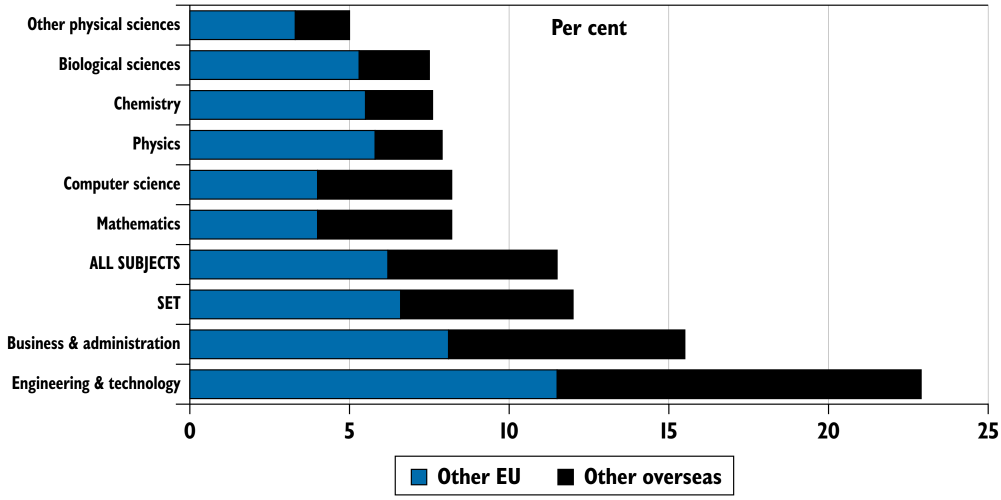
[227] Skills Task Force Research Paper 17, Science Skills Issues, The Institute for Employment Studies, Jane Aston, Nick Jagger, Richard Pearson, December 1999.

[228] According to data on the flows of scientific professionals from The International Passenger Survey, Office for National Statistics.

[229] International migration and the United Kingdom: Recent patterns and trends, RDS Occasional Paper No. 75, Home Office, Janet Dobson, Khalid Koser, Gail McLaughlan, John Salt, December 2001.

Figure 6.8: Proportion of non-UK domiciled students at undergraduate level by subject, 1999/00



Source: Unpublished HESA data from HEFCE.

6.49 The flows of non-UK domiciled science and engineering graduates add to the supply of scientists and engineers available for UK R&D businesses to employ. The OECD considers talent to be disseminated most easily through the physical movement of people, and considers those countries receiving large numbers of foreign students to be best-placed to exploit this and to take advantage of new ideas.[230]

6.50 The flow of scientists and engineers from overseas is an elastic source of labour; migrant labour flows are highly sensitive to changes in demand for certain professions. This source of labour therefore can help to alleviate supply problems in the short to medium term – providing the work permit system allows it to work successfully. (For example, the supply of scientists and engineers in the US has benefited from a high level of immigration of overseas scientists and engineers.)

Effectiveness of the work permit system for scientists and engineers

6.51 The work permit system allows employers based in Great Britain to employ people who are not nationals of a European Economic Area[231] (EEA) country and are not otherwise entitled to work in this country. The Government recognises that there are certain professions in the UK where vacancies are particularly difficult to fill with EEA nationals (one such area is electronic engineers and physicists of IEng[232] or equivalent level in certain specialist areas).

[230] OECD Science, Technology and Industry Scoreboard 2001: Towards Knowledge-based Economies, OECD, Paris.

[231] Countries other than the United Kingdom, that are members of the European Economic Area are Austria, Finland, Greece, Italy, Netherlands, Spain, Belgium, France, Iceland, Liechtenstein, Norway, Sweden, Denmark, Germany, Ireland, Luxembourg and Portugal.

[232] Incorporated Engineering degree.

6.52 Recent changes to the work permit system have smoothed the application procedure and the speed of processing applications significantly. For example, Work Permits UK, now part of the Home Office's Immigration and Nationality Directorate, turns around 90 per cent of applications within one day and employers can make applications on-line. Partners of overseas employees are also allowed to work in the UK, and dependent children (under 18) can travel to the UK with the work permit holder and attend schools in the UK.[233]

Changes to the work permit system

In October 2001, the Government announced the introduction of a new highly skilled migrant's permit. This allows skilled professionals such as scientists and engineers to transfer to the UK to seek work, without having already secured employment, providing they have the means to support themselves and meet a number of specific criteria concerning qualifications and work experience. This new scheme started operation in January 2002.

In addition, the Home Office is in the process of establishing formal procedures to allow certain overseas students (including those studying for degree level qualifications) who graduate in the UK to apply for a work permit without leaving the country. This will be beneficial to the number of overseas SET PhD graduates who wish to stay and work in the UK. Currently students can switch into work permit employment, but only on a discretionary basis.

These changes are part of a wider review of the work permit system which began two years ago, and has contributed to increasing the efficiency of the system and the range of skills which employers can access through this route, including extending the length of work permit available to five years.

6.53 Through the consultation process, a few R&D businesses said that they had recruited scientists and engineers from overseas in situations where the employee had required a work permit. Most of these businesses said that the work permit system now allowed them to recruit from abroad without difficulty, but that there were some additional costs, such as re-location and security clearance. These costs were not significant enough to deter most companies from recruiting from abroad.

6.54 However, the consultation also revealed that many employers – particularly smaller and medium-sized companies – are not aware of the recent changes to the work permit system.

[233] As well as helping UK employers to recruit scientists and engineers from outside the EEA, the Work Permit system also plays a key role in helping to alleviate difficulties in the teaching profession, as called for in chapter two. In 2000, 4,368 work permits were granted for teaching professionals, although it is not possible to identify which subject areas or levels were covered.

Recommendation 6.8: Migration and work permits

The Review welcomes the Government's campaign to raise HEIs' and overseas students' awareness of the recent improvements to the work permit system. However, given the lack of knowledge of these changes shown by businesses during the course of its consultation, the Review recommends that this campaign be extended to cover the business community, including smaller and medium-sized businesses engaged in R&D. Through this, more UK businesses will be able to draw upon worldwide scientific expertise in driving forward their R&D.

6.55 In addition to allowing overseas students to remain and work in the UK, taking action to encourage more EU nationals to study in the UK is also desirable. The Review's recommendation in Chapter 4 welcoming the possibility of extending maintenance grants to other EU students is therefore relevant.

ANNEX A: LIST OF RECOMMENDATIONS BY CHAPTER

Chapter 2: School and Further Education

Recommendation 2.1: The participation of women in science and engineering

The Review notes that, despite some recent progress, the proportion of girls studying mathematics and the physical sciences post-16 is still considerably lower than that of boys, which contributes to the under-representation of women in science and engineering more generally. The Review is clear that the under-participation of women in SET is damaging the UK's supply of scientists and engineers, and a number of the recommendations set out in this report should have an important influence on the participation of women in science and engineering.

The Review is aware of a separate study led by Baroness Susan Greenfield, who has been asked by the Government to recommend how to achieve a step change in the effectiveness of measures being used to increase the participation of women in science and engineering. This Review has therefore sought not to duplicate the work of that study but firmly believes that action is required.

Recommendation 2.2: The participation of ethnic minority groups in science and engineering

The Review is disappointed by the lack of awareness and analysis of differences in achievement and participation in science and engineering between ethnic groups. It is difficult to establish the root causes of these differences, based on the evidence available. However, the Review believes that they are significant and therefore recommends that the Government investigate this issue fully in schools, further education and higher education.

Recommendation 2.3: Primary school teachers

The Review recommends that the Government ensure that primary school teachers receive greater subject-specific training (in particular, in relation to the physical sciences and mathematics) both in their initial training and through Continuing Professional Development to enable primary teachers to build on the progress they have made so far. Furthermore, the Government should review, in three years' time, the progress made in improving primary school teachers' confidence in teaching all areas of the mathematics and science curricula, and take further action as necessary.

As Chapter 2 makes clear, many of the recommendations made on issues relating to secondary schools also apply to further education. For ease of reading, the recommendations are phrased in terms of secondary schools, but the intention of the Review is that the further education sector should be covered, wherever appropriate, by these recommendations.

Recommendation 2.4: Secondary school science teachers' training

The Review recommends that in order to enhance the quality of teaching across the sciences – and in the physical sciences in particular – the Government should act to improve significantly the subject-specific training and support given to science trainee teachers on initial teacher training and other teacher entry programmes. Furthermore, the Government should review, in three years' time, the progress made in improving secondary school teachers' confidence in teaching all areas of the science curriculum, and take further action as necessary.

The Review also recommends that in recruiting science graduates the Government should pay more attention to their areas of specialism (*e.g.* physics, chemistry or biology) to ensure an adequate supply of teachers able to teach the individual sciences (particularly physics and chemistry) at higher levels.

Recommendation 2.5: Teachers' remuneration

The Review recommends that, to solve the serious shortages in mathematics, science, ICT and D&T teachers, more must be done to address the pay and other incentives offered to teachers in these subjects. The Government, schools and colleges must compete for graduates in these disciplines in the labour market by, amongst other measures, providing more attractive remuneration for teachers in these subjects to better enable schools to attract graduates who can earn higher salaries in other sectors of the economy. This will require head teachers and governing bodies to pay teachers in shortage subjects more than other teachers, which is the economically efficient response to shortages in supply.

The Review therefore recommends that the Government tackle such recruitment and retention problems through increasing the remuneration offered to teachers of these shortage subjects – and also that head teachers and governing bodies use all the pay flexibility at their disposal. Furthermore, the Review recommends that this additional remuneration be linked – wherever possible – to teachers' take-up of CPD activities and opportunities, thereby rewarding those teachers who make particular efforts to improve further their subject knowledge and teaching style.

Recommendation 2.6: Secondary school teachers' Continuing Professional Development (CPD)

The Review recommends that the Government improve science teachers' access to, and take up of, subject related CPD, which will benefit their teaching and also act to improve retention. In particular, the Review recommends that all science teachers be incentivised to undertake CPD, and that the range of recognised CPD activities be as broad as possible. For example, it should include the possibility of participating in scientific research carried out in industry and universities. The Review welcomes the Government's commitment to a National Centre for Excellence in Science Teaching. It also notes the interest of the Wellcome Trust and hopes that the Government and the Trust can form the sort of partnership that has been so fruitful in other areas of science policy.

Recommendation 2.7: School laboratories

School science and D&T laboratories are a vital part of pupils' learning experiences in these subjects, and should play an important role in encouraging pupils to study these subjects at higher levels. However, it is clear that for many pupils this is not the case. To address this, the Review recommends that the Government and Local Education Authorities prioritise school science and D&T laboratories, and ensure that investment is made available to bring all such laboratories up to a satisfactory standard (as measured by OFSTED) by 2005. Furthermore, the Review recommends that these laboratories should be brought up to a good or excellent standard (again, as measured by OFSTED) by 2010; a standard which is representative of the world of science and technology today and that will help to inspire and motivate pupils to study these subjects further. The Government should take all appropriate steps to ensure that these targets are met.

Recommendation 2.8: Teaching assistants

The Review is convinced that the high pupil-to-staff ratios in schools in England – particularly in practical classes – is having an adverse effect on the quality of pupils' science and D&T education, and in turn on the supply of science and engineering skills. The Review believes these high pupil-to-staff ratios in practical classes are best addressed through the employment of skilled teaching assistants acting to support the teacher, and that science and engineering undergraduates and postgraduates are well placed to support teachers in this way since they have a good recent understanding not only of the subject but also of the school environment. They can also provide important role models for pupils.

The Review therefore recommends that the Government establish a major new programme, paying undergraduate and postgraduate students to support science and D&T teachers. The scheme should be implemented alongside the Researchers in Residence scheme, and should be open to postgraduates as well as undergraduates. The Government should pay students on a competitive footing with other sources of employment open to them. The Government should set an ambitious target for the number of science and engineering students participating in such a scheme by 2005.

The precise role of the teaching assistants should be for schools, universities and the students to decide locally, on the basis of guidance from the Government. Examples of possible roles could be direct support to teachers in supervising practical work, giving demonstrations or supporting science and D&T technicians. Naturally, it will be important to ensure that those participating have the skills and training to work in these capacities.

Recommendation 2.9: The science curriculum

The science curriculum – particularly in the physical sciences – is not, at present, sufficiently approachable nor appealing to all pupils between the ages of 11 and 16. This is a significant factor in the declining numbers of pupils taking these subjects at higher levels, and is widely thought to be a particularly important factor in discouraging girls.

The Review therefore welcomes both the QCA's ongoing work to modernise the science curriculum and the Government's Key Stage 3 strategy. These are important elements in making the study of science more attractive to pupils, and, in turn, helping to enthuse pupils to study science and related subjects at a higher level. The Review recommends that the Government ensure that these changes deliver significant improvements to the way that the sciences (particularly the physical sciences) are taught. In particular:

- improving the ability of all pupils to relate the science they study to the world around them and to potential career opportunities;
- encouraging appropriate links to be made with other subjects (particularly D&T);
- ensuring that, while pupils continue to study the fundamental principles of science, the curricula and assessments are not dominated unhealthily by reliance on the overall volume of scientific knowledge.

The Review notes that modernising the curriculum must go hand-in-hand with providing teachers with the necessary support and training to teach the new curriculum in a way that appeals to all pupils (especially girls).

The Review further recommends that the Government should review, in three years' time, the progress in improving the attractiveness and relevance of the mathematics and science curriculum, and take further action as necessary.

Finally, the Review welcomes the QCA's proposals for reforming GCSE science, which are a necessary and positive step in increasing the appeal of science to pupils. However, it will be important to support schools and colleges in dealing with what is likely to be a more varied intake to A- and AS-level courses, and enable pupils successfully to make the transition to A- and AS-level science.

Recommendation 2.10: Transition from GCSE to A-level

The Review welcomes the proactive approach of the QCA in considering the transition from GCSE science and mathematics to AS- and A-levels in these subjects. However, the consultation process revealed that the issue may not yet have been fully addressed and the Review therefore recommends that the Government give it further consideration, and take suitable action to allow pupils to make the transition from GCSE to AS- and A-level study – particularly in the physical sciences and mathematics – smoothly.

Recommendation 2.11: Difficulty of subjects

The Review welcomes the attention that the QCA has given to the issue of inter-subject standards, and urges the Government to undertake definitive research into the greater apparent difficulty of science and mathematics A-levels and to take appropriate subsequent action. It is essential that pupils have a broadly equal chance to achieve high grades in science and mathematics as they would in other subjects. Without this, fewer pupils will choose to study science and mathematics at higher levels. The Review is firm that arguments about the merits of 'levelling up' or 'dumbing down' are a distraction – if pupils generally find it more difficult to achieve high marks in science and mathematics, this needs to be corrected. The Review believes that this can and should be done without compromising the core knowledge and skills needed for studying science and engineering courses in higher education.

Recommendation 2.12: Enhancing the curriculum

The profusion of independent schemes aimed at enthusing and educating pupils in science and engineering (for example, the Industrial Trust Scheme and CREST), and the lack of support that schools and teachers have in identifying those most suited to their pupils, is inhibiting the collective effect of these schemes. The Review therefore recommends that the Government establish a single recognised channel through which schools access these independently-provided schemes. This will help schools and teachers to identify the schemes most suited to pupils at different ages in different subjects, thereby lowering the burden on teachers. Without better co-ordination (and rationalisation) of the existing schemes, important opportunities and resources will continue to be wasted.

The Review recommends that SETNET and its network of SETPoints, be given this responsibility in the areas of science technology, engineering and mathematics, while still recognising the wider role of the Education Business Links Consortia in England. However, if SETNET is to fulfil this function (and deserve the additional funding that this Review recommends the Government provide), it is important that it emphasises all areas of science and engineering equally, and also that those in the science, engineering, IT, technology and mathematics communities (particularly the scientific community) accept SETNET as the channel of communication. SETNET should work with the proposed idea of a National Centre for Excellence in Science Teaching in delivering this.

Recommendation 2.13: Improving the perception of careers in science and engineering

The Review believes that further action is needed from the Government, but also from businesses and others in scientific and technical fields, to ensure that pupils (especially girls) receive accurate and positive advice about the rewards (and the breadth of careers arising) from studying science and engineering. Specifically, the Review recommends that the Government establish a small central team of advisers (possibly within the new Connexions service, but working closely with SETNET) to support existing advisers, teachers and parents in advising pupils. Furthermore, the Government should review, in three years' time, the progress in improving pupils' knowledge of the rewards and the breadth of careers arising from studying science and engineering, and take further action as necessary.

Chapter 3: Undergraduate education

Recommendation 3.1: Quality of SET A-level students as degree-level entrants

Students sometimes struggle to make the transition from A-level study to degree level study in science, engineering and mathematics, since undergraduate courses often do not pick up where the students' A-level courses ended. Furthermore, the increasing modularisation of A-level courses has led to students entering higher education with wider variation in subject knowledge (differences in the mathematical knowledge of students are seen to cause particular problems in mathematics, physical science and engineering degrees). The Review recommends that to help students – particularly those in the past least likely to participate in higher education – make the transition from A-level study to degree level study in science, engineering and mathematics:

- A-level awarding bodies and the HE sector should review science, engineering and (in particular) mathematics education at the boundary between school/further education and higher education, and adjust their courses accordingly to ensure that this transition can be made smoothly; and
- the Government should fund HEIs to use new 'entry support courses' and e-learning programmes to 'bridge' any gaps between students' A-level courses and their degree courses.

Furthermore, the Government should in three years' time review progress in reducing the gaps between A-level and degree-level courses – to ensure that students are not discouraged from studying these subjects, and retain interest in them – and take further action as necessary.

Recommendation 3.2: Undergraduate course structure

Updating the nature and content of undergraduate courses to reflect the latest developments in science and engineering (through having lecturers who can draw on recent experience of work environments other than HEIs, and through explicit changes in course content) has the benefit of improving the attractiveness and relevance of the course to both students and employers. Accordingly, the Review recommends that employers and HEIs work more closely together, for example through:

- increasing the number of industrial placements offered to academic staff;
- encouraging industrialists to spend time in universities;
- encouraging greater engagement between businesses and careers services and, in turn, between careers services and science and engineering departments; and
- encouraging universities to be more innovative in course design in science and engineering.

These actions by HEIs and employers must be supported by those bodies that accredit science and engineering courses – for example, the Engineering and Technology Board and professional bodies which are members of the Science Council – who must work with universities to drive forward innovation in course design, and not allow the accrediting processes inadvertently to inhibit it. The Government should facilitate these forms of HEI/employer interactions through ‘third stream’ funding such as the Higher Education Innovation Fund (HEIF). Furthermore, the Government should in three years’ time review progress in this area and take action as necessary to further improve HEI/employer interactions.

Recommendation 3.3: University teaching laboratories

The Review recommends that the Government should introduce a major new stream of additional capital expenditure to tackle the backlog in the equipping and refurbishment of university teaching laboratories. The priority should be to ensure the availability of up-to-date equipment and that then, by 2010, all science and engineering laboratories should be classed as at a good standard or better, as measured by HEFCE. In delivering this recommendation, the Review believes it is important that the teaching infrastructure capital stream complements research infrastructure funding to facilitate the building, refurbishment or equipping of joint research and teaching facilities, where appropriate.

Recommendation 3.4: Recurrent funding for teaching

In order to ensure that in future higher education institutions can and do invest properly in science and engineering teaching laboratories, the Review recommends that HEFCE should formally review, and revise appropriately, the subject teaching premia for science and engineering subjects. The revisions should ensure that the funding of undergraduate study accurately reflects the costs – including paying the market rate for staff, as well as the capital costs – involved in teaching science and engineering subjects.

Recommendation 3.5: Undergraduate student funding

While student debt does not in general appear to be deterring potential students from undergraduate education, at the margin some undergraduates may be deterred from science and engineering courses, as they involve longer hours than other courses and as a result students find it more difficult to supplement their income by working part-time. In order for this not to deter the most disadvantaged students from studying science and engineering (and other courses with long ‘contact hours’), and to assist with widening participation, the Review recommends that the Government (through its guidance to HEIs) should ensure that the Access Funds and Hardship Funds adequately provide for students on courses involving a high number of contact hours. The Review recommends that additional funding should be provided to accommodate this, and that HEFCE monitor the targeting of this additional funding to ensure it reaches those most in need.

The Review also recommends that the Government closely monitor the impact that an additional year of student debt has on students’ choices of course, to ensure that the student funding system at undergraduate level is not discouraging students from studying (the longer) physical science and engineering courses.

Recommendation 3.6: University careers advisory services

The Review welcomes the recommendations of the Harris report on improving university careers advisory services. It is important that science and engineering students have accurate, up-to-date careers advice on the rewards and range of opportunities available to them (particularly opportunities in research and development). In particular, the Review endorses the recommendations in his report aimed at improving the links between careers advisory services and businesses, particularly small businesses, which will require action by both HEIs and by businesses.

Chapter 4: Postgraduate education

Recommendation 4.1: PhD stipends

In order to recruit the best students to PhD courses, it is vital that PhD stipends keep pace with graduates' salary expectations, particularly given the increasing importance of student debt on graduates' career choices. It is also important that stipends better reflect the relative supply of, and market demand for, graduates in different disciplines. The Review therefore recommends that the Government and the Research Councils raise the average stipend paid to the students they fund over time to the tax-free equivalent of the average graduate starting salary (currently equivalent to just over £12,000), with variations in PhDs stipends to encourage recruitment in subjects where this is a problem. Furthermore, the Review recommends that a *minimum* PhD stipend of £10,000 is established, to ensure that HEIs do not use this extra flexibility to attract extra PhD students at the expense of quality.

Recommendation 4.2: PhD training elements

Despite the welcome current moves by the Funding Councils to improve the quality of PhD training, institutions are not adapting quickly enough to the needs of industry or the expectations of potential students. The Review therefore believes that the training elements of a PhD – particularly training in transferable skills – need to be strengthened considerably. In particular, the Review recommends that HEFCE and the Research Councils, as major funders of PhD students, should make all funding related to PhD students conditional on students' training meeting stringent minimum standards. These minimum standards should include the provision of at least two weeks' dedicated training a year, principally in transferable skills, for which additional funding should be provided and over which the student should be given some control. There should be no requirement on the student to choose training at their host institution. The minimum standards should also include the requirement that HEIs – and other organisations in which PhD students work – reward good supervision of PhD students, and ensure that these principles are reflected in their human resources strategies and staff appraisal processes.

Furthermore, in order to assure employers of the quality of PhD students, as part of these standards the Review recommends that institutions should introduce or tighten their procedures for the transfer of students to the PhD. In particular, the Review believes that HEIs must encourage PhD projects that test or develop the creativity prized by employers.

Recommendation 4.3: Length and nature of PhD programmes

The Review believes that measures should be put in place to help nurture a diverse range of PhD programmes to train able students in research methods and technical skills, and help them acquire the advanced knowledge and transferable skills they will need in their future careers. This should include encouraging part-time working and the gaining of experience in business R&D. Individual institutions should be given flexibility to offer a range of provision. The Review therefore recommends that:

- the Government and the Research Councils should fund their present numbers of PhD students on the basis that the average full-time student requires funding for $3^{1}/_{2}$ years;
- it should be possible for the institution to use the funding flexibly to run three- and four-year full-time programmes (and also study of intermediate length) to support longer and more challenging projects, advanced courses and transferable skills training;
- both three- and four-year courses should be examined to the same standards, which should be at least as high as the current standards; and
- students should be able to exit early from PhDs (subject to satisfactory performance) with an MRes or an MPhil.

The Review believes that the EPSRC's doctoral training grants system represents a good way of achieving this flexibility, and urges other Research Councils to implement similar mechanisms.

Recommendation 4.4: EU PhD students

The Review would welcome the extension of PhD maintenance awards to EU students by the Research Councils as a means of maintaining and improving the quality of research in the UK. The effect of this on the number and quality of UK PhD students should be closely monitored in order to ensure sufficient supply of PhD holders for the needs of the UK economy.

Chapter 5: Employment in higher education

Recommendation 5.1: Academic Fellowships

The Review believes that there should be a clearer path for those who have completed PhDs into academic lectureships. This should be achieved through creating Fellowships that allow those involved to move from principally research-based work towards the role of lecturer, with an added role of reach-out to schools (for example, becoming a Science and Engineering Ambassador) and helping to widen access to higher education. The Review therefore recommends that the Government provide funds to establish a significant number (the Review believes 200 a year) of prestigious academic Fellowships to be administered by the Research Councils. The Fellowships should last for five years and should be designed to prepare people explicitly for an academic career, to be distributed and awarded on the basis of academic excellence across the range of subjects considered in this Review. The Research Councils should work with the funders of similar schemes (for example, The Royal Society and the Wellcome Trust) in introducing these Fellowships.

Recommendation 5.2: Industry secondments for postdoctoral researchers

The Review recommends that HEFCE and the Research Councils evaluate schemes such as the Research Assistants Industry Secondments run by the EPSRC as the basis for a wider mechanism for encouraging postdoctoral researchers into industrial careers, and as a mechanism for knowledge transfer.

Recommendation 5.3: A vision for postdoctoral researchers

It is important for postdoctoral researchers to be able to develop individual career paths, reflecting the different career destinations – Industrial, Academic and Research Associate – open to them, and that funding arrangements reflect the development of these career paths. The Review believes that enabling the individual to establish a clear career path, and a development plan to take them along it, is critical to improving the attractiveness of postdoctoral research. The Review therefore recommends that HEIs take responsibility for ensuring that all their postdoctoral researchers have a clear career development plan and have access to appropriate training opportunities – for example, of at least two weeks per year. The Review further recommends that all relevant funding from HEFCE and the Research Councils be made conditional on HEIs implementing these recommendations.

Recommendation 5.4: Postdoctoral researchers' salaries

In addition to establishing clearer career progression, the Review recommends that Research Councils should significantly increase salaries – particularly starting salaries – for the science and engineering postdoctoral researchers it funds, and sponsors of research in HEIs and PSREs should expect to follow suit. The Review considers that the starting salary for postdoctoral researchers should move in the near future to at least £20,000, and that further increases should be available to solve recruitment and retention problems in disciplines where there are shortages due to high market demand (for example, mathematics).

Recommendation 5.5: Academic salaries

As with contract researchers, there is a need for universities to improve salaries – particularly starting salaries – for many scientists and engineers. The Review is clear that universities must use all the flexibility at their disposal differentially to increase salaries, especially for those engaged in research of international quality, where market conditions make it necessary for recruitment and retention purposes. The Government should assist by providing additional funding to permit universities to respond to market pressures. As a first step, the HEFCE funding currently dedicated to the human resources strategy should be made permanent. Further additional funding for recruitment and retention, which will vary between institutions, should initially be part of a separate stream linked to the existing human resources strategy fund and appropriately focussed towards research excellence. However, once more market-based systems have been embedded, the funds should be incorporated into core funding for research and also into revised subject teaching premia.

Chapter 6: Scientists and engineers in R&D

Recommendation 6.1: Attractiveness of careers in R&D

Responding to the challenge of improving the attractiveness of jobs in R&D to match or surpass all other opportunities open to the best science and engineering graduates and postgraduates is crucial to individual businesses' future success – since their R&D underpins their future products, services and, ultimately, their future sales and profits.

Through consultation with businesses and scientists and engineers themselves, the Review has identified a number of issues related to work in R&D that employers must address in order to be able to attract the best science and engineering graduates and postgraduates.

- **Initial pay.** Starting salaries are an increasingly important factor in students' career choices, in part due to the effect of student debt and students' increasing commercial awareness. The starting salaries and bonuses paid to scientists and engineers working in R&D are often not as high as they could receive in other sectors or occupations. While it may not be necessary to match the highest salaries paid elsewhere, the Review is clear that businesses will ultimately need to raise the salaries and other financial rewards they offer if they are to compete for the best scientists and engineers (particularly those with an entrepreneurial spark or good commercial awareness). This goes hand-in-hand with the need for businesses to look at R&D not as a cost, but as an investment in their future survival and growth.
- **Salary progression.** Similarly, retention in an increasingly mobile workforce relies upon salary progression that compares well with the other opportunities available. Evidence suggests that the salary progression for scientists and engineers in R&D does not compare favourably with that for their counterparts in other sectors.
- **Career structure.** Science and engineering graduates and postgraduates can be put off entering R&D due to unattractive career structures – with short-term contracts, low levels of responsibility, few chances for progression within R&D and poor job design (*e.g.* jobs that do not use their skills to the full). It is clear

from the Review's consultation that many employers can do more to improve the career structures of scientists and engineers, through addressing these and other influential factors.

- **Training and professional development.** Scientists and engineers working in research do so partly because of their interest in the subject, and it is therefore key that they can stay in touch with the latest developments in their field. Employers should do all they can to provide time and resources to allow them to do this, and partake in CPD activities, which will also bring benefits in terms of recruitment and retention. There is a role for the Government and for trades unions in helping to make sure that smaller businesses are able to provide sufficient training and CPD to research employees.
- **Recruitment mechanisms.** The Review believes that many R&D businesses must improve their recruitment mechanisms to compete better with other employers. For most R&D businesses, especially the smaller ones, increasing marketing efforts and taking opportunities to widen the number of students they make contact with should improve their ability to recruit the scientists and engineers they need. R&D businesses must also take responsibility for improving the perception of jobs in R&D.

The Review is clear that the response of R&D employers to these challenges is crucial in providing an adequate supply of scientists and engineers for R&D. Without improved and more attractive opportunities to work in R&D, the UK's best scientists and engineers will doubtless be tempted elsewhere, since the demand for their skills – and the rewards offered – will only grow over time.

Recommendation 6.2: The challenge to employers

The Review recommends that the Government should establish a group of R&D employers to support and monitor employers' responses to the challenge of improving the pay, career structures and working experiences for scientists and engineers in R&D. The group should include representatives from businesses (large, medium and small) and others that employ scientists and engineers in an R&D capacity.

The Review believes the group must act as a driving force in taking the recommendations in this report forward, and should publish a report, before the next public spending review, setting out the response of employers to the challenges identified by this Review. The group might also play a key role in considering cross-regional and national R&D skills needs, referred to in Recommendation 6.4.

Recommendation 6.3: Skills planning

It is clear that although many businesses may plan their R&D projects a number of years in advance, they often do not plan their skills needs for this research more than a year ahead. Although there are difficulties in detailed skills planning, the Review believes that R&D businesses must do more to establish what science and engineering skills they will need for future research projects in order for them to be able to recruit the skilled scientists and engineers they need with less difficulty.

Recommendation 6.4: Skills dialogue

The Review believes that the supply of skills to R&D businesses can be improved through more coherent skills dialogue between these businesses and universities. The Regional Development Agencies (RDAs) should take a leading role in the coordination of regional dialogue between businesses and HEIs through the new FRESAs (Frameworks for Regional Employment and Skills Action) to ensure that demand for higher level skills at a regional level can be met.

Furthermore, the Review recommends that the sector skills councils (which, the Review believes, should be represented in FRESAs) work with the Learning and Skills Council, trade associations and other business groups to identify – based on the regional skills discussions – evolving cross-regional and national R&D-related skills needs.

Recommendation 6.5: Business involvement in higher education

Although universities need to be proactive in ensuring that courses are as relevant to business as possible, the Review believes that businesses must become more actively involved in university course design. In particular, the Review recommends that employers' bodies – for example, the CBI and trade associations – and the Government work to encourage more R&D businesses to participate in providing work placements for SET graduates and postgraduates (for example, in sandwich year courses).

Recommendation 6.6: Research collaboration between business and higher education

There are a number of Government sponsored schemes that act to encourage research collaboration between businesses and HEIs. However, the Review feels that the collective impact of these schemes is not as great as it should be. The Review therefore recommends that the Department of Trade and Industry, as part of its increased focus on innovation and skills, and more effective delivery of business support, should evaluate the success of existing initiatives in this area – in particular, paying attention to whether the training elements of these schemes are sufficiently supported and prioritised and the extent to which they play a strong role in employer-university communication and collaboration.

Recommendation 6.7: Innovation Partnerships for collaborative research

The Review recommends that the Government, while retaining successful initiatives, should develop stronger, more coherent and more substantial "Innovation Partnerships" to boost research collaboration between universities and businesses. The Review believes that these should incorporate the following principles:

- that the research be business-led and focussed on commercially-oriented R&D;
- that the partnerships be based on clusters of businesses with particular research interests, either nationally or regionally;
- that the Government invest in each partnership alongside the prime funders (business, higher education and RDAs);
- that each partnership could be virtual or could have a physical centre, depending on the nature of the research and the participants in the partnership; and
- that each partnership should have an explicit, core aim of prioritising skills training for SET students and graduates, building a critical mass of SET students and graduates with experience in commercial R&D, and encouraging the interchange of people and technology between business and academia.

Recommendation 6.8: Migration and work permits

The Review welcomes the Government's campaign to raise HEIs' and overseas students' awareness of the recent improvements to the work permit system. However, given the lack of knowledge of these changes shown by businesses during the course of its consultation, the Review recommends that this campaign be extended to cover the business community, including smaller and medium-sized businesses engaged in R&D. Through this, more UK businesses will be able to draw upon worldwide scientific expertise in driving forward their R&D.

Final remarks (repeated from the executive summary)

The recommendations set out in this report, which represent challenges for the Government, for employers and for the education system, are designed to help secure a strong supply of people with science and engineering skills. The Review believes that implementing these recommendations will be a crucial element in achieving the Government's agenda for raising the R&D and innovation performance of the UK to match the world's best.

The Review is clear that progress towards the goals set out in the report must be reviewed regularly in order to ensure that the UK's R&D and innovation performance can grow as intended. In particular, the Review recommends that that the Government should review progress on improving the supply of scientists and engineers, encompassing all the areas identified by this Review, in three years' time, and take any further necessary action to continue the process of improvement.

ANNEX B: TERMS OF REFERENCE FOR THE REVIEW

The study should:

1. compare the current demand for, and supply of, high-level scientific and technical skills in the UK, focusing on the type of skills required by businesses to lead and underpin their research and development activities (including examining the demand for highly specialised knowledge and skills in particular fields; for broad subject knowledge and for more generic skills);

2. investigate how the demand for, and supply of, these skills is likely to evolve over the next ten years by identifying the major sources of demand (including non science-related employment);

3. understand any factors (other than shortfalls in overall supply) that may hinder innovative companies in recruiting and retaining the highly skilled scientists and engineers with the relevant skills;

4. investigate the mechanisms through which businesses in the UK identify their needs for specific high-level scientific and technical skills and communicate these needs to the higher education sector (primarily, but not exclusively, higher education establishments and organisations in the UK);

5. investigate the way in which the higher education sector – in collaboration with other sections of the education sector – currently responds to these demands (including the process by which those in higher education can access the academic and business research opportunities available to them);

6. propose improvements, if necessary, to these mechanisms to ensure that the higher education sector can and does respond effectively to future shifts in the demand of businesses for particular skills; and

7. analyse whether, over and above any such proposals to improve to these mechanisms, more needs to be done in the short term to seek to address:

   i. any mismatch between the overall demand for particular scientific and technical skills and their overall supply; and

   ii. any factors that hinder the ability of innovative businesses to recruit and retain scientists and engineers with the relevant skills.

ANNEX C: GLOSSARY

This list includes abbreviations and acronyms commonly used throughout this report, as well as further information about some of the terms used.

AGCAS	**Association of Graduate Careers Advisory Services**
AGR	**Association of Graduate Recruiters**
AMAs	**Advanced Modern Apprenticeships**
ANRSE	A database (**Analytical Researchers, Scientists and Engineers**) maintained by the OECD – a data-set on human resources working on R&D in the business enterprise sector.
ARCS	**Academic Research Careers in Scotland** (a survey)
AST	**Advanced Skills Teacher** (Teachers who are deemed 'excellent' in a range of skills' in which they train colleagues).
BBSRC	**Biotechnology and Biological Sciences Research Council**
BCIS	**Building Cost Information Service Ltd** (Information services of The Royal Institution of Chartered Surveyors)
BCS	**British Computer Society**
BERA	**British Educational Research Association** (The aim of the Association is to sustain and promote a research culture in education.)
BERD	**Business Enterprise expenditure on Research and Development** (statistic)
CASE	**Co-operative Awards in Science and Engineering** (CASE projects aim to link universities, students and business employers in SET, and involve research students working on projects of one to three years in duration which are of direct relevance to a particular industry.)
Connexions Service	The government's support service for young people aged 13 – 19 in England, which aims to provide integrated advice, guidance and access to personal development opportunities.
CPD	**Continuing Professional Development**

CRC	**Cooperative Research Centres** (An Australian research centre programme which has five main areas of activity – manufacturing, information technology, mining and energy, agriculture-based industry, environment, medical science and technology.)
CRS	**Contract Research Staff**
CST	**Council for Science and Technology**
CSU	**Higher Education Careers Services Unit**
DfEE	**Department for Education and Employment** (the predecessor to the Department for Education and Skills).
DfES	**Department for Education and Skills**
D&T	**Design and Technology**
DTI	**Department of Trade and Industry**
doctorate	A qualification denoting training and achievement in original research; often a PhD/DPhil but also including EngD, DSc (Doctor of Science) etc. The 'new route PhD' is an experimental four-year PhD programme.
EEA	**European Economic Area**
EPSRC	**Engineering and Physical Sciences Research Council**
ESRC	**Economic and Social Research Council**
ETB	**Engineering and Technology Board**
Faraday Partnerships	Faraday Partnerships improve the flow of technology and skilled people between the science base and industry. Partnerships exist between industrially oriented research organisations and the science and engineering base, to carry out core research and provide industrially relevant postgraduate training.
FE	**Further Education**
FRESAs	**Frameworks for Regional Employment and Skills Action**
FTE	**Full-time equivalent**
GCE	**General Certificate of Education**
GCSE	**General Certificate of Secondary Education**
GNVQ	**General National Vocational Qualification**

GTP	**Graduate Teacher Programme** (This programme is designed to allow schools to employ unqualified teachers who are preparing for QTS assessment, assess them against the standards for the award of QTS, and devise individual training plans for them.)
grade drift	The movement of a member of staff from a lower pay-scale "grade" to a higher one in order to increase his or her salary, perhaps occurring when it is not possible to better pay the members of staff concerned on the lower scale (determined by national pay scale bargaining).
H&S	**Health and Safety**
HE	**Higher Education**
HEIs	**Higher Education Institutions** (encompassing colleges of higher education as well as universities).
HEIF	**Higher Education Innovation Fund** (A DTI Knowledge transfer/exploitation fund *(England only)* supporting the interaction of HEIs with businesses and the wider community.)
HEFCE	**Higher Education Funding Council for England**
HESA	**Higher Education Statistics Agency**
ICT	**Information and Communication Technology: telecommunication and computer technology**
IENG	**Incorporated Engineering degree**
IIES	**Institute of Employment Studies**
IMRCs	**Innovative Manufacturing Research Centres**
INSET	**In-Service Education of Teachers**
IoP	**Institute of Physics**
IT	**Information Technology**
ITT	**Initial Teacher Training** (required to attain QTS – see below).
JIF	**Joint Infrastructure Fund**
KT	**Knowledge Transfer**
LEAs	**Local Education Authorities**
MASN	**Maximum Allowable Student Numbers** (a term formerly used by HEFCE to determine the number of students allowed per HEI).

Master's degree (MSc/MPhil)	MSc degrees are awarded to graduates who have degree undertaken a further course of study, after an honours degree, either full or part-time. Master's degrees may be taken following a period of work experience and some courses take the form of company training programmes. MPhil degrees may be awarded following a period of research rather than a course of study. The Master of Research (MRes) degree is a one year full-time course with postgraduate training in methods and practice of research and in relevant transferable skills that are not normally offered in MSc courses.
MPhys/MEng	These are both examples of four-year undergraduate degrees whereby the fourth year of the courses leads to a Master's qualification usually required for advanced professional work (physics) and chartered status for engineers.
MRC	**Medical Research Council**
MSP	**Maths and Science Partnership Programme** (which supports schools working with universities and community to improve science, technology and mathematics education.)
NATFHE	**National Association of Teachers in Further & Higher Education** (The University and College Lecturers' Union)
NBER	**National Bureau of Economic Research**
NERC	**Natural Environment Research Council**
NICEC	**National Institute for Careers Education and Counselling** (based at Lucy Cavendish College, Cambridge).
NMW	**National Minimum Wage**
Neighbourhood Engineers Programme	The Neighbourhood Engineers Programme (NEP) aims to enhance young people's scientific and technical capability and raise awareness of the importance of engineering to the economy and society. Neighbourhood Engineers (NEs) attend schools to enthuse young people by practically assisting with curriculum linked activities. It is financially supported by the ETB.
OECD	**Organisation for Economic Co-operation and Development**
OFSTED	**Office for Standards in Education** (officially the Office of Her Majesty's Chief Inspector of Schools in England).
OST	**Office of Science and Technology**

PGCE	**Postgraduate Certificate in Education** (generally a one year postgraduate qualification) leading to Qualified Teacher Status.
PI	**Principal Investigator** (an academic who obtains funds to carry out a research project from Research Council or other funding).
PISA	**Programme for International Student Assessment** (carried out by the OECD)
postgraduate	A student on a course which normally requires a first degree as a condition of entry.
PPARC	**Particle Physics & Astronomy Research Council**
PSREs	**Public Sector Research Establishments**
QAA	The **Quality Assurance Agency** for Higher Education which assesses teaching quality in universities and HE colleges.
QCA	**Qualifications and Curriculum Authority** (a national body which determines the national curriculum and contributes to the design of national examinations).
QR	**Quality-related Research funding** – part of the block grant of state funding given to English HEIs by HEFCE.
QSEs	**Qualified Scientists and Engineers**
QTS	**Qualified Teacher Status** (required by teachers to work in maintained schools in England).
RAE	**Research Assessment Exercise** – The process of assessing the quality of research in UK HEIs for funding purposes. The RAE is carried out every few years by the four UK funding bodies. The last RAE was in 2001.
RAIS	**Research Assistants Industrial Secondments** scheme
RCs	**Research Councils**
RCI	**Research Careers Initiative** (This is to monitor progress towards meeting the agreed concordat on contract research staff concerning the management of staff appointed on fixed term contracts – set up in 1996).
RCGSP	**Research Councils Graduate Skills Programme**
RDAs	**Regional Development Agencies**
Researchers in Residence	A scheme run by a number of the Research Councils and the Wellcome Trust, in collaboration with Sheffield Hallam University, which allows PhD students to support school science to make it relevant and exciting for young people.

R&D	**Research and Development**
RDS	**Research Defence Society**
RTOs	**Research and Technology Organisations**
RTP	**Registered Teacher Programme** – a DfES programme for people that have completed recognised teacher training overseas, and who have been accepted onto a UK course leading to a first degree (or equivalent qualification). Schools employ RTP trainees, working in partnership with HEIs, since participants must complete a degree at the same time as qualifying as a teacher. This programme requires maths, English and science standards.
SARTOR	**Standards and Routes to Registration for engineers**
SBS	**Small Business Service**
SCAA	**School Curriculum and Assessment Authority** (predecessor to QCA)
SCOEG	**Standing Committee on the Employment of Graduates** (predecessor to AGCAS)
scientists and engineers	Often used in this report as shorthand for 'scientists, engineers, technologists and mathematicians'.
SEAs	**Science and Engineering Ambassadors programme** – this is sponsored by DTI and DfES, and encourages scientists and engineers to help in schools.
SET	**Science, Engineering and Technology** (including the mathematical sciences).
SETNET	**Science, Engineering Technology and Mathematics Network** (a network, funded in part by Government, which aims to act as an enabling interface between businesses and schools in the areas of science, technology, engineering and mathematics).
SETPoints	The regional branches of SETNET (above).
SHEFC	**Scottish Higher Education Funding Council**
SME	**Small or Medium Enterprise**
SRIF	**Science Research Investment Fund**
STEM	**Science, Technology, Engineering and Mathematics**
STEP	**Shell Technology Enterprise Programme**

stipend	A grant paid to PhD students to fund them while they carry out their research projects – often awarded by Research Councils.
TCS	A Government programme, formerly known as the **Teaching Company Scheme**.
TTA	**Teacher Training Agency**
third stream activity/funding	Colloquially, activity by HEIs which is not funded as teaching or research; in this report, principally refers to funding for HEIs to engage in joint activity with businesses.
UCAS	**Universities and Colleges Admissions Service**
UCEA	**Universities and Colleges Employers Association**
undergraduate	Student working towards a first degree, higher education certificate or diploma or equivalent.
UUK	**Universities UK** (formerly CVCP – Committee of Vice-Chancellors and Principals).
VCE	**Vocational Certificate of Education**
Wellcome Trust	An independent medical research-funding charity, established under the will of Sir Henry Wellcome in 1936, and funded from a private endowment.

LIST OF TABLES

LIST OF FIGURES