The Science and Mathematics Teaching Workforce

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Contents

Executive Summary

Teacher provision in the sciences and mathematics has been a long-standing and deep-seated problem in many countries. This review looks at provision in these subjects internationally, in the UK and England as an evidence base for making recommendations and commenting on the future.

A Global Perspective

We have identified countries that seem well supplied with science and mathematics teachers and those with persistent shortages from the latest rounds of TIMSS and PISA, with further data from Eurydice.

We have looked at five countries in detail: Finland and South Korea (without shortages); Australia and the Netherlands (with shortages); and the United States (surprising).

Countries with strong science and mathematics teacher workforces, such as Finland, Japan, Singapore, and South Korea, share a number of characteristics:

- teaching is regarded as an attractive, high status profession;
- sufficient science/mathematics graduates;
- good planning and monitoring model;
- careful selection of trainees;
- effective teacher preparation;
- respected qualifications;
- systematic professional development throughout career;
- good working conditions.

Provision in the UK

In international comparisons England and Wales are shown as having shortages, while Scotland and Northern Ireland are reported as balancing supply and demand. Closer inspection, however, reveals a more complicated picture.

Biologists dominated science provision in all the countries of the UK.

In Scotland, supply has fluctuated inversely with the economy. It has recently introduced a new planning model which has been much praised. An influential report has recommended more subject specialisation in primary teacher training.

In Northern Ireland, there is an over-supply of science teachers, but insufficient in the physical sciences. Those there are tend to be in grammar schools, with other schools staffed mainly by biologists.

Pointers from the UK to add to those from the international comparisons were:

- the case for subject specialisms to be listed on teaching qualifications;
- the need to re-design primary teacher training to put a greater emphasis on subject specialisms;
- the inverse relationship with the state of the economy.

Provision in England

England has rarely been able to meet its targets for training science and mathematics teachers. The stock has become unbalanced, with biologists in the majority. Recruitment rises with increases in graduate unemployment.

Meeting the targets for mathematics, physics and chemistry trainees would take over 40 per cent of the new home-domiciled graduates in these subjects, though other degrees, for example engineering, may be appropriate. In fact, the teacher trainees are recruited from 40 or more subject areas. One in eight of those with physics degrees opted to train to teach mathematics to avoid practicals and not to have to teach biology.

Science and mathematics teacher trainees enter on poorer degrees than those in the humanities. Low entry qualifications are associated with high dropout. Women are much more likely than men to want to become teachers, but only one in five of physics graduates is female.

The teachers are spread unevenly over the different types of school and college. Sixth form colleges, grammar schools and independent schools fared best, but the statistics on teachers by subject in sixth form colleges, the rest of FE, and independent schools is poor.

There is little up-to-date information on school science technicians. In school statistics they are lumped with other support staff, and in studies of technicians they are included with those in industry.

The Royal Society has recently conducted an inquiry into computing education in schools which makes important recommendations, including on teachers.

A number of issues arise from the data on science and mathematics provision in England for The Royal Society to consider:

- Is STEM a useful category?
- How can teaching the sciences and mathematics be made more attractive?
- Can available teachers be deployed more effectively?
- How can graduate output in the physical sciences and mathematics be increased?
- How can computing be taken forward as a school subject?
- How can sufficient good technicians be recruited to provide the necessary support for teachers?

Recommendations

To address the issues emerging internationally, in the UK and in England, we make ten recommendations to The Royal Society.

1. ***That*** it puts its weight behind helping the profession to establish a Royal College of Science and Mathematics Teaching.
2. ***That*** it should advocate the re-design of undergraduate degrees for primary teachers to include specialisms, preferably taught by university subject departments.
3. ***That*** it should press for targets to be set for science and mathematics specialisms for recruitment to PGCE courses for primary teachers.

4. ***That*** it advocates that the age range and subjects for which a teacher is qualified to teach should be listed on the teaching qualification.

5. ***That*** it discusses with the Department for Education the Government's planning model for science and mathematics teacher provision in England with a view to making it more effective.

6. ***That*** it considers how to deploy to best advantage the science and mathematics teacher workforce that can be recruited, and examines options such as excellence hubs, specialist schools and alternative pathways post 14.

7. ***That*** it considers whether higher salaries could play a part in attracting and retaining more teachers in shortage subjects, and whether headteachers and governors should have more freedom to decide teacher salaries.

8. ***That*** it considers what it could do to promote the systematic professional development of science and mathematics teachers, and in particular explores the role that a Fellowship of a Royal College of Science and Mathematics Teaching might play.

9. ***That*** it re-visits the provision of science technicians in schools and colleges in order to unravel the current situation and clarify what needs to be done to ensure the necessary support for practical classes and demonstrations.

10. ***That*** it moves beyond the acronym 'STEM' in its Vision Project and focuses on each subject since the issues that arise are often very different.

Looking to the Future

We are asked to look forward to 2030. Two decades is not a long time in education. The youngest recruits to teaching in that year are already beginning infants' school. The first bursaries to combat the shortages in physics and mathematics teachers were awarded in 1986, since when successive governments have done all they could think of to secure a good supply of science and mathematics teachers.

Making a difference will not be easy. Relatively few physics and mathematics graduates are attracted to teaching because working with children is very different from the impersonal pleasures of those subjects. Advanced industrial nations do not necessarily want their best graduates to go into teaching, but into research, innovation and wealth creation.

We ask The Royal Society not to put too much faith in technology. Schools, in essence, have not changed that much over 2,000 years because personal contact matters. Whatever the technological advances, there will still be a substantial requirement for science and mathematics teachers.

We also ask The Royal Society to move beyond the use of the acronym 'STEM' and focus on the subjects themselves since the issues to which they give rise are often very different.

The key to improving the quality of science and mathematics teaching in schools is to persuade more to want to become teachers so that those recruited can be carefully chosen both for their understanding of the subject and the ability to put it across.

We believe that our ten recommendations would be important steps towards realising the ambitious goals of the Vision Project.

1. Introduction

1.1 Provision of science and mathematics teachers has been a long-standing and deep-seated problem in England. There were problems from the outset (Devonshire Commission, 1875; Knight 1927). Attempts to get science off the ground in schools, following the Great Exhibition of 1851, were hampered by difficulties in finding the teachers. The Devonshire Commission recommended that the aim should be at least one science teacher for every 200 boys!

1.2 The teachers recruited generally failed to generate the excitement envisaged. Payment depended on the number of pupils who passed a special examination, so there was a tendency to cram. Teachers of other subjects were tempted to bolster their meagre earnings by giving science lessons, which often turned out to be dull and uninspiring. There was also a status issue.

> The men (qualified to teach science) were usually of a different social standing from the regular staff of public schools. Consequently in the rare cases when a science specialist was appointed he (it was a 'he') had an uncomfortable time in the common room (Knight, 1927, p 94).

1.3 The Devonshire Commission warned that:

> The Present State of Scientific Instruction in our schools is extremely unsatisfactory. We cannot but regard its almost total exclusion from the training of the upper and middle classes as little less than a national misfortune (Sixth Report, p. 10).

Dainton Report

1.4 Ninety years on things were only a little better. The Council for Scientific Policy's investigation into the swing from science (Dainton Report, 1968) highlighted science and mathematics teacher shortages. While it did not hold these shortages to be "a uniquely important factor", it did find that:

> Much of the science teaching to which pupils are exposed (in the crucial years between 10 and 13) would appear to be done by non-graduate teachers and to some extent by teachers not qualified in science (p. 46).

Thatcher Government

1.5 When Margaret Thatcher became Secretary of State for Education and Science in 1970 she was determined to do something to improve teacher quality (Thatcher, 1995).

> It seemed to me that the large increase in the number of teachers had to some extent been at the expense of quality. Although there were continuing difficulties about finding enough student teachers wanting to go into mathematics and sciences, there was not much substance to the complaints about 'teacher shortages'. The real shortage was in the number of good teachers (*The Path to Power*, p.177).

1.6 In order to sort out teaching training and address the quality issue, she appointed Lord James of Rusholme, a former High Master of Manchester Grammar School, to head an inquiry. She received the report he delivered politely rather than enthusiastically: "The report was workmanlike and made a number of sensible suggestions". Her disappointment was: "I got nowhere in my attempts to get the curriculum of the teacher training institutions discussed within the planned inquiry. It was still regarded as taboo for politicians to be involved in such matters". Another frustration was with the teacher unions where some representatives "were more trade unionists than teachers". Rather ruefully, she admits: "Fifteen years later the situation had not materially improved. As Prime Minister I would still be puzzling how to raise the quality of the teaching profession".

1.7 It was Kenneth Baker, her Secretary of State for Education and Science from 1986-89, who homed in on science and mathematics teachers (Baker, 1993).

> In 1986 we were short of 400 mathematics teachers and 150 physics teachers…I started therefore to develop new ideas for the training of teachers on the job. This led to the innovation of a teacher 'licensed to teach after one year's practice in the classroom under the supervision of an experienced teacher. Some Authorities, for example Surrey, found difficulty in recruiting teachers in mathematics, physics, science and technology. Yet there were many people who had studied these subjects at college or who had practised them in the armed services and now wanted a career change. The licensed route appealed particularly to them (*The Turbulent Years*, p. 247).

1.8 In 1989, the Department of Education and Science estimated there would be a shortfall of 20,000 teachers by 1995, with mathematics and science at the sharp end (Baker, 1993). It was the specification of the curriculum in 1988 that enabled these estimates to be made. Before the National Curriculum local authorities and schools were able to adjust what was taught to the teachers available. So if there was no physics teacher, then it was likely there would be no serious attempt to teach the subject. Swathes of children missed out. This was particularly the case in the comprehensive schools which had been secondary moderns. In the tripartite system of grammar, technical and modern schools, specialist science graduate teachers were considered essential only in the grammar and the technical schools. Since these together comprised less than a third of the total (technical schools were expensive and at their height took only about 7 per cent of pupils), the shortages were hidden. The acute deficits feared by Baker came from the new assumption that all children would have similar opportunities.

1.9 The silver lining to the economic recession of the early 1990s was that teacher recruitment picked up. But as the economy revived in the second half of the 1990s teacher provision plunged once more. Physics recruitment slumped to its nadir in 1998, and mathematics too came in well below target (Smithers and Robinson, 2000).

Blair Government

1.10 Baker's shortages were inherited by Blair's Government. David Blunkett, as Secretary of State, brought out a Green Paper, *Teachers: Meeting the Challenge of Change* (Department for Education and Employment, 1998), paving the way for major changes. Chief among them was a new salary structure with a higher range to reward the best teachers. But the upper pay scale became, in effect, part of the main spine since nearly all of the first 197,000 teachers who applied to cross the threshold were allowed to do so.

1.11 The Green Paper also proposed extending the diversity of routes into teaching, creating the grade of Advanced Skills teacher to encourage expert teachers to remain in the classroom rather than having to progress through becoming a manager, introducing bursaries as an incentive to train and 'golden hellos' as an incentive to take up teaching posts. This combination of measures boosted the attractiveness of teaching, but physics and mathematics still struggled to find enough well-qualified trainees.

1.12 The supply of high quality science and mathematics teachers became a particular concern to Gordon Brown's Treasury. In its Science and Innovation Investment Framework 2004-2014 (HM Treasury, 2004) it declared that its ambition was to "achieve a step change in the quality of science teachers and lecturers in every school, college and university ensuring national targets for teacher training are met". It announced new commitments to double the number of school-based training places, increase the value of training bursaries, deregulate the salaries of Advance Skills teachers, train a new cadre of Higher Level Teaching Assistants with science specialisms, undertake research to understand why and when teachers join and leave the sector, and increase the 'golden hellos' to science teachers. It also said that it was crucial that the Government should address the problems in mathematics both to meet the objectives of the framework and for the wider reasons identified in the Inquiry into Post-14 Mathematics Education (Smith 2004).

1.13 But the most significant change was announced in a further report (HM Treasury 2006). This kick-started the switch back to the separate sciences at Key Stage 4. Since the 1988 national curriculum, biology, chemistry and physics had been wrapped up together as 'science'. The move had been made with the support of 16 leading professional bodies including The Royal Society (Engineering Council and Secondary Science Curriculum Review, 1987). But the disadvantages, including the dominance of 'science' by biology and the decline of physics, were becoming increasingly apparent. Gordon Brown declared separate targets for biology, chemistry and physics teachers. His aspiration was that, by 2014, 31 per cent of science teachers should have a chemistry specialism and 25 per cent a physics specialism compared with the 25 per cent and 19 per cent respectively in 2005 (Moor et al, 2006). Forty-four per cent were biologists.

1.14 A wide variety of initiatives emerged to attract more physics teachers (Smithers and Robinson, 2008). They included:

- *Physics Enhancement Programme* offering a 26-week full-time course to enable graduates with some experience of physics post-16 to reach a standard which would allow take-up of a conditional place in initial teacher training.

- *Science Additional Specialism Programme*: following the Sainsbury Review (2007) the Government also announced enhancement courses to enable serving teachers to become accredited specialists in physics, chemistry and mathematics teaching, with supply cover paid to schools and a bonus of £5,000 paid to every teacher who completed the course.

- *Extended PGCE Courses* for those who wanted to teach science or mathematics, but needed some additional subject knowledge.

- *Booster Courses* of two-weeks or equivalent in a range of subjects including science taken before or during initial teacher training to top up subject knowledge in areas, for example, physics for biologists and vice versa.

- *Student Associates Scheme* which enabled university students to spend up to 15-days gaining first-hand experience of what a career in teaching involves. Priority was given to science and mathematics graduates.
- *Undergraduate Ambassadors Scheme* run by an independent organisation funded by the Training and Development Agency for Schools (TDA) to give undergraduate students the opportunity to volunteer for classroom experience.
- *Education Modules* in subject degrees.
- *Distance Learning Places in Secondary Shortage Subjects* provided by the Open University.

Cameron Government

1.15 Early in its first year the Cameron Government set out its plans for education in a White Paper, significantly entitled *The Importance of Teaching* (Department for Education, 2010). This signalled its intention to raise the quality of new recruits to teacher training, to reform initial teacher training so that more of it was school-led, expand the Teach First scheme for top graduates, and to develop a network of Teaching Schools on the model of teaching hospitals. It revived Kenneth Baker's 'troops for teachers' plans and built on Gordon Brown's restoration of the separate sciences.

1.16 In 2011-12, Brown's aspiration of separate targets for recruitment to teaching biology, chemistry and physics was translated into the actual allocation of training places. In the latest complete figures (Teaching Agency, 2012), the targets for chemistry (1,070) and physics (925) were set above those for biology which was bundled up with general science and given a target of 840. The targets for chemistry and biology/general science were more than met, but physics still fell short. In order to attract applications from highly qualified graduates in shortage subjects a revised bursary scheme was introduced, with the amount dependent on subject and degree class. Those with firsts in physics, mathematics, chemistry, modern languages, and computer science (added later) training as secondary school teachers from 2012-13 became eligible for a bursary of £20,000. In contrast, those with a first in biology were only eligible for £9,000. In both cases the amount fell with degree class. Those with general science degrees of whatever class are not eligible (DfE, 2013).

Remit

1.17 Over the past 150 years there have been many attempts to increase the numbers and improve the quality of mathematics and science teachers. But it is acknowledged to be an especially stubborn problem. It is a good time to take stock. We are very pleased to have been commissioned by The Royal Society as part of its Vision Project. There are two strands to the remit. First, to prepare an accessible Literature Review on the science and mathematics teaching workforce, the focus being on biology, chemistry, physics, mathematics and computing. And, secondly, to prepare a Commentary on the likely future, based in particular upon the literature review and the outcomes of a workshop to be convened by the Society. Specifically, we were asked to address these questions.

Literature Review

- What is the current state of the teacher availability and deployment in the sciences and mathematics across each of the four nations of the UK?

- How does provision vary across different types of schools and colleges, including independent schools?
- What trends have led to present provision, and how have they been influenced by the economy, government policies and other factors?
- What has been the relationship between supply and demand?
- From what subject backgrounds are science and mathematics teachers recruited?
- What factors influence recruitment and retention, such as graduate output, opportunities elsewhere, salaries, career progression and status of the profession?
- What has been the impact of the role of practical work on science teaching and the technician support available for carrying out practicals?
- Compared with the UK nations, how easy or difficult do other countries find it to recruit and retain the science and mathematics teachers they require, and what distinguishes those that are in surplus, shortage or have balanced proportions and numbers of these?
- How are science and mathematics teachers deployed internationally (ie outside the UK) by pupil age range, subject and by type of school or college, and what support is available to them?
- What is being done or proposed by those countries that are experiencing shortages of science and mathematics teachers to improve supply and appropriately deploy the teachers that are available?

Commentary.

- Solutions for developing a sufficient, stable, sustainable and high-performing schools and colleges teaching workforce in the UK, in particular in the core sciences (biology, chemistry and physics), computing and mathematics.
- How, in the long-term, the teaching profession in the UK can be transformed into one that commands wholehearted respect across all levels of society?
- What steps would need to be taken to achieve this and make it work?
- What forces and other obstacles to achieving the reform would need to be removed and how might these be successfully countered?

Shape of the Report

1.18 We discuss our methods in the next chapter. This is followed by three chapters in which we address these questions by exploring, in turn, the state of the science and mathematics teacher workforce in other countries, in the UK, and in England. The findings are discussed and recommendations put forward. We then offer a Commentary as a contribution to The Royal Society arriving at its Vision for 2030.

2. Methods

2.1 Our remit is to conduct a literature review as a basis for suggesting how a sufficient, stable, sustainable and high-performing STEM workforce might be achieved in the next twenty years. For this purpose STEM subjects are defined as physics, chemistry, biology, mathematics, and computing. We have organised the findings as three sections, devoting a chapter to each. First, we adopt a global perspective to set the UK in context. In the second section, we compare the countries of the UK and, in the third, look in detail at by far the largest part of the UK, England.

A Global Perspective

2.2 To take a global perspective we group countries according to whether they have reported shortages of science and mathematics teachers, surpluses, or are in balance. Of the countries that are well served, we ask how they have managed it; of the countries with persistent shortages, we ask what are they doing about it?

2.3 We have grouped countries by drawing on the latest rounds of PISA and TIMSS. In both, headteachers[1] were asked specifically about the recruitment of science and mathematics teachers, though the questions differ somewhat. In PISA 2009 they were asked to indicate on a four-point scale whether a lack of qualified teachers was "a hindrance to the school's capacity to provide instruction". In TIMSS 2011, again on a four-point scale, they were asked to record how easy they found it to fill vacancies. We have combined the percentages for the top two levels as an indication of teacher shortage. We have used this measure to put countries into three groups: above average shortages, average and below average. In PISA we have defined average as falling within the 95 per cent confidence limits of the OECD average. This was used also for countries outside the OECD participating in PISA. In TIMSS the limits are set by the confidence interval around the international average.

2.4 PISA 2009 and TIMSS 2011 can potentially be taken as replications, but unfortunately, fewer than half of the countries in the OECD took part in TIMSS 2011. We have, therefore, had to bring in a third international study, that of Eurydice, the education information network in Europe. In a survey, published in 2002, member countries were asked to report on the state of their teacher provision, identifying particular shortages or surpluses. We are, therefore, dealing with information that is more than a decade old and collected in a different way from PISA or TIMSS. Nevertheless, there are revealing similarities.

2.5 We have taken countries which came out similarly in two of PISA, TIMSS and Eurydice as the basis for case studies. Finland and South Korea were selected as examples of countries well supplied with STEM teachers. Interestingly, neither has always been in this happy position. Both have changed markedly in the past thirty years showing that transformation is possible. Australia and the Netherlands have persistent shortages and have been implementing a wide variety of measures – not unlike those tried in England – aimed at ameliorating the situation. The other country considered in detail is the United States which, in spite of all the breast-beating over shortages, emerges among those with significantly lower than average recruitment difficulties.

[1] We have used the English terms 'headteacher' and 'pupil' for readability; we are aware that other countries favour terms such as 'principal' and 'student'.

STEM Teacher Workforce in the UK

2.6 We begin Chapter 4 with a numerical picture of science and mathematics teacher provision in the UK. It was much harder than it should have been as The Royal Society (2007), itself, found its *State of the Nation Report*. England generally has good published statistics, but its data on teachers by specialism (DfE, 2012) include every subject a teacher teaches so there is multiple counting. The best source of information on Wales is the registrations of the General Teaching Council (GTCW, 2011), but these are self-reported and include teachers no longer working in schools. The General Teaching Council for Scotland (GTCS, 2012) also publishes data on registered teachers by main subject taught, but again it is self-reported and not all on the register are still in schools. There is an alternative source of information for Scotland, the annual teacher census (Scottish Government, 2011) which indicates that less than half the registrations are of teachers currently employed in schools. There are no published statistics that we can find of teachers by subject in Northern Ireland.

2.7 There is a further complication in the numbers for England. The shape of the re-organisation to non-selective secondary education was left to the local authorities, and some opted for sixth form colleges served by several 11-16 schools. Although an intrinsic part of the school system they were transferred to the FE sector in 1993. The Learning and Skills Improvement Service (LSIS, 2012) has conducted workforce surveys, but it has adopted broad categories so the sciences and mathematics are all put together. Moreover, it is based on contracts, and staff can hold several contracts at once. It also records subject taught, but not qualification. LSIS was abolished at the end of July 2013 and its data have been transferred to the Education and Training Foundation, but it is too soon to know whether there will be future surveys. Another potential source of information on the subject specialisms of teachers in sixth form colleges is the recurring Local Government Association *Teacher Resignation and Recruitment* surveys. These used to be conducted by the LGA itself, but are now contracted to the National Foundation for Educational Research. The most recent with usable information on staffing in sixth form colleges was carried out in 2006 (NFER and LGA, 2008). A later survey, conducted in 2008 (Passy, R. and Golden, S., 2010), does not provide population estimates.

2.8 Although data limitations make it difficult to draw comparisons between the countries of the UK, it is possible to discern patterns. STEM teacher provision in Scotland, Northern Ireland and Wales is looked at in detail through the policy documents and reports of those countries. England is given a chapter of its own.

Teacher Provision in the Sciences and Mathematics in England

2.9 Our major sources for teacher provision in England are: data published by the Department of Education (in its various incarnations); the National College for Teaching and Leadership (formerly the Teaching Agency, the Training and Development Agency for Schools, and the Teacher Training Agency); the School Teachers' Review Body; the Graduate Teacher Training Agency; The Royal Society's *State of the Nation* reports; and publications from our Centre which has conducted during the past 25 years an extensive programme of research on teacher recruitment and retention.

2.10 England has some of the best data on teachers of any country. Nevertheless, there are important gaps. The Independent Schools Council, an invaluable source of information on the sector, does not publish statistics on its teachers by main subject taught. There are 11 per cent of 16 to 18 year-olds in sixth form colleges, (and a further 48 per cent in that age range in general further education colleges), yet the teacher data are not brought together with those for schools. This is in spite of the sixth form colleges originating in the school system and *de facto* operationally being still part of it. There are few good statistics on computing teachers, since it is still not clear what the subject is. The Royal Society's (2012) recent report devotes a lot of space to distinguishing computing from information technology, information and communications technology, and digital literacy. Teacher classification has not yet caught up. While the National College for Teaching and Leadership willingly carried out a number of special analyses for us, they could not provide us with data on computing teachers, because "we currently have a technical problem relating to the 'change' from ICT to Computer Science".

2.11 Where possible we have updated graphs and statistics, but as the remit makes clear we were commissioned to conduct a literature review. Neither the timescale nor the budget allowed for the extensive quarrying necessary to construct a completely up-to-date account from the disparate sources of data and information available. The patterns that we have been able to uncover seem to be relatively enduring, so we are confident that the picture we present is a good basis for The Royal Society's deliberations.

Pointers for The Royal Society

2.12 The organising principle for our reviews of the state of teacher provision in the sciences and mathematics worldwide, in the United Kingdom, and in England has been to draw out the implications for the Vision Project. They are discussed in a separate section at the end of each of the three substantive chapters. In Chapter 6 we bring the evidence together and make recommendations. In the final chapter we show how the recommendations could be steps along the way towards creating a world-class science and mathematics workforce for schools and colleges.

3. Global Perspective

3.1. England is not alone in finding it difficult to recruit enough good science and mathematics teachers. Many countries are experiencing shortages. With the current penchant for international comparisons we are in a position to identify systematically the countries most affected.

A. International Comparisons

3.2. As a starting point, we have looked for replication in the most recently published data from PISA[2] (2010)[3] and TIMSS[4] (2012).

PISA 2009

3.3. The fourth round of PISA took place in 2009. Schools from the 34 OECD countries plus 40 other jurisdictions took part in the assessment of 15-year-olds in science and mathematics, as well as in reading. In addition, headteachers completed a questionnaire on which, among other things, they were asked to indicate on four-point scales the extent to which lack of qualified teachers was "a hindrance to the school's capacity to provide instruction". We have taken the percentages at the two highest levels as evidence of teacher shortage.

3.4. The perceived shortages of science teachers and mathematics teachers were very strongly correlated ($r = 0.943$ for the 33 OECD countries which administered the questionnaire[5] and $r = 0.936$ for all 73 jurisdictions responding, with $P<0.001$ in both cases). We have, therefore, combined them to create a single measure. The headteachers completed the same scale for 'other teachers'. The responses correlate significantly with the combined measure, but not quite as strongly as the association between science and mathematics ($r = 0.812$ for the 33 OECD countries, and $r = 0.802$ for the 73 jurisdictions, $P<0.001$). Shortages of science and mathematics teachers, therefore, seem to be part of a general picture.

3.5. The ten countries with the highest and lowest levels of reported difficulty in recruiting science and mathematics teachers are shown in Table 3.1. This is s summary of Tables A1 and A2 in the appendix. The results for the UK, which comes eleventh, are also included. There are some surprises. Shanghai, whose pupils were the outstanding performers in PISA 2009, came out with the fourth highest level of perceived science and mathematics teacher shortage. The United States which continually agonises over teacher supply is significantly below average for reported recruitment difficulties (see Table A1).

3.6. There are also some interesting discrepancies between the perceived shortages of science/mathematics teachers and 'other' teachers. The OECD average comes out higher for 'other teachers', but this is to be expected since the former is a bag of subjects. The strong correlation between the shortages in science/mathematics and subjects generally is also borne out by the percentages for individual countries. But

[2] Programme for International Student Assessment under the auspices of the Organisation for Economic Co-operation and Development.

[3] Date of publication; survey conducted the year before, similarly with TIMSS.

[4] Trends in Mathematics and Science Study under the auspices of the International Association for the Evaluation of Educational Achievement (IEA) based at the International Centre, Boston College, in the United States.

[5] France is the odd one out.

there are differences. Luxembourg seems to be considerably better off for 'other teachers' than it is for science/mathematics teachers. Germany and Belgium, in spite of the high levels of perceived teacher shortage in science and mathematics, seem to find it even harder to fill other posts. This is also true of the Slovak Republic which reports little difficulty when it comes to science and mathematics teachers. The UK, on the other hand, appears to be less well off in the sciences and mathematics than in other subjects.

Table 3.1: PISA 2009: Headteachers' Perceived Shortages

Country[1]	Science Teachers	Mathematics Teachers	Combined Science Mathematics	Teachers Other Subjects
Turkey	76.5	79.4	78.0	81.3
Luxembourg	57.5	77.9	67.7	35.1
Germany	41.6	28.3	34.9	50.0
Shanghai	33.8	32.2	33.0	35.4
Netherlands	30.9	30.7	30.8	42.4
Chile	29.9	31.5	30.7	28.1
Belgium	26.1	34.2	30.1	48.6
Australia	24.3	30.0	27.2	24.9
Macao	23.7	30.0	26.8	21.9
Mexico	27.0	26.3	26.6	32.8
Sweden	8.5	2.8	5.7	14.4
Hungary	5.2	5.2	5.2	6.2
Japan	4.2	4.0	4.1	12.0
Slovak Republic	5.3	2.4	3.8	28.0
Hong Kong	1.9	4.9	3.4	9.7
Finland	3.6	2.5	3.1	13.3
Poland	3.4	0.6	2.0	5.3
Portugal	1.3	1.8	1.6	4.7
Slovenia	1.7	0.6	1.2	4.5
Spain	1.2	1.0	1.1	6.2
OECD Average	17.7	17.9	17.8	23.5
UK	14.6	26.3	20.4	15.0

1. France did not provide these data.

Source: Calculated by CEER from OECD PISA (2009) Database.

3.7. The extent of perceived science teacher shortages correlates only weakly with the performance of OECD countries on the PISA science test (r = 0.362, for 33 cases, P<0.05) and did not reach significance for mathematics (r = 0.312, for 33 cases, ns), which is a reminder that many factors besides teacher quality contribute to performance in PISA. Science and mathematics teacher shortages in OECD countries, if anything, were negatively associated with GDP per capita (r = -0.222, 33 cases, ns) which probably reflects the difficulty teaching has in competing with other occupations for graduates in wealthier countries.

TIMSS 2011

3.8. Schools from 42 countries took part in TIMSS 2011. Headteachers, as in PISA, completed four-point scales, this time focussing on the difficulty of filling vacancies. Again, we have taken the two highest levels as an expression of teacher shortages. As with PISA, we found a strong correlation between the difficulty of recruiting science teachers and recruiting mathematics teachers ($r = 0.896$, for 42 cases, $P<0.001$), and have combined them. Table 3.2 shows the ten countries in TIMSS reporting the highest and lowest levels of difficulty. It is a summary of Table A3 in the appendix, which shows the countries participating in TIMSS in three groups: those within the 95 per cent confidence limit of the international average, those above and those below.

Table 3.2: TIMSS, 2011: Difficulty of Filling Vacancies

Country[1]	Science	Mathematics	Combined
Thailand	51	58	54.5
Australia	39	41	40
Israel	41	29	35
England	31	37	34
New Zealand	22	44	33
Qatar	37	28	32.5
Bahrain	31	33	32
Ghana	33	30	31.5
Indonesia	33	26	29.5
Syrian Arab Rep	30	29	29.5
Georgia	10	6	8
Italy	8	8	8
Tunisia	6	9	7.5
Hong Kong	6	8	7
Ukraine	8	3	5.5
Slovenia	3	6	4.5
Romania	2	4	3
Singapore	4	2	3
Lithuania	3	1	2
Armenia	2	1	1.5

1. Hungary did not provide information for science.

Sources: Data for science and mathematics from the respective TIMSS reports.

3.9. The TIMSS 2011 results are similar in a number of ways to those of PISA two years earlier. Thirty-one countries were common to both. The correlation between the mathematics teacher shortages in the two studies was highly significant ($r = 0.552$, for 31 countries, $P<0.001$). The correlation for science was somewhat lower but still significant ($r = 0.427$, for 30[6] countries, $P<0.05$). The combined measure correlated to the extent of $r = 0.493$, for 30 cases, $P<0.01$. Unfortunately, only 15 of the countries participating[7] in both were OECD countries.

3.10. In consequence, the confirmatory evidence from Table 3.2 for Table 3.1 is rather thin. Only Australia emerges among those with the most severe shortages, and Hong Kong and Slovenia among those reporting the least difficulty in both surveys. England does

[6] Hungary did not provide the information for science.

[7] Strictly speaking only 13, but becomes 15 if the average of the benchmarking data for three Canadian provinces is included as the figure for that country and allow England to stand for the UK.

show up in TIMSS as having shortages, but these are masked in PISA when it is present as part of the UK. Twelve countries emerge as experiencing lower than average recruitment difficulties in both PISA and TIMSS: Canada, South Korea, United States, Japan, Malaysia, Finland, Georgia, Hong Kong, Slovenia, Romania, Singapore and Lithuania. There is not complete consistency. Kazakhstan emerges as above average in PISA and below in TIMSS; the Russian Federation as below in TIMSS and borderline above in PISA.

EURYDICE 2001

3.11. The lack of confirmatory evidence in TIMSS for the teacher shortages emerging in PISA, largely as a result of the absence of many OECD countries from TIMSS, has led us to turn to a third source of data. Eurydice (2002), the information network on education in Europe, reported on a major study in which 31 European countries provided information on, among other things, the supply of, and demand for, teachers in lower secondary education[8]. Twenty-one of the 31 countries were experiencing shortages, either general (13) or specific (8). Eight countries indicated the sciences and mathematics were giving most concern. England and Wales, Belgium (all three communities), Germany, Sweden, and Malta specified both subjects. The Netherlands indicated shortages in the sciences, and Luxembourg and Slovenia in mathematics.

3.12. Although the PISA and Eurydice surveys are nearly a decade apart, the picture that emerges is similar in spite of the time lapse and the different methods of data collection. Belgium, Germany, Luxembourg and the Netherlands come out in both as having science/mathematics teacher shortages, pointing to persistent shortfalls. Conversely, Austria, Finland, Italy, Portugal and Spain come out as well supplied in both.

Synthesis of PISA 2009, TIMSS 2011 and EURYDICE 2001

3.13. Countries where shortages are found in at least two out of the three studies are shown in Table 3.3.

Table 3.3: STEM Teacher Shortages

Countries	PISA	TIMSS	EURYDICE
Australia	●	●	
Belgium	●		●
England[1]	(●)	●	●
Germany	●		●
Luxembourg	●		●
Netherlands	●		●

1. In PISA, the UK does not report STEM teacher recruitment difficulties significantly greater than the average. England on its own, however, in TIMSS and combined with Wales in Eurydice is prominent among those with shortages.

3.14. Four countries – Belgium, Germany, Luxembourg and the Netherlands – report difficulties in recruiting STEM teachers in both PISA and Eurydice. Australia emerges with significant shortages in PISA and TIMSS. England shows up as having teacher shortages in TIMSS and Eurydice, but these are masked in PISA by being included

[8] The nearest equivalent to lower secondary education is Key Stage 3 though in some education systems, for example those of Scandinavia, it extends to age 16.

with Scotland and Northern Ireland as the UK. Interestingly, these two parts of the UK were two of only four countries in the Eurydice survey reporting being able to balance demand and supply.

3.15. Table 3.4 displays in similar fashion the countries reporting they do not have shortages. It is a longer list. Finland comes out as well provided in all three studies. Schools in 13 countries reported in both PISA 2009 and TIMSS 2011 that they were not experiencing difficulty. They included as well as Finland, the United States, Canada (represented in TIMSS by three provinces which differed among themselves), four of the big five Asian 'countries' (Hong Kong, Japan, Singapore, South Korea – Shanghai did not take part in TIMSS), plus Georgia, Lithuania, Romania, Slovenia, Malaysia and Tunisia. Three countries besides Finland come out as free of STEM teacher shortages in both PISA and Eurydice: Austria, Portugal and Spain. Similarly for Italy in TIMSS and Eurydice, but not PISA where it scrapes into the average group.

Table 3.4: No STEM Teacher Shortage

Countries	PISA	TIMSS	EURYDICE
Austria	●		●
Canada	●	●	
Finland	●	●	●
Georgia	●	●	
Hong Kong	●	●	
Italy		●	●
Japan	●	●	
Lithuania	●	●	
Malaysia	●	●	
Portugal	●		●
Romania	●	●	
Singapore	●	●	
Slovenia	●	●	
South Korea	●	●	
Spain	●		●
Tunisia	●	●	
United States	●	●	

B. Five Countries

3.16. The statistical analyses reveal the broad patterns. In order to get a better feel for what lies behind the numbers we now look more closely at five countries: Finland and South Korea which appear to have no difficulty recruiting science and mathematics teachers; Australia and the Netherlands which have persistent shortages; and the United States, which thinks it has shortages, but in terms of the present indicators apparently does not. The aim is to try to uncover how some countries come to be well provided while others struggle to get the teachers they need. A third section to this chapter will draw pointers for the UK from the statistical tables and the case studies.

Finland

3.17. Finland is the acme of success in international tests, and this is frequently attributed to its outstanding teachers (Barber and Mourshed, 2007; Chang, 2010; Meyer and Benavot, 2013; Sahlberg, 2010; Tucker, 2011; Whelan, 2009). But Finland has not always been an education star. Its leap to prominence coincided with the coming of PISA in 2000. In the international tests in mathematics and science till then it had been mainly an average performer (Sahlberg, 2010).

3.18. Schwartz and Mehta (2011) suggest that the rapid progress made in Finland may have its roots in the transformation of teacher education. Its Teacher Education Reform Act of 1979 transferred teacher preparation from teacher colleges to the universities and rigorously overhauled the basic qualification making it a master's degree. Teaching had always been a respected occupation in Finland, but these changes – resisted at first by the universities as being beneath them – enhanced its status and made it very attractive to the highly able. Not only was the master's degree regarded as a valuable teaching qualification, but it opened the way to doctoral studies and for entry to other careers.

3.19. In 2010 there were, on average, about ten applicants for every primary education place. This enabled the university education departments to be highly selective. Admissions involved first sifting through the applicant's matriculation exam results, upper-secondary school record and other accomplishments. For the survivors a second stage consisted of a written examination, assessment of interaction and communication skills, and an interview. Regularly each year the primary teacher trainees are selected from the top quintile of upper-secondary school graduates. Female applicants outnumber males by about four to one.

3.20. A notable feature of the Finnish system is the degree of subject expertise required of teachers in the primary age range. Teachers in Finland are licensed to teach particular stages and subjects. The schools are usually all through from age 7 with six years of primary followed by three years of lower secondary. Transfer to upper secondary is at age 16. Education is the major field of master's programmes for primary teachers, but in addition they are expected to study two of the subjects of the national curriculum. These subjects are studied not in the education department but alongside other undergraduates in the subject departments of universities. According to Sahlberg (2010), at the University of Helsinki, about 15 per cent opt to take mathematics as the minor subject, which enables them to not only to obtain a licence to teach the primary age range (Years 1-6), but also to be licensed as a subject teacher for Years 7-9. Science is taken as a minor subject by about ten per cent of the trainees. In order to be licensed to teach a subject in high school, teachers must pass this as the major in their master's degree, with education integrated into a five-year course or concentrated in the fifth year on completion of their subject major.

3.21. Although Chung (2010), in her analysis of Finland's success in PISA cautions against policy borrowing, there would seem at least two interesting policy pointers for England: (i) find ways of making teaching sufficiently attractive so that the recruits can be highly selected; and (ii) ensure that there are teachers in primary schools with specialist expertise in science and mathematics so that the children get a good introduction to these subjects.

South Korea

3.22. Teaching is a very popular career choice in South Korea. Teachers have high status, are well paid, have good working conditions and have the security of being employed as civil servants. Class sizes are large, but actual teaching hours are relatively light. The large classes mean that South Korea needs fewer teachers in relation to the size of the pupil population than countries that opt for small class sizes. Whelan (2009) argues that this is an important trade-off with the fewer teachers required being rewarded more generously. South Korea pays its teachers well, but at a cost of less GDP per capita than the average for OECD countries.

3.23. Many more in South Korea want to become teachers than are required. The falling birth rate has reduced demand further (Kim and Han, 2002). The profession is, therefore, highly selective and this itself serves to raise its status. Selection operates differently for the primary and secondary phases. In primary it is through competition to win a place on one of the limited number of undergraduate degrees in education; in secondary, it is through examinations for entry to employment.

3.24. Admission to undergraduate degrees in primary education in South Korea is by the College Scholastic Ability Test (Suneung). Competition is such that only those scoring in the top five per cent have a realistic chance of getting in. The number of places is controlled to match demand so that the trainees completing their four-year courses are very likely to be able to find employment as a teacher. The supreme importance of tests in gaining valued school and university places leads to most pupils receiving private tutoring in crammers (Hogwans). Kim (2010) reported that 88 per cent of elementary pupils and 61 per cent in general high schools received extra tuition on which families spent, on average, about six per cent of their income.

3.25. There is a diversity of routes for training to be a secondary school teacher, with less control of places. The popularity of teaching leads to many more being trained than are required so there is a surplus, even in mathematics and science, some of whom have to seek employment overseas. Barber and Mourshed (2007) reported that about five times as many secondary teachers are trained each year as are needed. They are joined in the search for a teaching post by disappointed applicants from previous years. Who gets the posts is decided by competitive examination. There are three stages. According to Jensen (2012) the first is a multiple choice examination on various aspects of education and pedagogy. The second consists of essays and problem-solving questions testing content knowledge and both general and subject-specific pedagogy. The third stage is a demonstration lesson in front of an expert committee including academics and school leaders. The Ministry sets the number who will pass the first stage at roughly double the number of vacancies. This is halved during the second and third stages so the number eventually passing matches the number sought. The difficulty of becoming a secondary teacher after successfully completing the training is creating a backwash rendering it less attractive.

3.26. South Korea has been very successful in international tests. In PISA (2009) it was ranked fourth in mathematics and sixth in science. In TIMSS (2011) it came top and third respectively in the primary and secondary science tests, and second and first in the mathematics tests. The top places were all occupied by East Asian countries. It so regularly appears among the top-performing nations that it might be supposed that educational achievement is deeply embedded within the Korean psyche. Perhaps the desire is, but the means has only been created in the past forty years.

3.27. Sorensen (1994) charts how remarkable the transformation has been. In 1945 at the end of the Japanese occupation there were no indigenous teachers or students with the level of education to become a teacher, and 78 per cent of the population was illiterate. From 1948 when the Republic was founded to the 1970s, the emphasis of Korean education was on building a nation state through inculcating loyalty, patriotism, self-reliance and anti-communism. The push on scientific and technical education began only in 1973 so all its achievements in these fields have been in the past 40 years. Sorenson attributes the immense progress to "upward mobility through schooling dominating the lives of South Korea parents and children" and "so long as there are distinctions between high status and low status, rich and poor, South Koreans feel most comfortable justifying those differences on the basis of educational attainment (this) is perhaps the most important legacy of Confucian culture for Korean education".

3.28. Both Finland and South Korea have made great strides in educational achievement in recent years. This suggests that limits are not fixed by genetic inheritance, culture or resources. The key is to find the right levers. In both countries teaching is a highly attractive profession and those who eventually obtain teaching posts have been very carefully selected. The pointer for any country which wished to emulate them is to make teaching highly attractive. But this is easier said than done.

Australia

3.29. Australia's experience of teacher recruitment is very similar to England's. Ainley (2008) pinpointed a number of areas of concern in science and mathematics teacher education in Australia. In postgraduate training these were: (i) linking science/mathematics study to teacher training; (ii) balance of studies – about two-thirds were from the biological sciences; and (iii) attracting graduates from the sciences and mathematics into teaching. They could be read unchanged for England.

3.30. The *Staff in Australia's Schools 2010* survey (McKenzie et al, 2011) found shortages, poorly qualified teachers, and classes being covered in a variety of ways. It found that 8.3 per cent of secondary schools had unfilled vacancies on the first day of term for mathematics teachers and 7.3 per cent unfilled vacancies in the sciences (of which 0.1 per cent were in biology). In Years 11 and 12 (the sixth form years), 45.9 per cent of those teaching physics had had less than three years studying the subject at university. For mathematics in Years 7/8-10 it was 54.2 per cent, reducing to 35.9 per cent by the sixth form years. The main strategies the headteachers adopted for coping with these shortfalls were 'requiring teachers to teach outside their field of expertise' (46.7 per cent), 'recruiting retired teachers on short term contracts' (28.4 per cent); and 'reducing curriculum offered' (25.3 per cent). The teacher workforce in shortage subjects is also aging. In South Australia, for example, only 39 per cent of secondary teachers under 40 years of age had a major in physics compared with 63 per cent of teachers of 40 and over.

3.31. A recent report requested by then Australian Prime Minister, Julia Gillard, from her Chief Scientist, Professor Ian Chubb (Office of the Chief Scientist, 2012), expressed concern at both the low participation rate of Australian students in the STEM fields and the declining performance in international studies. He found that between 1992 and 2009 the proportions of pupils in the final year of secondary schooling studying physics, chemistry and biology fell by 31 per cent, 23 per cent and 32 per cent respectively. Analysing data from the National Science Foundation in the United States (National Science Board, 2006) the Chief Scientist contrasted Australia's 22.2 per cent of first degree graduates in the STEM subjects with the 64.0 per cent in Japan, 52.1 per cent in China, and 40.6 per cent in South Korea[9]. For the UK incidentally the figure was 25.8 per cent compared with the international average of 26.4 per cent. Although Australia does well in PISA the Chief Scientist notes that while only two countries were above it in 2000 there were six in 2009 (although to be fair three of those above it in 2009 - Hong Kong, Shanghai and Singapore - did not take part in 2000). More concerning will have been Australia's performance in TIMSS where it regularly falls below England in mathematics and science (Smithers, 2013a). The 2011 TIMSS results, which came too late for the Chief Scientist's report, caused an outcry. As the Australian Financial Review (2012) put it: "Australian students get C on global report card".

3.32. The Chief Scientist pinpointed better teachers as the key to raising the quality of STEM education. He recommended greater specificity to qualifications "with the goal that only teachers who are qualified or accredited to teach mathematics and science subjects do so". He further recommended extra funding tied to specific criteria for mathematics and science teacher education, encouraging universities to establish internships in schools for mathematics and science undergraduates not enrolled in education programmes, more focused and better quality professional development for mathematics and science teachers, and a National Centre for Mathematics and Science Teachers to facilitate support. In response the Australian Government provided in its *Budget Review 2012-13* (Dow and Harrington, 2013) $54.0 million over four years to increase participation in STEM subjects, of which $18.9 million was to improve the quality of teacher training and provide support and training for teachers.

3.33. The Gonski *Review of Funding for Schooling* for the Australian Federal Government (Gonski, 2012) recommended an increase of $5 billion a year across all sectors of schooling. But there are fears that university funding will be cut to pay for it. Prince (2013) of the Australian Mathematical Sciences Institute argues that this will reduce the number of mathematics graduates, so schools will find it more difficult to recruit high quality teachers to enable them to make use of the extra mathematics funding.

3.34. The Productivity Commission (2012), an independent research and advisory body of the Australian Government, has recently conducted an inquiry into the schools' workforce. It makes a number of proposals for improving teaching quality, reducing teacher shortages and expanding the evidence base, for example, a longitudinal teacher workforce study. It highlighted the substantially higher pay that teachers in subjects like mathematics and science can earn in other professions and advocated more explicit and greater use of salary differentials. It recognised there would be opposition, but thought this would "likely soften over time".

3.35. Australia has been looking at education in other countries to see how it can improve. The Grattan Institute, an influential think-tank of which the Australian Government was a founder member, looked in detail at the education systems of Hong Kong, Singapore, Shanghai and South Korea. Its report, *Catching Up: Learning from the Best School Systems in East Asia* (Jensen, 2012), dismisses the suggestions that their success is down to the Confucian culture, rote learning, teaching to tests, or Tiger Mothers. It argues that what Australia can learn from these countries is "a relentless, practical

[9] This a relative, not an absolute, figure. In the United States, for example, only 16.8 per cent of graduates in the STEM fields, because it has a mass higher education system with many students in other fields. But in terms of people it has the highest STEM graduate output of all countries.

focus on effective learning and the creation of a strong culture of teacher education, collaboration, mentoring, feedback and sustained professional development".

3.36. The Australian Council of Learned Academies (ACOLA) has focused specifically on STEM subjects, building on the work of the Chief Scientist (Office of the Chief Scientist, 2012). ACOLA commissioned reports on 19 countries and regions, including Australia itself, together with five special interest reports, and via a high-level national workshop distilled the main themes. The final report (Marginson *et al*, 2013) identifies two main features of STEM teachers in countries strong in these fields. First, they "enjoy high esteem, are better paid and work within more meritocratic career structures than found elsewhere". Secondly, "they are expected to be fully qualified in their discipline and to teach in that field and not others".

The Netherlands

3.37. The Netherlands emerges as having teacher shortages in mathematics and science in both Eurydice (2002) and PISA (2009)[10]. It, nevertheless, performed well in PISA, coming sixth out of the 34 OECD countries in mathematics and eighth in science. The Ministry's most recent projections for teacher provision are set out in *Working in Education 2012*. A double whammy is anticipated: rising pupil numbers and more teachers leaving. Teacher shortages are expected to peak in 2015-16, with 4,000 job vacancies annually (about 6 per cent of posts), reducing to about 1,500 by 2020, when hopefully supply and demand will balance. Teacher attrition 2011-2015 is estimated to be higher in physics (27 per cent) and chemistry (29 per cent) than the 25 per cent overall.

3.38. In 2011 the Dutch Government published a series of action plans for education, including *Teaching 2020* (Netherlands Ministry of Education, Culture and Science, 2011a). The elements of the Plan will be familiar to a British audience – there is even a Teach First scheme - including some that have now been discontinued in this country:

- schools to be provided with additional financial resources to reward teachers in higher pay scales and reduce the number of salary increments so teachers enjoy larger incremental pay rises;
- additional budget to fund professionalization activities and proposed performance related pay provisions;
- grants to encourage teachers to continue their training to master's level – currently about a fifth hold master's degrees;
- work towards the implementation of the Education Professions Act (2006) which requires a competency document to be maintained for each teacher – in 2011 only about 25 per cent of secondary teachers had such a document;
- a professional register;
- reward qualifications and performance by better career prospects, including more responsibility and higher pay;
- teacher training to be improved by continuation of the language and numeracy test, developing the knowledge base and devising new training routes.

[10] Absent from TIMSS (2011).

3.39. As in England, the measures are an attempt to drive up standards through incentives and accountability, in contrast to the approach adopted in Finland which is to get in good people and give them their heads. The measures are aimed at teaching generally rather than in just STEM subjects.

United States

3.40. There is a paradox at the heart of the United States' science and mathematics teacher work force: the PISA and TIMSS surveys appear to indicate that recruitment is better than in most countries, yet there is continual anxiety about shortages. As Ingersoll and Perda (2010) neatly phrase it: "Few educational issues have received more attention in the past few decades than the challenge of staffing the nation's classrooms with qualified mathematics and science teachers". A raft of influential reports comes to mind: the National Commission on Excellence in Education (1983), the National Academy of Sciences (1987). the National Commission (the Glenn Commission) on Mathematics and Science Teaching for the 21st Century (2000), the National Research Council (2002) and the National Academy of Sciences (2007).

3.41. The diagnosis and remedies have focused on teacher supply. A wide range of initiatives has been proposed: "mid-career change programs, such as 'troops-to-teachers', alternative certification programs, overseas recruiting initiatives, and financial incentives such as scholarships, signing bonuses, student loan forgiveness, housing assistance, and tuition reimbursement" (Ingersoll and Perda, 2010). The impact has been patchy. The National Academy of Sciences (2010) when took it stock had to admit that the assurance to have "qualified math and science teachers available to every student (has) languished".

3.42. The failure of an imaginative array of initiatives to deliver suggests something may have been overlooked. Sterling (2004) has argued that securing a high quality teaching workforce is as much a matter of retention as recruitment. Ingersoll and Perda (2009) found the difficulties with mathematics and science teacher provision are not due primarily to inadequate supply. Rather the shortfall arises when pre-retirement turnover is factored in. Science and mathematics are affected, to a greater extent, than other subjects because the teachers are more likely to resign through job dissatisfaction and they have more job opportunities elsewhere. Neither is there the cushion of surplus new supply as there is in, for example, English. Ingersoll and Perda (2009) suggest the best hope of improving teacher retention is to make the work more satisfying. They found that schools have significantly lower levels of teacher turnover if there is "more support for new teachers, more generous salary schedules, fewer student discipline problems, more adequate resources and classroom supplies, more effective leadership, and enhanced faculty input into school-decision making".

3.43. The idea of different salaries for different subjects is gaining support. Ladd (2007) found mathematics and science teacher shortages are common in large cities and remoter rural areas, and argues that this could be tackled by relaxing the policies that make salaries uniform across subjects and location. West (2013) analysing Florida's database of public school teachers found that science and mathematics teachers earn the same average salary as those teaching English (not a shortage subject), but on leaving can earn 12-15 per cent more. On this evidence, West argues there is a strong case for modifying teacher compensation systems so as to offer larger salaries to teachers of shortage subjects such science and mathematics.

3.44. We thus have a possible resolution of the paradox with which we began. It looks as if the United States headteachers' responses to the PISA and TIMSS questionnaires provided an accurate picture. Supply may be adequate, but there are shortages due to poor retention. If these findings can be replicated, a clear pointer for England would be that it is not only necessary to boost supply, but also to find ways of holding on to those teachers that schools want to keep.

C. Pointers for The Royal Society from Abroad

3.45. Our review identifies countries that have a strong teaching workforce in science and mathematics (Finland, Japan and South Korea) and those with persistent shortages (Australia, the Netherlands and the United States). The main difference between them is that in the former teaching is a high status profession. Both are subject to feedback loops. In those countries where teaching has high status it attracts plenty of applicants so it is difficult to enter, and the difficulty of getting in enhances its status. The converse is neatly described in *Teaching and Leadership for the Twenty-First Century* (Asia Society, 2012): "Teacher shortages lead to lower standards for entry, producing lowered confidence in the profession, resulting in more prescriptions to teachers, which in turn tend to drive the most talented teachers out of the profession".

High Status

3.46. The status of the teaching profession may not, however, have much to do with the particular features of a country's education system. In Table 3.5 we show aspects of the salaries and working conditions of teachers in the two groups taken from the OECD's *Education at a Glance 2013*. The only hint of a difference between them is in the hours taught, with fewer in those countries with strong teacher workforces. The other indicators differ as much within groups as between them. Neither is culture necessarily the decisive factor. Finland and South Korea, our case studies of countries with good supply, have very different cultures. Meyer and Schiller (2013) characterize that of Finland as "egalitarian and individualistic" and that of South Korea as "collectivist and paternalistic".

3.47. What unites Finland and South Korea, and also Singapore, is that they are small nations of recent origin. Japan, another country in which teachers enjoy high status, has a long history, but had to start afresh after the Second World War. At the outset, these countries were faced with the acute problem of how to pay their way in the world. They recognised that a good education system was vital to their survival, and that good teachers were crucial to a good education system. The countries finding it difficult to recruit enough teachers, especially in the sciences and mathematics, in the main, are long established nations. In these mature systems, the teachers tend to be taken for granted. The heroes of the economy are those who create the wealth rather than those who educate them. The status of teachers may thus be a reflection of the extent to which education is recognised to be essential to the well-being of a country.

3.48. If the status of teaching is so bound up with a country, can it be raised by direct intervention? Are there levers? Sahlberg (2011) argues that the status of primary teaching in Finland was transformed by moving the training into universities and making the qualification a master's degree. But primary teaching in South Korea also has high status and teacher preparation there mainly takes place in training colleges (Centre on International Educational Benchmarking, 2013). Boosting salaries may be an answer. In Japan, following World War II there were fears that traditional respect for teachers (this has its roots in the samurai) would erode and the Government decided to underpin it by raising salaries to 30 per cent above that of other civil servants (Tucker and Ruzzi, 2012). But would something similar be affordable in the UK?

Table 3.5: Countries With and Without STEM Teacher Shortages[1]

Country	Salary				Working Conditions		
	After 15 Years[2]	Compared to Other Graduates[3]	Ratio of Top to Starting[4]	Per Hour After 15 Years	Teaching Hours/ Year	Average Class Size	Pupil Teacher Ratio
Well Supplied							
Finland	40,917	0.98	1.31	69	595	20.3	13.1
Japan	45,741	-	2.21	76	602	32.7	13.1
South Korea	48,146	1.34	2.78	78	621	34.0	17.2
Shortages							
Australia	49,144	0.91	1.41	61	811	23.5	12.0
Netherlands	63,695	0.84	1.70	85	750	-	16.7
United States	45,950	0.67	1.50	43	1,068	23.2	15.2
OECD Average	39,934	0.85	1.61	58	709	23.3	13.6
UK/England[5]	44,269	0.92	1.46	64	695	21.8	16.3

1. Data for Lower Secondary Education.

2. In equivalent US dollars converted using purchasing power parity.

3. Ratio of salary to earnings for full, full year workers with tertiary education aged 25-64.

4. Ratio of salary at the top of the scale to starting salary.

5. Data for England in Tables D3.2 and D4.2, but for the UK in Tables D2.1 and D2.2.

Sources: *Education at a Glance 2013: OECD Indicators*, Tables D3.2, D4.2, D2.1and D2.2.

3.49. Whelan (2009) has suggested that “the role of cultural and social factors in determining the status of the teaching profession seems to be over-stated”. He offers Teach First in England as an example of raising status through re-branding and creating competition for places. But this seems to be a higher status relative to other routes into teaching rather than that of teaching itself. Another approach might be to consciously make it more difficult to become a teacher on the Marxian principle, Groucho that is, that people are less likely to want to join something if just anyone can. The Coalition Government in Britain strongly supports Teach First, but is pinning its hopes on enhancing status through raising entry requirements. Given the persistent shortfalls in the recruitment of science and mathematics teachers, this runs the risk of making matters worse at least in the short term.

Attractive Profession

3.50. The practical expression of higher status is that teaching is more attractive. But it is chicken-and-egg: does the status or the attraction come first? In the absence of obvious levers to raise status directly, it may be better to concentrate on increasing attraction. If this were possible, there would be more competition to enter, that would allow more careful selection, getting in would be recognised as an achievement, and that would tend to elevate the status.

3.51. But how can teaching be made more attractive? Australia and the Netherlands, the two countries we selected as examples of those with persistent science and mathematics teacher shortages, are adopting a wide range of measures to boost recruitment. The United States is similarly active. The proposals and policies have a familiar ring to them – new teacher training routes, improving teacher training, encouraging more teachers to continue their training to master's level, and incentives of various kinds. The spread and similarity of approaches suggests there is no silver bullet.

3.52. Rosenberg (1957) identified ten aspects of occupations that made them attractive. They fell into three groups: intrinsic satisfactions (e.g. use of special abilities), extrinsic rewards (e.g. salary and security) and people-oriented (e.g. help others). Our international comparisons provide a number of examples of each in operation.

- ***Intrinsic Satisfaction***

3.53. An important intrinsic occupational value is the opportunity to use special abilities. Countries with strong science and mathematics teacher workforces provide good opportunities for teachers to develop and use their special abilities. In Finland and South Korea both primary and secondary school teachers have subject specialisms listed on their teaching qualifications. On the other hand, Australia, like the UK, has a general teaching qualification. The Australian Council of Learned Academies (Marginson *et al*, 2013) noted, "the incidence of 'out of field teaching' is especially high…Arguably, this is a crucial weakness of Australian education, impairing both the breadth and depth of STEM learning".

- ***Extrinsic Rewards***

3.54. Salary is a very attractive feature of teaching in some countries, but not in all those where it has high status. Table 3.5 shows that salary is high relative to that of comparable graduates in South Korea, but not in Finland. Per hour of teaching it is higher in the Netherlands, which has difficulty in recruiting science and mathematics graduates, than in Japan and South Korea which are well supplied. Relative salary does seem especially low in the United States which may contribute to its retention problems.

3.55. Countries in which teaching is attractive often offer teachers greater security than other areas of employment. In Greece and Cyprus teachers are career civil servants appointed for life and paid irrespective of whether or not there is a school to which to go. Not surprisingly, they are among the few European countries with teacher surpluses (Eurydice, 2002). In Finland teachers also have civil servant status though they are not appointed for life (European Commission/EACEA/Eurydice, 2013). Australia (every five years) and the United States (every ten years) are examples of where tenure is subject to regular appraisals (OECD, 2013a). They are two of the countries with shortages, but Japan which it well supplied is also about to introduce ten-year renewals.

- ***People Orientation***

3.56. Teaching is a people oriented profession *par excellence*. It is essentially about being with people and helping them. If they are key values for you then there is ample opportunity in teaching to express them, but if you are happier with things than people teaching may not be for you. Subjects differ considerably in the personality-type they attract (Smithers, 1969; Ormerod and Duckworth, 1975) and in the appeal of teaching (Rosenberg, 1957; Smithers and Hill, 1989). Physics and drama are at the opposite ends of the spectrum

3.57. But people-orientation is only fulfilled if the pupils share the goals of the school. If they do not, they can play up. A major reason for teachers leaving secondary schools in England is poor pupil behaviour (Smithers and Robinson, 2001, 2003). In countries where teaching is an attractive high status profession there is generally good discipline and an eagerness to learn. It is one of the reasons that large classes are possible in South Korea, Japan and China.

Pool of Potential Recruits

3.58. The pattern of subjects studied at university varies among nations. OECD statistics bear out the analysis of Australia's Chief Scientist (para 3.31) that countries with shortages of science and mathematics teachers tend to have low proportions in those fields. According to the OECD's (2013a) *Education at a Glance 2013*[11] , Finland (34.7%) had the highest percentage of new entrants to tertiary education in STEM fields in 2011 (the latest figures available), and South Korea (32.0%), the fourth highest. The Netherlands (15.3%) had the lowest, and Australia (20.5%) the fifth lowest. The UK (22.6%) is in the bottom half. It is possible that teacher status differences are compounded by the size of the graduate pools when it comes to recruiting STEM teachers. But the data require careful interpretation since the STEM category includes 'engineering, manufacturing and construction', which make a major contribution. Although convenient in many ways 'STEM' may be too broad a category when it comes to teacher supply.

3.59. Nevertheless, it is obvious that the pool of graduates must be large enough to recruit the good teachers that are needed. If relatively few graduates of a subject like physics are attracted to teaching then the pool has to be that much bigger. Finland and South Korea lay the foundations for their graduate pools in the primary school. In Finland the trainee primary teachers take subject specialisms alongside other university students as part of their basic qualification which is a master's degree. (Centre on International Benchmarking, 2013). In South Korea there is a national curriculum for the four-year primary teacher training course covering subjects and pedagogy. Every teacher is required to have a subject major which is listed on the teaching certificate. In England there is no nationally agreed programme for primary teacher training degrees. An attempt has been made to compensate in mathematics through a masters-level Mathematics Specialist Teacher Programme (MaST) funded as a pilot for four cohorts. An evaluation by the National Foundation for Education Research and the consultancy SQW (Walker *et al*, 2013) was cautiously positive, but there are doubts about its future.

Planning and Monitoring

3.60. One of the reasons for the high status of primary teaching in Finland and South Korea is that the courses are difficult to get on to since the places are limited to the numbers required by schools. This implies that these countries have good planning and monitoring models. *Key Data on Teachers and School Leaders 2013* (European Commission, 2013) records[12] Finland as having a forward planning model based on the most likely scenarios in future supply and demand. Scotland is similarly praised. On the other hand, the Netherlands is content with monitoring general trends in the workplace. England has had a model for generating targets for teacher training since 1983 (DES, 1990, DFEE, 1998b), but the European Commission regards this as merely market monitoring. However, as we shall see in Chapter 5, whatever the accuracy of the targets, the major problem has been that not enough well-qualified people have been coming forward to meet them.

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[11] StatLink to Table C3.3a, page 302
[12] Figure B1, page 43.

Retention

3.61. The United States comes out unfavourably on most indicators in Table 3.5, so it is not difficult to see why it might be finding it difficult to retain teachers. The evidence from Ingersoll and Perda, 2009 indicates that the schools are able to recruit science and mathematics teachers, but find it difficult to hold on to them. In particular, salaries for graduates in these subjects tend to be much higher elsewhere (West, 2013), but pupil behaviour is also an issue. The American experience underlines the importance of addressing retention alongside recruitment.

Differential Salaries

3.62. The availability of science and mathematics teachers is affected by factors that govern teacher provision in general. It tends to rise and fall with the popularity of teaching as whole. But, over and above the general run, there are special features, in particular employment opportunities elsewhere. A number of countries experiencing shortages, including Australia and the Netherlands, are actively considering paying teachers differently according to subject. It is an idea that is much discussed, but Marginson *et al* (2013) in their review of consultants' reports that had been commissioned on 19 countries were able to find only one example of differential salaries being implemented and that was in the United States.

Conclusion

3.63. A major finding from the point of view of The Royal Society's Vision Project is that it is possible to transform education systems. Finland (Sahlberg, 2011), Japan (Akiba and LeTendre, 2009), Singapore (Stewart, 2011) and South Korea (Kim, 2010) are all examples.

3.64. In countries well supplied with science and mathematics teachers, teaching generally enjoys high status and is an attractive profession. But there are no isolatable portable features consistent across countries. Status is embedded in the country itself. Different combinations of satisfactions and rewards operate to make teaching attractive in different countries. Not all the features that have been shown to be linked to teacher recruitment are affordable or desirable, for example, very high salaries, or appointment as career civil servants.

3.65. A crucial question for The Royal Society's Vision Project is how to make teaching more attractive. If ready-made solutions are not available from other countries, then new thinking is required. We will present our best ideas as recommendations in Chapter 6.

4. The Science and Mathematics Teaching Workforce in the UK

4.1. The education systems of the countries of the UK are administered separately and are very different[13]. England has a diversity of state schools, the legacy of successive waves of reform, grammar schools, comprehensive schools, specialist schools and academies among them. Scotland and Wales are mainly comprehensive, but in Northern Ireland there is a selective system. In England, in the move to comprehensive education, some local authorities created sixth form colleges fed by 11-16 schools. The colleges were relocated to the FE sector in 1993, but remain essentially part of the school system.

4.2. Table 4.1 shows the relative sizes of the state school systems in the four home countries (not including the sixth form colleges in England). England is by far the largest with, in 2011, 83.8 per cent of the pupils and 79.6 per cent of the schools. The figures for teachers are less comparable since they are counted in different ways, but nevertheless over three-quarters are in England.

Table 4.1: Maintained Schools and Teachers in UK[1]

	England	Scotland	Wales	Northern Ireland
Schools				
Primary	16,884	2,081	1435	863
Secondary	3,310	367	222	217
Pupils				
Primary	4,137,755	366,429	259,189	163,378
Secondary	3,262,635	297,109	201,230	147,902
Teachers[2]				
Primary	158,800	22,851	13,399	7,874
Secondary	117,300	24,241	12,935	10,085

1. Base year 2010-2011.

2. Full-time qualified teachers in England and Wales; headcount in Scotland; and full-time equivalents in Northern Ireland.

Sources:
***England*:** Schools, Pupils and their Characteristics, January 2011. SFR 12/2011. London: DfE; S*chool Workforce in England: November 2011*. SFR 06/2012 London: DfE.
***Scotland*:** *Summary Statistics for Schools in Scotland No2*. 2011 Edn. www.scotland.gov.uk/publications/.
Wales: *Schools, Pupils, Teachers. Schools' Census 2011: Final Results – Revised*. Statistical First Release. SDF 153/2011(R). Welsh Government: Cardiff.
***Northern Ireland*:** *Education Statistics Facts and Figures*. www.deni.gov.uk/index/facts-and-figures.new.htm/.

4.3. In Scotland, Wales and Northern Ireland all teachers must register with the relevant General Teaching Council if they want to teach in a state school. They are eligible to register if they hold a relevant degree and a recognized teaching qualification. In

[13] Education in Scotland has been organised separately from that in England and Wales since the Union in 1707. Following the partition of Ireland in 1921, Northern Ireland was established as a separate political entity to the rest of the UK. Legislation in England and Wales was replicated in Northern Ireland with the 1944 Act enacted in 1947. It did not, however, follow England and Wales in going comprehensive. When power was again devolved to the NI parliament in 1999 following a period of direct rule it was decided to abolish the national 11-plus examination, but the system remains selective with schools setting their own tests. The education systems of England and Wales were administered together until responsibility for education in Wales was devolved to the National Assembly of Wales established in 1999 following the referendum of 1997.

Scotland new teachers are provisionally registered until they successfully complete a probationary year. In England, the General Teaching Council was abolished in 2012 with some of its functions absorbed into what is now National College for Teaching and Leadership, an executive agency of the Department for Education. Qualified teacher status is awarded by the NCTL (having taken this over from the DfE), which receives information on successful completions from the training institutions.

4.4. Compulsory registration means that the General Teaching Councils, where they exist, are a source of information on the subject specialisms of teachers and we have drawn on them in compiling Table 4.2. Limitations are that they give the numbers of registrations, not teachers currently working in schools, and they are self-reported. This can make a big difference as we can see for Scotland where there are about double the number of registrations (Scotland B) as are recorded by schools in the annual teacher census (Scotland A). In England the figures are subject to double or triple counting since teachers are included for each subject taught. It is not possible, therefore, to make comparisons between teacher numbers in the countries, but it is possible to consider similarities and differences in the STEM patterns.

Table 4.2: Teachers of STEM Subjects in State Schools in UK[1], 2011

Subject	England[2]		Scotland A[2]		Scotland B[4]		Wales[5]	
	N	%	N	%	N	%	N	%
Biology	8,500	3.5	1,157	5.1	2,978	6.2	476	2.9
Chemistry	6,900	2.9	928	4.1	2,850	6.0	459	2.8
Physics	5,900	2.4	850	3.8	1,873	3.9	430	2.6
Science	34,700	14.4	141	0.6	39	0.1	1,260	7.7
Mathematics	35,200	14.6	2,533	11.2	5,535	11.6	1527	9.4
Computing/IT	18,600	7.7	675	3.0	1,868	3.9	778	4.8
Total	241,500	100.0	22,571	100.0	47,892	100.0	16,317	100.0

1. No information available for Northern Ireland.

2. Headcount, but double counting because teachers counted for each subject taught, regardless of the proportion of the time spent teaching that subject.

3. By main subject taught.

4. Registered teachers by main subject.

5. Registered teachers by subject taught.

Sources:

1. No information available for Northern Ireland.

2. England: *School Workforce in England, November 2011*. Statistical First Release 06/2012. London: DfE.

3. Scotland A: *Teacher Census Supplementary Data, 2011*. Edinburgh: The Scottish Government.

4. Scotland B: *Statistical Digest Spring 2011*. General Teaching Council Scotland.

5. Wales: *Annual Statistical Digest, March 2011*. General Teaching Council Wales.

4.5. Across the countries, biology is the most commonly occurring science specialism and physics the least. England appears to have a much higher proportion of general science teachers than Scotland and Wales. This is consistent with 'science' being the subject in the national curriculum, but it also reflects the way the teachers have been counted. The numbers for England include all subjects taught including where a specialist teaches some general science in addition. But in Scotland and Wales only the main subject is counted. The higher percentages in England for mathematics and computing/IT may also arise from the teachers teaching them in addition to a specialism in another subject.

Sixth Form Colleges in England

4.6. Sixth form colleges are still *de facto* part of the school system in England, but statistics relating to them are mainly buried among those of the FE Sector as a whole. The first workforce survey conducted by the Learning and Skills Improvement Service[14] (LSIS, 2012) adopts broad categories. It shows that in 2010-11, the base year for Table 4.2, there were 6,399 (6.0%) in science and mathematics, 5,935 (5.6%) in engineering, technology and manufacturing and 5,003 (4.7%) in ICT out of a total of 106,053.

4.7. The latest data we have been able to find for the sixth colleges is in a survey[15] on teacher resignations and recruitment conducted for Local Government Association by the National Foundation for Education Research (NFER and LGA, 2008). Table 4.3 shows that, as in schools, biologists are in the majority amongst the scientists. Since these are sixth form teachers it is to be expected that they would all be specialists.

Table 4.3: Staff[1] Sixth Form Colleges

Subject	N	%
Biology	378	5.0
Chemistry	228	3.0
Physics	221	2.9
Other Science	72	0.9
Mathematics	590	7.8
Computing/IT	563	7.4
Total	7,553	100.0

1. Full-time permanent staff. In addition there were 2,612 PT permanent teachers and 709 on fixed term contracts either full-time or part-time making 10,874 in all.

Source: NFER and LGA (2008). Staff are listed alongside turnover and resignations in the period 2003-6

4.8. According to the National Audit Office (2011), 11 per cent of 16-18 learners were in sixth form colleges, 32 per cent in school sixth forms (including academies) and 48 per cent in general FE colleges. Information from the Sixth Form Colleges Association's (SFCA formerly SFC Forum) website[16] shows that, in 2012, more than 150,000 16-18 year olds were enrolled on a course at a sixth form college, most (90%) studying for a Level 3 qualification (A-level or equivalent). Sixth form colleges punch above their weight in terms of achievement. The NAO (2011) found that they came top on most measures of learner achievement. SFCA reports that in 2012 14 per cent progressed from sixth form colleges to higher education, more than to be expected from proportion of 16-18 year olds in full time education in state-funded 16-18 education providers.

Independent Schools

4.9. Most of the published statistics are confined to publicly funded schools. The Independent Schools Council (ISC) publishes an annual census giving data on teacher

[14] LSIS ceased to exist on 31 July 2013. Its data have been transferred to the Education and Training Foundation, which is not, as we write, fully up and running. There is no equivalent dataset for colleges to the DfE's School Workforce Survey.

[15] A later survey was published in 2010, but the tables are based on respondents only, and not grossed up to 100 per cent as in the 2008 publication. A new survey was commissioned for 2009-10, but there is as yet no publication.

[16] Sixth Form Colleges Association: www.sixthformcolleges.org/.

and support staff numbers in UK independent schools including pupil-teacher ratios and turnover. But they do not include teacher qualifications and main subject taught. The report on the 2013 census does comment that "recruitment of appropriate candidates appears to be slightly tougher for maths and science where 11.1% of schools reported that it was easier than three years ago and 32.9% that it was harder" compared to 15.4 per cent and 19.3 per cent respectively for suitably qualified staff generally. This is reinforced by the further comment that "in general, schools have found it easier to recruit since the start of the economic crisis; in 2007 only 10.3% of schools reported that recruitment was easier than three years previously while 36.9% felt it was more difficult, the equivalent figures for maths and science recruitment in 2007 were 6.7% and 48.4%".

Balancing STEM Teacher Demand and Supply

4.10. In Eurydice (2002) four governments reported that they were able to match teacher demand by supply. They were Finland and Spain and two administrations on England's doorstep, Scotland and Northern Ireland. That these parts of the UK seem better provided than England is borne out by PISA (2010) and TIMSS (2012). In the TIMSS study England is among the countries with STEM teacher shortages. But in PISA with Scotland and Northern Ireland added in, the UK as a whole comes out average (just). Have Scotland and Northern Ireland succeeded where England has struggled or is it something of an illusion? We now look in detail at the situation in these two countries and Wales, and we devote the following chapter to England.

Scotland

4.11. In Scotland balancing teacher demand with supply has proved something of a roller coaster (Donaldson Report, 2010). At the end of the Second World War the rapidly rising birth rate led to acute shortages when the children were of school age. By the late 1970s, however, the pendulum had swung the other way with an over-supply of teachers as a decreasing school age population and curbs on public expenditure began to bite.

4.12. The response was to cut back on the intake to initial training. Following a review published as *Teacher Training from 1977 Onwards* (Scottish Education Department, 1977) the number of teacher training colleges was cut from ten to five. The remaining colleges were subsequently merged with Scottish universities (Sutherland Report, 1977). Since 1999, following devolution, a tenet of policy has been to reduce class sizes by increasing the number of teachers and thereby the training intake. But with school rolls dropping and pressures on budgets, demand for teachers fell by 2010. The outcome was high levels of teacher unemployment, especially among those who had just completed their induction year. It was reported that in 2009-2010 only 16.1 per cent had obtained a full-time permanent contract and 19.5 per cent a full-time temporary contract (General Teaching Council Scotland, 2010).

4.13. The overall picture is thus one of fluctuating shortage and oversupply. Recent reports suggest that provision has been brought into balance with teacher unemployment in Scotland at its lowest level since 2007 and the lowest in the UK (BBC, 2013). Entry to initial teacher education in Scotland is highly competitive. Application rates are strong with a high ratio, 8:1, of applicants to places. This is its great strength since those admitted can be carefully chosen.

4.14. Donaldson nevertheless recommended the government workforce planning model be improved to try to ensure that the numbers entering teacher training were consistent with the posts available. Teacher workforce planning in Scotland is singled out for special mention in the latest edition of *Key Data on Teachers and School Leaders in Europe 2013* (European Commission /EACEA/Eurydice, 2013). "In the United Kingdom (Scotland), the Scottish Government annually carries out a teacher workforce planning exercise, in consultation with an advisory group comprising representatives of the General Teaching Council for Scotland, the local authorities, teacher unions and the universities. The basis of the exercise is a model…It then calculates the student intake required…At the end of this process, the Government issues a letter of guidance to the Scottish Funding Council". England's approach is compared unfavourably as labour market monitoring. In the forthcoming academic year, 2013-2014, additional places are targeted at specific priorities. Extra places have been allocated to physics to address what it is referred to as 'the year-on-year under recruitment to physics' and also to chemistry and computing (Scottish Funding Council, 2013).

4.15. A recent report, *Supporting Scotland's STEM Education and Science Culture* (Science and Engineering Advisory Group, SEEAG, 2012) does suggest that difficulties have been encountered in attracting sufficient science and mathematics graduates. The reason, it believes, is that teaching has been seen as less desirable or less financially rewarding as a career path than business, industry or other employment sectors. It warns that in any general strategy to raise the qualifications for entry into the teaching profession in Scotland, the risks to the number and quality of teachers in some STEM areas should be borne in mind. Part of the solution, SEEAG suggests, lies with the universities in encouraging high-quality STEM graduates and those with high-level aptitudes and skills for teaching into careers in teaching.

4.16. The SEEAG report goes on to consider how to tackle what it labels as the 'STEM primary challenge'. Among the strategies suggested are changes to the selection criteria for primary teacher training. Donaldson's recommendation, that the traditional B.Ed degree should be phased out and replaced with degrees that combine university-level academic study with professional studies and development, is supported. It argues that this would introduce "a greater degree of subject specialism into and across the primary teaching profession founded on the model of practitioners as generalists. It would offer particular advantages in creating a primary teacher cohort with a STEM specialism". SEEAG believes that an increase in subject specialisation in science and mathematics is necessary and would address the relatively poor performance of Scottish science and mathematics education in international studies.

Northern Ireland

4.17. Northern Ireland, if anything, has an over-supply of teachers (Northern Ireland Assembly Debates, 2011; Belfast Telegraph, 2012). The continuing concern at the difficulties experienced by newly qualified teachers in finding permanent posts prompted a major review of teacher education. Evidence gathered in a series of commissioned reports, conferences and a review of the main findings (Osler, 2005) culminated in the publication of a consultative document, *Teacher Education in a Climate of Change: The Way Forward* (Department of Education and Department for Employment and Learning, 2010). Following a consultation period launched by ministers in 2010 the two government departments involved are currently finalizing the draft strategy and the implementation plan scheduled for 2013.

4.18. Teacher supply in the sciences and mathematics was scrutinized in a STEM Review by the two departments (DE and DEL, 2009). It found that applications to PGCE courses in the physical sciences tended to be low compared with biology, reflecting the relatively low numbers graduating in these subject areas. It also noted that mathematics applications were dropping. But there seemed to be no evidence of teacher shortages from school vacancies. "Indeed", the STEM Review points out, "a substantial number of science students emerging from PGCE courses fail to secure full-time permanent positions on entry to the profession".

4.19. The science teaching workforce was found to consist disproportionately of biologists. In 2009 there were 628 compared with 188 for physics and 386 for chemistry. This imbalance is confirmed by the Northern Ireland Supply Register. The physics and chemistry teachers were mainly in the grammar schools, while the biologists were mainly in the non-selective schools. There were concerns also for the future since about half the physics teachers were aged 50 and over. Headteachers complained that the teacher vacancy data did not tell the whole story as they had to employ teachers to teach out of subject and there were difficulties in finding substitute STEM teachers to cover for absence and training. The STEM Review itself expressed concern that Key Stage 3 classes tended to be taught by non-specialists, at the stage when subject attitudes were being formed. It argued that the take-up of STEM subjects would be boosted by an injection of the expertise and enthusiasm at an earlier age rather than the specialists being reserved for advanced level.

4.20. A paper, *The Labour Market for Teachers in Northern Ireland,* for the Office of Manpower Economics (Bennett, 2010) was more sanguine. It concluded that there was a fairly good match overall between supply and demand and that the vacancy surveys do not highlight teacher shortages in specific subject areas.

Wales

4.21. In little more than a decade Wales has moved from a shortage to over-supply. In 2001 the General Teaching Council for Wales found there were serious difficulties recruiting mathematics and physics specialists, especially in Welsh medium schools (GTCW 2001a and 2001b). But in December 2004, the Welsh Assembly Government (WAG), against a background of evidence of unemployed newly qualified teachers and falling pupil numbers, commissioned a review of initial teacher provision in Wales. The review (Furlong *et al*, 2006) found an over-production of new teachers. It recommended that the Statistical Directorate of WAG should develop a teacher supply and planning model and that by 2010/11 overall primary targets should be reduced by 50 percent and secondary by 25 per cent. Crucially, regarding STEM subjects, that targets should be established over the next five years to match more clearly than at present the demand for secondary subject teachers. In response the WAG accepted these recommendations, which were to be taken forward in short-term and medium term strategies.

4.22. By 2011, the Higher Education Funding Council for Wales, in a circular setting out the initial teacher training intake targets for 2012/13, (HEFCW 2011), identified continuing problems of under-recruitment to some secondary subjects at the same time as over-recruitment to primary training. Earlier (HEFCW 2010) identified mathematics, physics and chemistry as priority subjects for recruitment. The target for physics and chemistry was allocated jointly, with the proviso that trying to meet the physics target should not be at the expense of chemistry. In that year HEFCW commented on an improvement in the recruitment situation, largely as result of the economic slowdown, and that it was a welcome respite for the shortage subjects.

4.23. As in Northern Ireland, the Welsh Government has directed its attention to STEM subjects and skills as “essential for an innovative and modern economy”. A report in 2011, from the Welsh Assembly, *The Science, Technology, Engineering and Mathematics (STEM) Agenda,* acknowledged that “there remains a critical lack of suitably qualified (STEM) teachers within schools particularly in mathematics”. The inquiry was, in part, prompted by the relatively poor performance of Wales in the 2006 and 2009 PISA tests, where it fell was below its UK counterparts and the OECD average.

4.24. Damming evidence presented to the Enterprise and Learning Committee inquiry by the Welsh schools inspectorate (Estyn) painted a worrying picture of science and mathematics teaching in Welsh secondary schools. It reported that the quality of teaching was poorer than in other subjects, and departments were less well led. A disproportionate amount of teaching at Key Stage 3 was by biologists. Information provided by the Institute of Physics in Wales identified 158 qualified teachers of physics in Wales and 198 teachers teaching physics that were not trained in physics. The inquiry also received evidence from Software Alliance Wales of insufficient numbers of ICT and computer science teachers. Quoting the Sector Skills Council, it pinpointed “pupils’ experience of IT at KS 4 as the biggest single factor in the drop in uptake of this subject beyond KS4”.

4.25. Among its many recommendations the STEM Agenda report urged better data collection and improved recruitment strategies for STEM subjects: “We recommend the Welsh Assembly Government should produce definitive data on the quantity and quality of STEM teachers and should develop measures for encouraging and recruiting high quality physics, chemistry and mathematics teachers where there is an identified need”. In response to the “critical lack of suitably qualified teachers, especially in mathematics”, it recommended that more engineers should be encouraged into teaching and continuing profession development (CPD) for STEM teachers should be improved to help specialists who had to teach outside their subject.

Pointers for The Royal Society from Scotland, Northern Ireland and Wales

4.26. The data and descriptions of the countries of the UK offer a number of pointers for The Royal Society’s Vision Project. We highlight planning and monitoring; the need the teaching qualification to record subject specialism; the lack of scientific expertise in primary schools; science teaching dominated by biologists at Key Stage 3; and the dependence of teacher recruitment on the economy.

Planning and Monitoring

4.27. Scotland has responded to boom and bust in teacher supply by developing an approach to planning which involves wide-ranging consultation. It has been praised by the European Commission for doing so (European Commission /EACEA/Eurydice, 2013). The Furlong Review in Wales recommended that the Welsh Assembly Government should develop a Teacher Supply and Planning Model. But the planning models in the UK, other than in Scotland, are mainly statistical without the consultation. Scotland’s approach has enabled it to match supply to demand for teachers in general. But there are still concerns in the STEM subjects. No matter how good the planning model if applicants do not come forward there will be shortfalls. Crucially, teaching must be made attractive to STEM graduates. But our reading of the literature for the home countries has not provided us with compelling examples of how this could be achieved.

Subject Expertise

4.28. Decisions on training allocations appear to us to lack focus. Northern Ireland and Wales have been concerned about an over-supply of teachers, but do not seem to be well-supplied with STEM teachers. Teacher training provision has been cut in Scotland and Wales, yet science and mathematics teachers seem to be in short supply. The science teachers are disproportionately biologists. What, in our view, would greatly help with planning would be if the subject specialisms were entered on the teaching certificate. The age range for which trained could be shown also. Then an over-supply of primary teachers would not colour provision for STEM teaching. Identifying the STEM specialisms would not allow a comfortable feeling that science targets were being met if there were shortfalls within the category. Northern Ireland seems content that it has enough science teachers, but they are mainly biologists and it is only the grammar schools that are well staffed with physicists.

Primary Schools and Key Stage 3

4.29. One of the reasons why it is so difficult to recruit enough good STEM teachers is that there are not enough graduates, particularly in physics, mathematics and computing, for the occupations in which they are in demand. Weaknesses in the foundations for these subjects in the primary school and Key Stage 3 seem to be an important contributory factor. In Scotland some recent influential reports (Donaldson, 2010; Science and Engineering Education Advisory Group, SEEAG, 2012) have recommended that the primary teacher training qualification be re-designed to include greater emphasis on subject specialisms. Donaldson recommended a degree combining university-level academic studies with education. SEEAG supported this emphasizing the need for primary teachers with a STEM specialism.

4.30. Key Stage 3 has also come under scrutiny. The Enterprise and Learning Committee (2011) in Wales received evidence, from the schools inspectorate, among others, that at Key Stage 3 science teaching was mainly in the hands of biologists and there was a severe shortage of computer science specialists. The Northern Ireland Government's STEM review (Department of Education and Department for Employment and Learning, 2010) expressed concern that teaching at Key Stage 3 was mainly by non-specialists at an age when subject attitudes were being formed. Concerns raised over science in primary schools and at Key Stage 3 in Scotland, Wales and Northern Ireland raise questions which The Royal Society should consider:

- What qualifications would it expect of STEM teachers in primary schools and at Key Stage 3?
- If it thinks there should be a greater specialisation, where are the teachers to come from given there are shortages already?
- Is there a case for re-designing the primary teaching qualification and would the new courses attract sufficient applicants?
- Should more specialists be re-deployed to Key Stage 3?
- How can 'science' at Key Stage 3 be re-balanced towards the physical sciences?

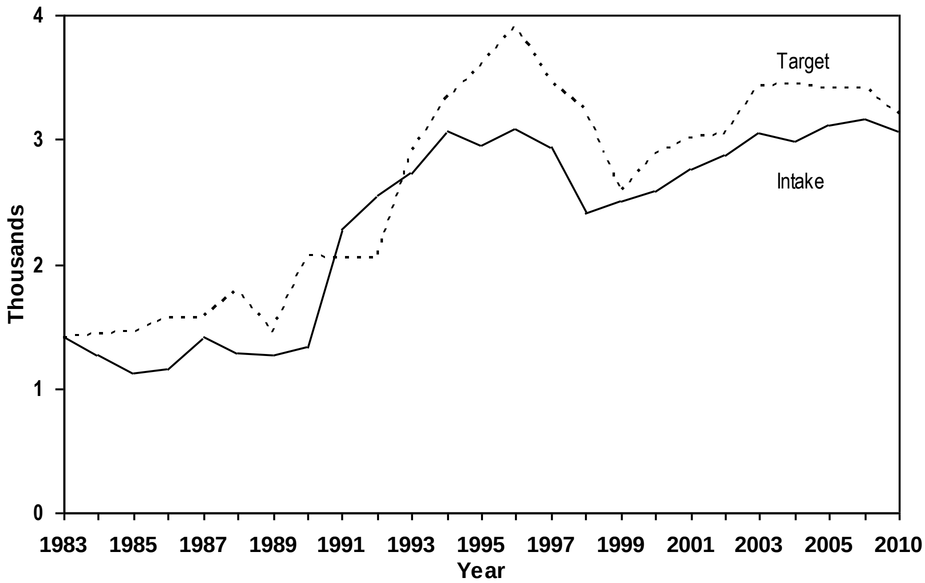
Dependence on the Economy

4.31. It is widely recognised that the UK needs more STEM teachers, but there are continuing shortfalls. Every so often there appears to be an improvement. As the Higher Education Funding Council for Wales (2011) observes, this tends to occur during economic downturns. The recession which the UK has suffered recently has given a boost to STEM teacher recruitment. The Independent Schools Council (2013) notes that their members have found it easier to recruit since the start of the economic crisis. But this should not fool us into thinking that the attractiveness problem has been solved. As the economy picks up we will find that if significant changes have not been made, past experience suggests we are likely to plunge back into shortages.

5. Teacher Provision in the Sciences and Mathematics in England

5.1. England has always found it difficult to meet its requirements for high quality science teachers. In Chapter 1 we traced the history. In Figure 5.1 we show what has happened since 1983 when the DES first developed a model for setting recruitment targets (DES, 1990). The number of trainees has more than doubled since then, but it is striking that the target has only been met briefly at the beginning of the 1990s when the country was falling into economic recession. The influx of recruits gave the government of the time the confidence to raise the targets, but intakes have never matched them even when they were lowered again. The continuing shortfall means that schools will have found it difficult to recruit new science teachers. But even more important will have been the cumulative effect of creating a less than ideal science teaching force. Even if it were possible to begin to meet the targets, there would still be in schools the teachers recruited in leaner times, many on full-time permanent contracts.

Figure 5.1: Trends[1] in PGCE Science Targets[2] and Intakes[3]



1. England and Wales but update for 2010 is England only.

2. PGCE targets do not include employment-based routes.

3. PGCE intakes do not include employment based routes.

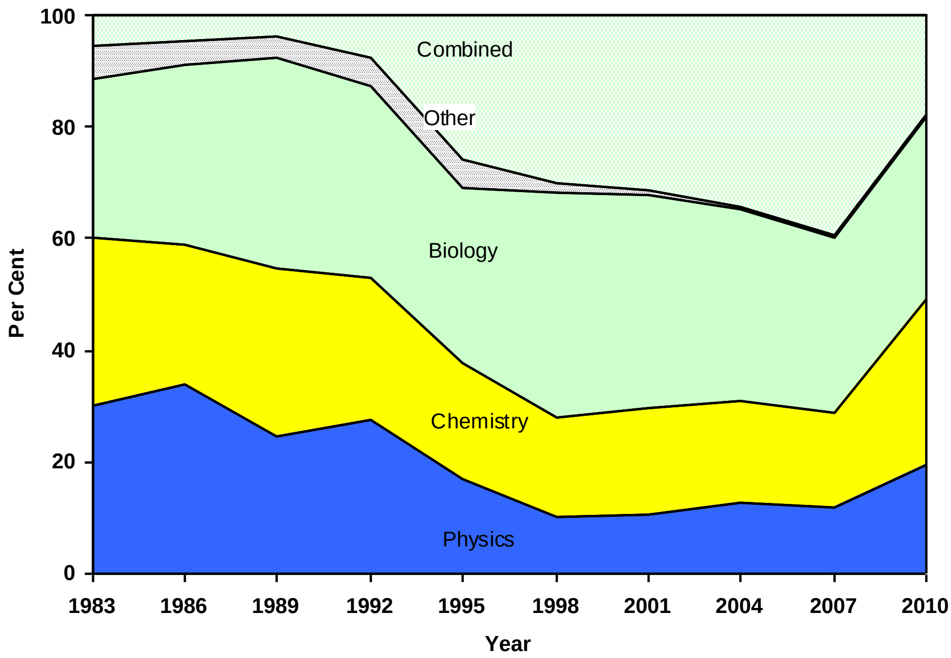
Sources: Annual DFEE/DfES/DCSF Statistical Evidence to the STRB. TDA Initial Teacher Training Census Data summary 2010-11. Adapted from Smithers and Robinson (2008). There is currently no convenient source for targets and intakes on the same basis.

5.2. Categories like 'STEM teachers' and 'science teachers' mask the real issue which is the shortage of physics teachers. Figure 5.2 shows that within the science intake figures of Figure 5.1 there is a good supply of biology teachers, but a dearth of physics teachers. From about 30 per cent of the PGCE intake in 1983 physics fell to remain at around 11 per cent in the decade to 2007. Chemistry dropped to around 19 per cent. The decreases partly reflect the numbers coming forward, but were mainly driven by a shift in policy. The national curriculum of 1988 framed the subject as 'science' and associated GCSEs were developed. The original intention was to make 'science' the exclusive route to A-levels, but the separate sciences at Key Stage 4 were saved by the independent schools, which did not have to comply (Smithers and Robinson, 1994).

With science as the subject it was logical to train the teachers in it. By 2007 40.0 per cent of the science teacher trainees were on general science courses. Biologists not only comprised a substantial proportion of the intake in their own right, but were the majority of the general science group. As recently as 2007, over 60 per cent of the science teacher trainees were from the biological sciences.

5.3. The policy of 'science' as exclusively the subject up to GCSE was reversed by the Science and Innovation Investment Framework (HM Treasury, 2006), since when, as Figure 5.2 shows, the proportions of physics and chemistry trainees have been recovering. The aspirational targets declared in 2006 are on their way to being met. Against a target for 2014 of 25 per cent of science teachers to have a physics specialism, the intake for training was 19.6 per cent in 2010. In chemistry, the respective figures were 31 per cent and 29.5 per cent. This is, of course, what they were training to teach. We take up in Table 5.2 how qualified they were in terms of the degrees they held to teach these subjects.

Figure 5.2: Subject Balance in PGCE Intakes[1] in the Sciences



1. England and Wales with the years labelled at the beginning of the academic year, so that 2010 stands for entries 2010-11.

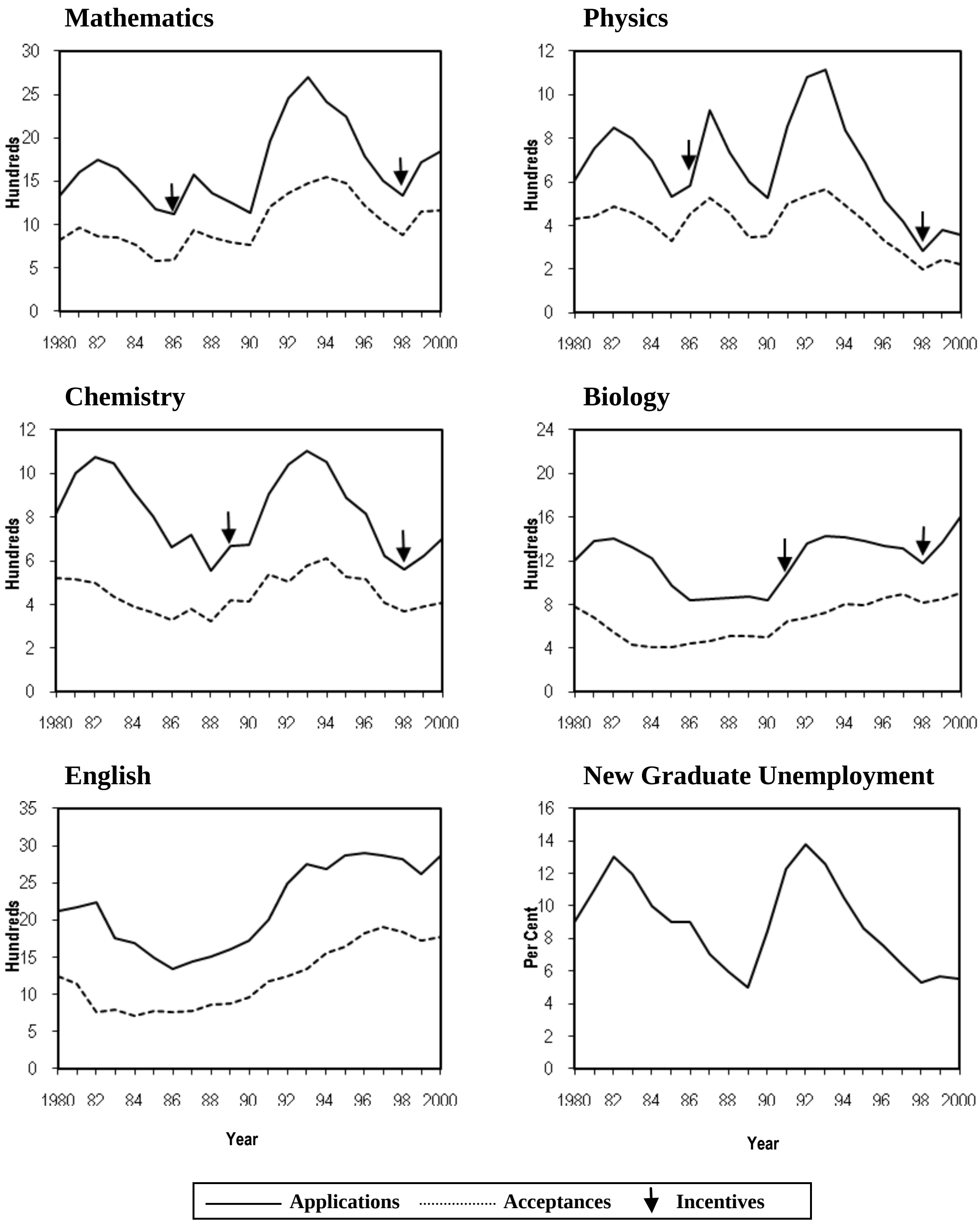
Sources: Annual Reports of the GTTR to 1998 and from 2001 from GTTR.ac.uk/stats/. 2010 From TDA Initial Teacher Training Census Data Summary for England only. Adapted from Smithers and Robinson (2008).

5.4. In Figure 5.3 we reproduce from Smithers and Robinson (2000)[17] the time courses of applications and acceptances for the individual sciences in the period 1980-2000, along with English for comparison, and a graph of new graduate unemployment plotted to the same scale. There are peaks around 1982 and 1992 corresponding to high levels of unemployment among new graduates. It is reasonable to infer, therefore, that interest in becoming a teacher goes up when there are fewer opportunities elsewhere. The first

[17] With the diversification of teacher training routes and the separation of the statistics for England and Wales following devolution on 1st July 1999 it is now difficult to get a sufficiently clean data set on the same footing.

set of arrows in the graph, those on the left, indicate when bursaries were first offered to tempt applications to train as physics and mathematics teachers. The bursaries were later extended to chemistry and biology (where an incentive was not needed, but was given in applying the policy to 'science')[18]. The bursaries did have a perceptible effect on recruitment to physics and mathematics teacher training, but they tended to be short-lived in relation to the underlying drivers.

Figure 5.3: Recruitment to Selected Secondary PGCE Courses[19]



Sources: Graduate Teacher Training Registry (2001a) and Higher Education Statistics Agency (2001). Adapted from Smithers and Robinson (2000).

[18] Another example of what can happen when the concept is too broad for the issue.
[19] The key is for the five recruitment to PGCE graphs; the employment graph shows the percentage of new graduates without jobs six months after graduating.

5.5. The second set of arrows represents the 'golden hellos' introduced in 1998 and again there appears to be an effect, but it is small in relation to the overall trend. Two pointers towards understanding what increases the appeal of becoming a science or mathematics teacher are: (i) it depends on the competitive position of teaching *vis-à-vis* other graduate occupations; and (ii) it is possible to stimulate interest by financial incentives, but the effect may be small and not last long.

Graduate Output and Teacher Training

5.6. In reviewing the science and mathematics teaching workforce worldwide we identified the size of the graduate pool an important factor in teacher recruitment. This is borne out by the figures for England. Table 5.1 shows graduate output and initial teacher training targets for 2010. On the assumption that a degree in the subject is the most appropriate qualification, we can see that it would take over 40 per cent of the graduate output to meet the targets for mathematics, physics and chemistry. Now that it is to take an unduly purist view and subjects such as engineering will be relevant to mathematics and physics. But, in Table 5.2, we show just how widely the net has to be spread. The picture for biology is very different. Graduate output is higher and the target has been reduced recently in an attempt to begin the re-balancing of the science teaching workforce, so the percentage required to meet teacher training targets seems much more manageable. These differences are a further indication that the 'STEM' category may not be very helpful when considering teacher supply.

Table 5.1: Graduate Output, Intakes and Targets, England

Subject	Graduate Output[1] 2010	ITT Intake[2] 2010	Intake as % Output	Targets 2011[3]	Target as % Output
Mathematics[4]	5,520	2,565	46.5	2,635	47.7
Biology[5]	8,255	1,068	12.9	840	10.2
Chemistry	2,555	943	36.9	1,070	41.9
Physics[6]	2,215	605	27.3	925	45.1

1. Institutions in England
2. PGCE and employment based.
3. Separate targets for biology, physics and chemistry not declared in 2010; there was an overall figure for 'science'
4. Mathematical sciences
5. Biological sciences minus psychology and sports science and exercise.
6. Includes materials science and astronomy.

Sources: Students in Higher Education Institutions 2009/18, Table 18d, HESA; *Initial Teacher Training Census 2012: Summary*, TDA. Adapted from Smithers and Robinson (2008).

5.7. The National College for Teaching and Leadership (formerly the Teaching Agency and the Training and Development Agency for Schools) kindly cross-tabulated subject of PGCE training against subject of degree[20]. for us. The results are shown in Table 5.2. What stands out is how few of the trainees actually have degrees in the subjects which they were training to teach. In physics the trainees came from 44 different subjects. Only 40 per cent were known to have a degree in physics. After physics itself the most common degrees were mechanical engineering and sports science. A quarter of those with physics degrees were training to be teachers of other subjects, principally mathematics. Our interviews (Smithers and Robinson, 2005) revealed two main reasons: no practicals in mathematics, and not having to teach biology.

[20] For the latest training year which its statistics are publicly available, 2010-11.

5.8. Of the trainee mathematics teachers about half (52.2 %) were known to have a degree in the subject. The other half held degrees in a wide range of fields: engineering and technology (10.7%), economics (6.9%), science (4.3%), science-related (6.2%) and 'others' (19.6%).

Table 5.2: Teacher Training Subject[1]. by Degree Subject, 2010-11

Degree Subject	Subject of PGCE Training						Total
	Physics	Chem	Biol	Comb/Gen Science	Maths	Other[2]	
Physics	244	4	1	27	40	2	318
Other Phys Sci[2]	19	16	12	13	8	19	87
Chemistry	13	359	7	35	15	7	436
Biology[3]	19	103	458	131	17	17	745
Science Related[4]	30	56	127	77	117	1,298	1,705
Mathematics	38	1	2	2	978	301	1,322
Eng & Tech	30	8	3	8	201	109	359
Economics	2	-	2	1	129	76	210
Other[5]	24	19	15	12	368	5,664	5,992
Undefined	186	377	441	310	692	5,000	7,006
Total	605	943	1,068	616	2,565	12,383	18,180

1. All routes except assessment only and including Key 2/3.

2. Except chemistry which is listed separately.

3. Biological sciences minus psychology and sports science, which are included under science related.

4. Medicine, dentistry, medical related, veterinary science, agriculture, psychology and sports science.

5.Wide variety of subjects including architecture, law, social studies, business and administration, mass communication and documentation, languages, history and philosophy, creative arts, education.

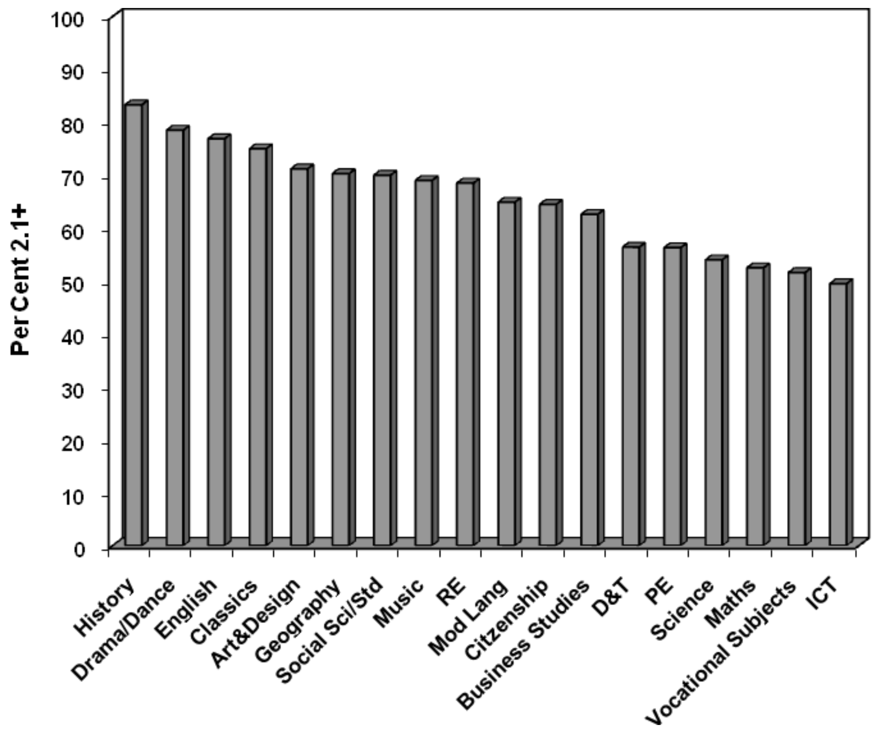
Source: National College for Teaching and Leadership, special analysis 2013 updating of Smithers and Robinson (2008).

5.9. The impression of the physics and mathematics teacher training providers struggling to fill places is borne out by comparing degree classes[21]. Figure 5.4 shows that in those subjects where there is more competition for places three-quarters or more of the trainees have at least an upper-second: history (83.3 per cent); drama/dance (78.5 per cent; English (76.9 per cent); and classics (75.0 per cent). But trainees in the sciences and mathematics were much less well qualified. The lowest percentages of good degrees were in ICT (49.5 per cent), mathematics (51.5%) and science (54.0%). Within the science category (see Table 5.3) the best degrees were in biology (62.4% good) and the worst were in physics (47.9%).

5.10. An obvious interpretation of these data is that they reflect the numbers of applicants and competition for places. Degree classes will tend to be better when there is more opportunity to select. If we accept that knowing your subject is a necessary condition for being a good teacher – though not sufficient because personal qualities will come into play – then pupils are likely to get a better experience in the arts and humanities than the sciences and mathematics. This may well have a bearing on future subject choices and the size of the graduate pools.

[21] Subject of degree, not necessarily of subject training to teach

Figure 5.4: Per Cent Good Degrees[1]



1. All entrants to universities, SCITTs and EBITTs holding UK degrees or equivalent with an upper-second or above, but excluding non UK degrees. Economics EBITTs and 'Other' EBITTs not included since fewer than ten trainees. From Smithers and Robinson (2012).

Table 5.3: Degree Classes of Teacher Trainees[1] and Graduates[2]

Degree Class	%Physics[3] Teacher Trainees	%Physics[3] Grads	%Chemistry Teacher Trainees	%Chemistry Grads	%Biology[4] Teacher Trainees	%Biology[4] Grads	%Mathematics[5]s Teacher Trainees	%Mathematics[5]s Grads
First	12.7	32.2	11.7	24.5	11.6	16.2	13.9	29.7
Upper Second	35.2	36.4	38.8	35.5	49.5	46.2	37.6	35.0
Lower Second	36.9	22.1	36.5	25.3	33.0	27.8	35.2	23.5
Third	7.9	7.7	7.8	10.2	2.3	6.6	7.5	9.7
Not known/ Unclassied	1.5	1.6	0.9	4.5	1.2	3.1	1.0	2.1
Total	520	2,855	810	2,710	933	10,525	1,898	6,465

1. PGCE trainees only in year 2010-11; in addition there were on employment-based routes 53 physics trainees, 70 chemistry trainees, 89 biology trainees and 442 mathematics trainees. They have been separated off because they would not have been older and graduated in earlier years.

2. UK domiciled students graduating with first degrees in 2010.

3. Physics plus material science and astronomy.

4. Biological sciences minus psychology and sports science.

5. Mathematical sciences.

Sources: CEER analysis of TDA Performance Profiles 2012 dataset, training year 2010-11, extracting PGCE secondary teacher trainees with UK degrees on full-time one-year courses; and data on graduates from 2009-10 who if they embarked on teacher training directly would be training in 2010-11 obtained from HESA *Students in Higher Education 2004-05*. (Adapted from Smithers and Robinson, 2008).

5.11. The percentages of good degrees awarded vary with subject. Table 5.3 sets the degree classes of those entering teacher training with science and mathematics degrees alongside the classes awarded. Again it emerges that teaching is the preferred option for relatively few of those who do best. Remarkably, in 2010-11, nearly a third of the physics degrees (32.2%) were awarded as 'firsts', but only 12.7 per cent of the teacher trainees had achieved this level. In mathematics the respective figures were 29.7 per cent and 13.9 per cent. On the other hand, in biology the proportion of 'firsts' in teaching training was over 70 per cent of the total awarded. The difference probably reflects both opportunities elsewhere, and also differences in the gender and personality of those attracted to the subjects.

Gender and Personality

5.12. Smithers (1969), Ormerod and Duckworth (1975) and Smithers and Hill (1989) found that students in different subjects looked for different satisfactions from their careers. The key dimension was 'person-orientation'. Teaching is very much a person-oriented career. It involves being with children day in, day out. In contrast, physics and mathematics are essentially about impersonal patterns and the people drawn to them may not attach much importance to being with people. Indeed, they may be uncomfortable at the thought of spending most of their time with boisterous youngsters. The genders also differ in their person-orientation, with females attaching much more value to it.

Table 5.4: Gender and Teacher Training, 2010-11

Subject	Teacher Trainees		Graduates	
	%Male	%Female	%Male	%Female
Physics	66.2	33.8	79.0	21.0
Chemistry	41.7	58.3	57.8	42.2
Biology	35.3	64.7	39.2	60.8
Mathematics	49.3	50.7	60.5	39.5

Sources: as Figure 5.3.

5.13. The patterns revealed in Table 5.4 can be interpreted in terms of these differences. Person-orientation helps us to see why there should be comparatively few females in physics and mathematics. It is also helps us to understand why, irrespective of subject, females are more likely to want to become teachers. It also takes us to the heart of the problem that The Royal Society is addressing. It is not going to be easy to recruit good physics graduates to teaching because physics and teaching provide very different satisfactions, so fewer graduates will consider teaching. Put all this together and we have a neat explanation of why recruitment to physics teacher training goes up and down with other subjects but it always lags behind them. Similar explanations apply to mathematics and chemistry, but in less sharp form. Biology though is quite different. It appeals more to females and personality studies show it to be more person-oriented. These important differences can be masked if we treat STEM subjects or the 'sciences and mathematics' as one category.

Deployment across Different Types of School and College

5.14. Teachers are spread very unevenly across the different types of school and college. If there are not enough good teachers to go round some institutions will be much better staffed than others. Smithers and Robinson (2005) found that overall 23.8 per cent of schools had no physics specialist at all. There was a big difference in this respect between 11-16 schools (41.2%) and those with sixth forms (10.5%). Schools to age 16 were mainly established in comprehensive systems where pupils transferred to sixth form colleges or further education colleges. Tables 5.5 and 5.6 show that these colleges tended to be able to attract well-qualified physics lecturers. But the absence of physics specialists in many 11-16 schools could leave the colleges short of students since the young people had not had a proper chance to develop their interest and confidence in the subject. Since 2006-07 the proportion of staff in FE teaching science and mathematics has declined from 7.2 to 5.7 per cent and with impending retirements (48 per cent age 45-64) there are concerns about the future (Thomson, 2009).

5.15. Table 5.6 also reveals more on the uneven distribution of physics specialists. Grammar schools and the leading independent schools were much more likely to have teachers with honours degrees or higher degrees than comprehensive schools, particularly those without sixth forms, and secondary moderns.

Table 5.5: Degree Subjects of those Teaching Physics in Different Types of Institution

Subject	Comprehensive to 16	Comprehensive to 18	Sec Mod	Gram	Independent to 16	Independent to 18	Sixth Form College	FE College
Physics	23.6	39.3	18.1	65.5	18.2	64.6	75.9	80.0
Chemistry	13.7	14.7	15.3	0.0	18.2	7.0	3.4	0.0
Biology	27.6	23.4	38.9	0.0	54.5	5.7	3.4	0.0
Engineering/Technology	3.1	6.8	4.2	13.8	9.1	12.0	13.8	5.7
Geology/Geography	3.3	2.6	1.4	3.4	0.0	1.9	0.0	2.9
Mathematics	0.3	0.7	0.0	1.7	0.0	1.9	0.0	2.9
Medicine/Vet Science	5.4	2.9	5.6	1.7	0.0	2.5	0.0	0.0
Other Physical Science	2.6	1.9	8.3	1.7	0.0	3.8	0.0	5.7
Other	3.1	2.9	1.4	1.7	0.0	0.6	0.0	0.0
Unknown	17.2	4.8	6.0	10.3	0.0	0.0	3.4	2.9

Source: Smithers, A. and Robinson, P. (2005). *Physics in Schools and Colleges: Teacher Deployment and Student Outcomes*. Buckingham: Carmichael Press.

Table 5.6: Highest Qualification in Physics of Physics Teachers by Types of Institution

Highest Qualification in Physics	Comprehensive to 16	Comprehensive to 18	Sec Mod	Gram	Independent to 16	Independent to 18	Sixth Form College	FE College
PhD	0.7	2.7	0.0	5.4	0.0	5.7	10.3	17.1
MSc/MPhys	3.3	4.1	2.8	5.4	0.0	5.1	17.2	4.2
Natural Sciences II	0.0	0.6	0.0	1.8	0.0	2.5	0.0	0.0
Single Hons Degree	14.8	28.0	12.5	50.0	9.1	45.6	44.8	48.6
JT/Comb Hons	4.7	4.2	2.8	5.4	9.1	5.7	3.4	5.7
Degree Subsidiary	14.3	10.0	8.3	12.5	27.3	13.3	6.9	20.0
A-level	29.7	28.6	29.2	16.1	54.5	17.7	17.2	0.0
GCSE	32.5	21.8	44.4	3.6	0.0	4.4	0.0	0.0

Source: Smithers, A. and Robinson, P. (2005). *Physics in Schools and Colleges: Teacher Deployment and Student Outcomes*. Buckingham: Carmichael Press.

5.16. There were also differences in the universities attended. Smithers and Tracey (2003) found that teachers in independent schools were more likely to have attended top universities (which is an indication of their A-level grades): 51.0 per cent of those in independent schools had graduated at Oxbridge and other leading universities against only 17.9 per cent in maintained schools, where a quarter (24.1%) had graduated from an ex-CAT, former polytechnic or a HE/FE college.

5.17. These findings are supported by Green *et al* (2010) who, using large-scale survey and administrative data, found that independent school teachers are more likely than state school teachers to possess post-graduate qualifications and be specialists in shortage subjects. For both men and women there was evidence of a substantial pay premium for independent school teachers teaching shortage subjects, about 16 per cent for men and 18 per cent for women. Comparing years 1996-2000 with years 2001-2005, revealed that, while independent schools continue to be more successful in attracting teachers with science and mathematics degrees "the gap seems to be narrowing over time, even before the government's 'golden hello' scheme for new teachers was slanted especially towards shortage-subject teachers in 2000".

Retention

5.18. American research has emphasized the importance of teacher retention (Ingersoll and Perda, 2009). Smithers and Robinson (2003) found that, among established teachers, loss was associated more with region and gender than subject, though in this analysis science was treated as one category. Overall, in 2002, 13.1 per cent of the teachers left their schools, but 5.8 points of this were transfers to other schools, so actual wastage was 7.3 per cent. Difficult schools suffered a disproportionate loss (Smithers and Robinson, 2005).

5.19. Fewer science and mathematics teacher trainees make it to the classroom than trainees in other subjects. Table 5.7 shows that loss in mathematics and sciences, except biology, was above 30 per cent against less than ten percent in classics and less than 20 per cent in English and drama/dance. This corresponds closely with the entry qualifications of Figure 5.4. The figures for mathematics are interesting. It has among the highest drop-outs from training courses consistent with the low entry qualifications, but an above average take-up of successful trainees by schools, reflecting their need for them. Undergraduate courses make almost no contribution to the supply of science teachers. Of the 50 final-year trainees in 2010-11, a fifth failed to complete and only 33 obtained teaching posts. Only one physics teacher and seven chemistry teachers came through this route.

Computing.

5.20. Computing is in a dire state in schools. In the 2013 A-level (Joint Council for Qualifications, 2013a) there were only 3,758 entries (0.4%) for computing, and even together with the 10,419 (1.2%) in ICT they amounted to only 1.6 per cent of the total. This is less than half what it was a decade ago when with both subjects classified as computing it accounted for 3.8 per cent of entries. For comparison, in mathematics, in 2013, there were 88,060 (10.4%) entries, in biology 63,969 (7.5%), in chemistry 51,818 (6.1%) and in physics 35,569 (4.2%). The Government has responded by offering the same generous bursaries available to physics and chemistry teacher trainees to computer science teacher trainees. This, however, has led to a major re-classification and the National College for Teaching and Leadership has been unable to supply us at the present time with figures for either computing or ICT as it willingly done for the other sciences and mathematics. The Royal Society's (2012) own report, *Shut Down or Restart? The Way Forward for Computing in UK Schools,* takes space to distinguish carefully between computing, ICT, computing, information technology and digital literacy.

Table 5.7: Postgraduate Secondary Trainee Outcomes by Subject

Subject[1]	Final Year Trainees	Awarded QTS	%Awarded QTS	In Teaching	% In Teaching
Classics	48	46	95.8	44	91.7
Drama/dance	504	476	94.4	417	82.7
English	2,334	2,154	92.3	1,884	80.7
History	675	632	93.6	535	79.3
Geography	728	674	92.6	572	78.6
Physical education	1,176	1,125	95.7	920	78.2
Social sic/studies	127	119	93.7	98	77.2
Business studies	601	550	91.5	452	75.2
D & T	1,217	1,098	90.2	863	70.9
Mathematics	2,706	2,322	85.8	1,881	69.5
Religious education	848	762	89.9	589	69.5
Art and design	631	549	87.0	437	69.3
Music	668	604	90.4	463	69.3
Vocational subjects	460	409	88.9	315	68.5
Science	3,444	2,888	83.9	2,330	67.7
Biology	*1,126*	*985*	*87.5*	*830*	*73.7*
Physics	*639*	*524*	*82.0*	*434*	*67.9*
Chemistry	*981*	*826*	*84.2*	*644*	*65.6*
Science	*698*	*553*	*79.2*	*422*	*60.5*
Modern languages	1,536	1,340	87.2	1,021	66.5
ICT	939	791	84.2	588	62.6
Citizenship	289	255	88.2	175	60.6
Total	18,949	16,811	88.7	13,601	71.8

1. Economics (7), 'Other' EBITT (4) and Assessment based (7) are not shown separately but are included in the total. (From Smithers and Robinson, 2012)

5.21. Data compiled for the report show that, in 2010, there were 18,400 ICT teachers in England, of whom 65 per cent had no post A-level qualification in the subject. Half of all secondary schools had unqualified teachers teaching ICT and one in five had no qualified ICT teacher at all. In Table 5.7 we showed that nearly 40 per cent (37.4%) of the ICT teachers in training in 2010-11 had not taken up posts in schools in the year following, a drop-out rate only slight less than those for citizenship and general science.

5.22. In Wales the teachers are classified as 'computer science and information technology' teachers and in Scotland as 'computing' teachers. Data from the General Teaching Councils in both countries[22] show that whatever they are called there are rather few of them. In Wales there was an increase of about a quarter between 2009 and 2011. In

[22] The General Teaching Council for Northern Ireland does not register teachers by subject specialism

Scotland General Teaching Council registrations (including provisional registrations) show a small increase (5.1%) from 2008 to 2010, but the Scottish Government's census of main subject taught records a drop of 10.9 per cent between 2007 and 2010. In contrast to the sorry state in the UK, the European Commission (European Commission/Eurydice, 2011) reports that across Europe digital literacy is mainly taught in secondary schools by specialist teachers, and in about half it is also taught by science and mathematics specialist teachers.

5.23. The Royal Society's Inquiry received over 120 submissions in response to its call for evidence, held workshops and commissioned analyses. It found that the current delivery of computer education in UK schools is 'highly unsatisfactory'. Pupils are not inspired by what is taught and they gain little beyond basic digital literacy skills such as how to work a word processor or a database. Teachers unable to teach beyond basic digital literacy were identified as one of the main reasons for this. Another is the inappropriate national curriculum in ICT which is often broadly taught and reduced to the lowest level with non-specialist teachers teaching it.

5.24. A key recommendation is to improve the supply of specialist teachers. Targets should be set. Its recommendation that there should be training bursaries to attract computer science graduates has already been accepted by the Government. The Government was also urged to set a minimum level of CPD provision.

5.25. The problem of insufficient specialist teachers is seen as the driver in a self-perpetuating cycle: ICT lessons delivered by non-subject specialists; ICT reduced to basic digital literacy; it is perceived as low-level skills; few people study computing post-16; inadequate pool from which to draw future specialist teachers. The report wants to see an Action Plan in place to break this cycle so that in future all pupils will be able to study IT and computing.

Technicians

5.26. Good technical support is necessary to sustain practical classes in science, and it is a factor in the recruitment and retention of teachers. Smithers and Robinson, (2008) found that nearly a quarter of the physics graduates training to be teachers were training to be mathematics teachers because, among other things, "there were no practicals in maths". The most recent data from the DfE (2013) show that in 2012 there were 24,500 (FTE) technicians in publicly funded schools in England. Most, 22,000, were in secondary schools. On average there were 9.8 technicians per academy (11,400 in 1,163 academies) compared with five per local authority maintained secondary schools, (10,600 in 2,105 schools). These data of course do not take into account the size of school, the disparity with type of school, or hours of science lessons taught. Nor do they give an accurate picture of the number of specialist science or IT technicians since the data cover all technicians including laboratory assistants, design and technology assistants, home economics and craft technicians. We do know, however, that since 2005 technician numbers have increased by just over ten per cent, peaking in 2010 at 25,400.

5.27. There is little data specific to STEM technicians in schools and colleges. The most comprehensive account was published over a decade ago, in 2002, by The Royal Society and the Association for Science Education. Technicians and heads of science were surveyed and school and college inspection reports scrutinized. It was estimated, albeit without precise current figures, that an extra 4,000 science technicians were required. The report expressed concern that young recruits were not being attracted into the job. The report called for a census of the school and college technician workforce and a strategy to improve the attractiveness and status of the role. It also recommended national guidelines on the management and deployment of staff, and a national career and salary structure including support through induction and CPD.

5.28. The impact of the shortage of technicians on science teaching has been explored in two recent reports. Research for the Gatsby Charitable Foundation (2012) found that a quarter of the science teachers surveyed had reduced the practical work in their courses. The reasons they gave were: changes in the curriculum (76%); assessment priorities (49%); budgets (30%) and lack of technician support (22%). The Science Community Representing Education (SCORE, 2013) conducted online surveys and telephone interviews to investigate the resourcing of practical work in science in primary and secondary schools. It found that inadequate technician support is limiting practical work in secondary schools. Just over a quarter of respondents within state-funded schools reported that they needed at least one additional technician and that good technician support is being lost because of poor working conditions.

5.29. The Gatsby Charitable Foundation has a particular interest in the training and qualification of technicians. It is funding a two-year programme to support practical science in schools and FE colleges in England, which began in 2012. The focus of the programme is better assessment, improved access to teaching resources and a strengthening of the roles of technicians. It has also catalysed the establishment of the Technician Council which has launched a professional technician standard[23]. The Technician Council (2012) published a report drawing attention to an alarming skills gap between current technician numbers in the UK and the 450,000 it estimated to be needed by 2020. The Science Council[24] responded by introducing a professional register for science technicians with an associated Registered Science Technician (RSciTech) award. This is for science technicians in general, not just those in schools. Schools are likely to find themselves in an increasingly competitive market for technicians (CBI, 2013). Funding reductions are likely to make this difficult (Smith, 2012; Voice, 2012).

Pointers for The Royal Society from the Data on England

5.30. The questions posed by the detailed look at England seem to us to be:

- Is STEM a useful category?
- How can teaching the sciences and mathematics be made more attractive?
- Can available teachers be deployed more effectively?
- How can graduate output in the physical sciences and mathematics be increased?
- How can computing be taken forward as a school subject?
- How can sufficient good technicians be recruited to support teachers in mounting practical classes?

[23] http://www.professional-technician.org.uk/technician_council.php/.
[24] http://www.sciencecouncil.org/content/science-council-answers-call-develop-technician-workforce-uk/.

5.31. The National Science Learning Centre (2013) has recently issued what it calls a white paper, *The Future of STEM Education*. Its first recommendation to policy makers is to improve the recruitment and retention of specialist teachers. The specific proposals are to: commit to sustained funding of attractive bursaries; provide placements in schools and colleges for STEM undergraduates to encourage take-up of initial teacher training; and dedicate long term core funding for subject specific CPD.

'STEM'

5.32. STEM is a catchy and convenient acronym, but is it helpful in addressing the issues raised in this report or does it cloud them? There are shortages of STEM teachers, but mainly in physics, mathematics and computing. Biology is well supplied and chemistry fares not too badly. The acute problems surrounding computing in schools risk being lost under the general rubric. In order for the The Royal Society to make a difference, it may have to focus more sharply on the individual subjects, as indeed it did in its report on computing (The Royal Society, 2012).

Attractiveness

5.33. There is clearly a need to attract more physicists, mathematicians and computer scientists to teaching, but how to do it? We saw in the international comparisons there is a link to status, but status cannot simply be assigned. Governments around the world have wracked their brains as to how to make teaching more attractive. They appear to have tried, or are trying, everything they can think of. In order to go beyond pious hopes there have to be practical steps. Paying more to teachers of subjects where recruitment is difficult is a possible approach. Green *et al* (2010) found that there was a pay premium for teachers of shortage subjects in independent schools of about 16 per cent for men and 18 per cent for women. Although the schools still found it more difficult to staff science and mathematics than other subjects, they generally were able to attract more highly qualified subject specialists from the top universities than state schools. We take up differential salaries and other possible ways of making teaching more attractive in the next chapter.

Deployment

5.34. A prospect which has to be faced is that it may not be possible to greatly increase the supply of good physics teachers. Physics and teaching attract people of different temperaments (Smithers and Hill, 1989). There is a larger graduate pool in mathematics and more take it as a subsidiary subject so there is scope for increasing the supply of teachers. Computer science is a very young field which is only just beginning to establish an identity so it is possible that more teachers could be found. Biology is already amply supplied and shortages are less severe in chemistry. But for physics there is likely to be a continuing shortfall.

5.35. Children with potential in physics may never discover they have this if they go to a school without teachers who have expertise in the subject. Their lives may take an entirely different turn and the country will miss out on scarce talent. But it is difficult to envisage that there will be sufficient good physics teachers in the near future. It may be necessary, therefore, for The Royal Society to come at the shortage problem from another direction and consider what changes to the education system would enable the physics teachers we have – and by extension other science teachers - to be deployed more effectively. How can children with the ability and interest be brought together with the expert and enthusiastic teachers there are? There are several possibilities, none uncontroversial, which we will set out in Chapter 6.

Graduate Pools

5.36. The sciences, except biology, are seeking to recruit from small graduate pools. How can their size be increased to boost the chances of finding more good teachers? An idea which springs to mind is to build a better platform for them in schools. There are currently two main weaknesses. The first is that the qualification to teach in a primary school is a general qualification specifying neither the age range nor subject specialism or specialism or specialisms. Is there a case for redesigning the undergraduate education degrees for primary teachers? And what are the pros and cons of stating on the teaching qualification the age range for which a person is trained and the subject specialism(s). If teachers with specialisms in biology, chemistry, physics, mathematics and computing science were identified as such, planning for a better balance between the subjects at Key Stages 3 and 4 would become easier. With better specialist teaching in secondary schools continuing increases in the take-up of the sciences and mathematics at A-level and university could be confidently expected.

Computing

5.37. The Royal Society (2012) has already conducted a major inquiry in this field and several of its recommendations are echoed here as also applicable to the sciences and mathematics. The first is to disaggregate the term ICT into clearly defined areas such as digital literacy, information technology and computer science; we argue that STEM should be similarly disaggregated into its component subjects which clearly differ from each other in many ways. The second is: "The government should set targets for the number of Computer Science and Information Technology specialist teachers, and monitor recruitment against these targets". This is already happening in the other sciences and mathematics, but the planning model may need to be improved. The report urges the Government to set a minimum level of provision for subject-specific CPD for computing teachers, again something that could usefully be implemented across the sciences and mathematics.

Technicians

5.38. Good technician support is vital for practical classes and sufficient provision is likely to improve both the recruitment and retention of science teachers. But present data and information leave a lot to be desired. Recent reports from the Audit Commission (2011), Training and Development Agency for Schools (2009) and the Department for Children, Schools and Families (2009b) on support staff in schools do not treat technicians as a separate group. The Royal Society in association with the Association for Science Education (2002) did conduct an inquiry into science technician in schools and colleges, but it is long in the tooth. In taking its Vision forward The Royal Society should undertake or commission a new study, which would take account of, among other things, the impact so far of the new Registered Science Technician qualification.

Conclusion

5.39. Detailed examination of the data relating to the provision of science and mathematics teachers in England has brought to light a number of issues for The Royal Society to consider. They resonate with the implications of the international comparisons of Chapter 3 and of the findings from Scotland, Wales and Northern Ireland in Chapter 4.

6. Discussion, Conclusions and Recommendations

6.1 At the end of each of the three substantive chapters[25] on science and mathematics teacher provision across the world, in the UK and in England, we drew out what seemed to us to be important for The Royal Society to consider in formulating its Vision for 2030. In this chapter we bring those three strands together to make ten recommendations which we believe, if implemented, would make a difference to recruiting and retaining good teachers in the sciences and mathematics.

6.2 Countries with strong science and mathematics teacher workforces, such as Finland, Japan, Singapore, and South Korea, share a number of characteristics:

- teaching is a high status profession;
- there are sufficient science and mathematics graduates;
- they have good planning and monitoring models;
- they are able to carefully select of trainees;
- they have effective teacher preparation programmes;
- the qualifications are respected;
- there is systematic professional development throughout the career in education;
- the working conditions are good.

6.3 The success of these countries in getting the teachers they need is bound up with their histories and cultures. The specific things they do may not be transposable. But it is important to ask whether there are ways of achieving these ends in the British context. Much has already been attempted by successive governments. The present one is attempting to tackle shortages by raising the status of teaching through making it more difficult to enter, offering generous bursaries to graduates with top degrees, and increasing the range of routes into teaching including the prestigious Teach First. It is not possible to know at this stage how they will work out in the long run, but we will take them as a given and propose steps beyond them.

Attractive High Status Profession

6.4 Raising the status of teaching as a profession would greatly increase its appeal. But occupational status cannot be assigned, it has to be earned. Teaching seems to be regarded as not quite a profession. There may be something that can be learned from the undoubted professions, such as medicine, about status. Each of the branches of medicine is underpinned by a Royal College which safeguards its standards (Shepherd, 2013). The Colleges have a role in training, examinations and qualifications, and take on a range of functions including policy development, research, international influence, and bestowing recognition. But they have absolutely nothing to do with the terms and conditions of employment, which are the province of the British Medical Association.

6.5 There is already a groundswell of interest in a Royal College of Teaching (Leslie, 2013), which envisages one College for the whole profession. We suggest that, as in medicine, there should be a number. It is for the profession itself to establish a College

[25] These should be read in conjunction with this chapter.

or Colleges; it is not something for the Government. But for it to come from the grass roots, teachers would need strong support. The danger is that the teacher unions - whose Easter conferences are probably one reason why the public does not accord teaching the status of other professions – will try to take over and scupper it in the way they did with the General Teaching Council in England. The Royal Society could convene a powerful body of subject associations, including the Royal Society of Chemistry, Institute of Physics, the Institute of Biology, the Chartered Institute for IT and the mathematics associations that would help interested science and mathematics teachers to make the Royal College of Science and Mathematics Teaching a reality. The College could be of England or the UK. Not least, the involvement of The Royal Society could help to secure the royal imprimatur.

We recommend that The Royal Society puts its weight behind helping the profession to establish the Royal College of Science and Mathematics Teaching.

6.6 A Royal College would greatly help the cause of science and mathematics education and enhance the status of the teachers, but it would have advantages for The Royal Society itself. It would give The Royal Society a strong voice in the training and professional development of teachers. In helping to set the conditions for membership and the award of a fellowship the College would, in effect, be creating new qualifications, which in time could replace the inconsequential PGCE and Qualified Teacher Status. The fellowship would specify required professional development providing the incentive for the systematic engagement which is often lacking. A family of Royal Colleges of Teaching would pose less of a threat to the unions who are always quick to protect their power[26].

Increasing the Output of Science and Mathematics Graduates

6.7 One of the reasons for the shortage of science and mathematics teachers in the UK, particularly in England, is that graduate output in those subjects is too low. How might it be increased? Finland and South Korea, where graduate output is sufficient, build from the bottom having subject specialisms in the training qualification for primary school teachers. In England, the teaching certificate is a general qualification specifying neither age range nor subject. An attempt has been made to increase the expertise of primary school teachers through the Mathematics Specialist Teacher Programme (Walker *et al*, 2013), but this is a bolt-on rather than intrinsic to the initial qualification. It our view there is a strong case for training more teachers with science and mathematics specialisms for primary schools in the UK. We address both the undergraduate and postgraduate routes.

We recommend that The Royal Society should advocate the re-design of undergraduate degrees for primary teachers to include specialisms, preferably taught by university subject departments.

We recommend that The Royal Society should press for targets to be set for science and mathematics specialisms for recruitment to PGCE courses for primary teachers.

[26] The General Teaching Council (England) was neutered by the unions who took it over and prevented it becoming a threat to them.

6.8 The Royal Society could go a step further and propose that teaching qualifications should become more specific listing the age range and subjects for which the teacher has been trained. This would have a number of advantages. Being able to identify whether a science teacher was a specialist in biology, chemistry or physics would make the imbalances at Key Stages 3 and 4 more obvious and be a step towards correcting them. The dominance of biology at those stages weakens the paths through to the physical sciences at A-level and university. There has been some increase in the take-up of the physical sciences recently, but by nowhere near enough.

6.9 It could also be more satisfying for the teachers. Being able to use special abilities is an important attraction of teaching, but in countries with general teaching qualifications, like Australia and the UK, teachers can be asked to take on a lot of 'out-of-field' teaching, which in theory they are qualified to do. But specifying age range and subject in the teaching qualification is no panacea. The Netherlands, which does do this, has suffered persistent shortages. The case against specificity is that it reduces flexibility. Nevertheless, we think it is something The Royal Society should consider.

We recommend that The Royal Society advocates that the age range and subjects for which a teacher is qualified to teach should be listed on the teaching qualification.

Planning and Monitoring Teacher Provision

6.10 Countries that have strong teacher workforces have good planning and monitoring systems able to forecast the numbers of trainees required and allocate places accordingly. England does set targets, but there are reasons for doubting their efficacy. As Figure 5.1 shows, the targets for science teacher trainees seem to be driven more by the likelihood of filling places than careful assessment of requirements. A paper on the method of arriving at the targets was published 15 years ago (DfEE, 1998). But there is no regular consultation on targets and some of the data are questionable. Following the Donaldson Review (2011), Scotland has overhauled its planning and monitoring of teacher recruitment introducing consultation across the sector. It was singled out for praise in the latest *Key Data on Teachers and School Leaders in Europe 2013* (European Commission /EACEA/Eurydice, 2013).

We recommend that The Royal Society discusses with the Department for Education the Government's planning model for science and mathematics teacher provision in England with a view to making it more effective.

6.11 Through the Teacher Training Profiles of what is now the National College for Teaching and School Leadership – a government executive agency and quite different from the Royal College we have proposed – England does have excellent monitoring of its teacher training (Smithers and Robinson, 2012), but the targets are given to it by the Department for Education.

6.12 It also seems to us that the real problem is not to do with targets, but actually meeting them.

Using the Teachers to the Best Advantage

6.13 An issue which The Royal Society has to face is that it may never be possible to recruit enough good teachers in the sciences and mathematics. While teacher supply in general goes up and down in the opposite direction to the economy, entries to physics and mathematics teacher training always run below the general trend. This is the experience of other countries also.

6.14 There may be a fundamental reason for this[27]. There is a big difference in the attractions of teaching and subjects like physics and mathematics. Relatively few of the people drawn to the impersonal patterns of these subjects will want a career which involves continual interaction with large groups of children. This would explain why the great variety of imaginative measures being employed in Australia, the Netherlands and, indeed, England aimed at boosting recruitment appear to be having only modest impact. It is interesting that it does not seem to be a problem in East Asia. It could be that the culture of obedience in those countries means that teaching is more about delivering the subject than controlling the children.

6.15 If the personal disposition argument is correct, there is a very important implication. Alongside measures to attract teachers serious consideration must be given as to how best to deploy the good teachers there are. It may be necessary to match the pupils with the ability and interest in physics with the teachers who have the most expertise. There are a number of ways this could be done, of which we think three are promising.

- ***Specialist Schools***: Establish genuinely specialist schools such as there are in Singapore, South Korea and the United States. (The present science schools are a residue of the Blair Government's specialist schools policy and are specialist in name only). There is already provision for some mathematics specialist schools, but only from the age of 16 which seems rather late to us. Age 14 after completing the national curriculum would seem to us to be a more logical age to begin specialising.

- ***Excellence Hubs***: Instead of spreading scarce teachers thinly across schools where they could be the only teacher in their subject, bring them together in teams to serve school partnerships. The Cabot Learning Foundation, in Bristol, is a good example of what can be achieved. It is an academy chain. But many forms of school partnership are emerging – federations, teaching school networks, and within local authorities – all of which, in principle, could have specialist teams in shortage subjects.

- ***Pathways from Post 14***: The Vision Project has twin aims: to educate citizens to be scientifically and technologically engaged and informed; and to educate the scientists and technologists of the future. These may best be served by educating on a common curriculum to the age of 14 followed by an array of science options. Alongside biology, chemistry and physics, a new course, plus an associated GCSE, could be developed in the public understanding of science. This would meet the first aim, and the sciences, themselves, the second. A wider range of talents would be needed to teach the public understanding course and be likely to tap into new sources of graduates. The scarce science graduates would then be available to teach those who had chosen to study the sciences *per se*.

[27] See paragraphs 5.12 and 5.13

We recommend that The Royal Society considers how to deploy to best advantage the science and mathematics teacher workforce that can be recruited, and examines options such as excellence hubs, specialist schools and alternative pathways post 14.

Salaries

6.16 When students are asked about what is important to them in future careers those that become teachers do not often say the salary. They are much more likely to respond 'use of special abilities' and 'opportunity to help others'. Nor does salary appear to be an important factor in teachers leaving the profession in England (Smithers and Robinson, 2001 and 2003). 'Workload' and 'pupil behaviour' are more likely to be given as the reasons. But salary does seem to be a major attraction in Japan and South Korea[28]. It is also involved in the premature loss of teachers in the United States (West, 2013).

6.17 Schools in looking for physicists and mathematicians are competing not just against other schools, but major financial institutions and blue-chip companies. Independent schools, which are generally strong in these subjects, pay what it takes to get good teachers, offering a premium, on average, of about 17 per cent (Green *et al*, 2010). An academy chain has recently been reported (Garner, 2013) as intending to pay all its teachers above national scales, particularly starting salaries, in a bid to attract the best.

6.18 There is a case, therefore, for considering whether salaries could usefully be used as an incentive to attract physics and mathematics graduates into teaching. Headteachers have allowances within their budgets as part of the existing salary structure, but have been slow to use them (Griggs *et al*, 2011). They do, however, recruit new teachers in shortage subjects at several rungs up the pay scale, which has the perverse effect that these teachers are more quickly promoted out of the classroom.

We recommend that The Royal Society considers whether higher salaries could play a part in attracting and retaining more teachers in shortage subjects, and whether headteachers and governors should have more freedom to decide teacher salaries.

6.19 One way of moving to differential salaries without abandoning national pay scales (which would be over the unions' dead bodies) would be for the national machinery to set minimum levels. Over and above these, a substantial amount could be put into schools' budgets for salary awards at the discretion of the headteacher and governors.

Professional Development

6.20 The House of Commons Education Committee (2012) contrasted the arrangements for professional development in England with those in Singapore. In that country teachers are entitled to l00 hours per year for professional development as well as a small personal budget of around £300 for materials such as journal subscriptions and personal computers. The Committee's view of provision in England was that "CPD[29] for teachers has lacked coherence and focus ….we are seriously concerned that England lags seriously behind its international competitors in this regard, and

[28] The salaries are afforded by having large classes – which are possible because there is a culture of obedience.

[29] Continuing Professional Development

recommend that the Government consult on the quality, range, scope and content of a high-level strategy for CPD". Among the ideas that the Committee, and its predecessor committee (House of Commons Children, Schools and Families Committee, 2010), came up with for improving teachers' professional development were: more space in a teacher's timetable for CPD, as in Finland; building specified professional development into chartered teacher status or a master's degree; and requiring teachers to hold a licence to practice that has to be renewed on a regular basis. Registrations in Australia have to be renewed periodically, usually every five years, and certification with the National Board for Professional Teaching Standards in the United States is good for ten years, after which a teacher must re-apply (OECD, 2013a).

6.21 The previous government (DCSF, 2009a) was planning to introduce teacher licences linked to professional development which had to be renewed periodically (its White Paper suggested every five years), but it fell before the policy could be implemented. This approach was rejected by the incoming Coalition Government. In its response to the present Select Committee (House of Commons Education Committee, 2012) it was clear that it wanted decisions about CPD to be taken locally and it did not believe that a nationally imposed hours-based entitlement would be consistent with local autonomy.

6.22 Incentives can be carrots or sticks. Renewable licences are a stick which runs the risk of compliance at the expense of development. But a more systematic approach to professional development would serve both to improve teacher quality and help to increase the retention of good teachers. It would be a matter of finding the right incentives. If The Royal Society wanted, and was able, to help the profession establish the Royal College of Science and Mathematics Teaching we have recommended, then taking specified courses in the subject and pedagogy could be among the requirements for the award of a fellowship.

We recommend that The Royal Society considers what it could do to promote the systematic professional development of science and mathematics teachers, and in particular explores the role that a Fellowship of a Royal College of Science and Mathematics Teaching might play.

School Science Technicians

6.23 Good science technicians have a crucial role in enabling teachers to mount demonstrations and practical classes. We know from the Gatsby Charitable Foundation (2012) and SCORE[30] (2013) that science teachers have been reducing the amount of practical work because they have not had the necessary technical support. The Gatsby Foundation has a particular interest in technicians and has been promoting the role and catalysing the development of training programmes and qualifications. But these embrace technicians in general. Science technicians tend to be put together with other support staff in school statistics (Department for Education, 2013a; Audit Commission, 2011; Training and Development Agency for Schools, 2009, Department for Education, 2009b).

6.24 As important as technicians are we have very little current precise information about them. The Royal Society did conduct a survey with the Association for Science Education, published in 2002, which estimated – it has to be said without any firm

[30] School Community Representing Education

basis - that an extra 4,000 school science technicians were required, and lamented that young people were not attracted to the role. It called for a census of current numbers, a strategy to increase the attractiveness and status, national guidelines on the management and deployment of staff, a national career and salary structure, and support for technicians through induction and professional development. Very little has happened. It is time for the Royal Society to re-visit the issue, perhaps in collaboration with the Gatsby Charitable Foundation.

We recommend that The Royal Society re-visits the provision of science technicians in schools and colleges in order to unravel the current situation and clarify what needs to be done to ensure the necessary support for teachers.

6.25 Better technician provision would help both recruitment and retention of science teachers who might otherwise be lost to subjects without practicals.

A Procedural Point: 'STEM'

6.26 'STEM' is a neat acronym, but it glosses important differences. There is no shortage of well-qualified biology teachers. Indeed, they tend to dominate science teaching in England up to the age of 16. All the countries of the UK similarly have a majority of biologists in their science teacher workforces. Physics, and to a lesser extent chemistry, have teacher shortages and that is where the focus should be.

6.27 There are teacher shortages in mathematics also, but these are different from those in physics. Mathematics, along with English, is the backbone of the curriculum and requires many more teachers. But there are enough teachers who have studied mathematics to some level at university to have someone in front of every class. The key question is: are they good enough?

6.28 'STEM' is also too broad a category. Computing was included in our brief. As The Royal Society (2012) has demonstrated, it has major problems in its own right. Engineering, manufacturing and construction are included in international STEM comparisons. What about design & technology? Is this properly in or out?

We recommend that The Royal Society moves beyond the acronym 'STEM' in its Vision Project and focuses on each subject since the issues that arise are often very different.

Conclusion

6.29 Our ten recommendations to The Royal Society emerge from our reviews of science and mathematics teacher provision around the world, in the UK and in England. None is a silver bullet. But they do present ideas which we believe will help The Royal Society towards its Vision for 2030.

7. Looking to the Future

7.1 We are asked to look forward to 2030[31]. Two decades is not a long time in education. Teachers who will be qualifying twenty years from now have already been born. Indeed, even the youngest will be beginning infants' school. If part of the solution is better foundations for science education in junior schools, there is not a moment to lose. The first bursaries to boost recruitment to physics and mathematics teacher training were awarded in 1986 (chemistry joined them in 1989). Since then successive governments have tried all they could think of to secure better teacher provision. As well as incentives to train, salaries have been increased, workload has been reduced, and there new ways of qualifying. The current government has introduced a raft of new measures which are working their way through the system.

7.2 The hope is often expressed that science and mathematics teaching in the coming decades will be transformed by technology. Better use of what exists and new devices skilfully applied, it is argued, could dramatically reduce the requirement for teachers. But we are not convinced, partly because of what we would call the 'weight-watchers effect'. In principle, it is perfectly possible to lose weight on your own by eating less and exercising more, but many people are willing to pay fees to join Weight Watchers for the support social interaction provides. Similarly, with learning, it is perfectly possible to learn on one's own, but for many it is much easier and more effective to share the experience with other people. That is why schools are the universal means of providing education for the young. It is no accident that teaching and learning, in essence, have not changed that much since Roman times, although the technology is very different.

7.3 The Open University in providing degrees by distance learning was careful to provide regular tuition and summer schools, in which the students came together with each other and with experts in their subjects. They were, in any case, mature not children. The massive online open courses (MOOC) being pioneered in the United States are not entirely successful. Research from the Massachusetts Institute of Technology and Harvard (Breslow *et al*) has shown that personal contact matters. Online students who worked on course material offline with fellow students or teachers did better than those who did not.

7.4 There is no doubt that there will be exciting developments in technology in the future which can be harnessed to improve science and mathematics education. But it is by no means certain that they will reduce the requirement for teachers. They have not done so in 2,000 years.

7.5 The key to improving the quality of science and mathematics teaching in schools is to persuade more to want to become teachers, so that those recruited can be carefully selected, both for their understanding of their subjects and the ability to put it across. This is easy to see, but hard to achieve.

7.6 Not all countries have difficulty in recruiting sufficient good science and mathematics teachers. What distinguishes countries like Finland, Japan, Singapore and South Korea from the UK, particularly England, is that their teachers are highly respected. This has

[31] Our commentary builds on the evidence and recommendations. We will not re-run the detail, nor exhaustively re-reference. We have avoided the use of 'STEM', since in our view it conflates and confuses.

come about for many reasons, tradition and culture among them, but in particular education is recognised to be crucial for the economic well-being of those countries. Most are young nations without much in the way of natural resources which can see that their economic survival depends above all else on developing the talents of the young. The high status accorded to those doing the teaching attracts the top graduates and the competition to get in reinforces the status. In contrast, George Bernard Shaw struck a chord in England when in one of his plays he had a character say ‘those who can, do; those who can’t, teach’[32]. As insulting as this is, it does embody a truth. Advanced industrialised nations like, the UK, the United States, and Germany, do not necessarily want their best brains to go into teaching; they want them to be at the cutting edge of research, innovation, creativity and wealth generation.

7.7 But that said it is damaging that teaching in the UK is seen as not quite a profession in the mould of medicine, law and accountancy. This is not helped by the public posture of the teacher unions. Behind the scenes they do excellent work for their members on the terms and conditions of employment. But what is on view is trades unions battling with employers and each other, opposing almost everything, and forever threatening strikes and go-slows. The Easter conferences where activists are in full voice create a particularly bad impression.

7.8 To help counteract this and raise the status of teachers we have recommended The Royal Society takes the lead in helping the profession to set up a powerful body to represent the professional interests of science and mathematics teachers. We have suggested The Royal College of Science and Mathematics Teaching on the model of the royal colleges in medicine. It would take a leading role in training, examinations and qualifications, and have a range of functions, including policy development, research, international influence, and bestowing recognition. But it would have nothing to do with terms and conditions of employment which would remain the province of the teacher unions. It is important that such a body should be developed at a distance from the unions. Their involvement in the General Teaching Council for England, essentially to protect their power, served to sink it. A royal college along the lines suggested could be the engine for making The Royal Society’s Vision a reality.

7.9 Increasing the respect for teachers would not necessarily bring in more recruits, though it would make for happier working lives. Status does not loom large in either what potential teachers say is important to them in choosing a career or among the chief reasons for leaving prematurely. The main reasons for quitting in 2002 were workload, continual policy change and, from secondary schools, poor pupil behaviour. Governments since then have attempted to tackle these issues. They have brought in a wide range of reforms including financial incentives, an improved salary structure, a diversity of routes into teaching to allow those with experience of other careers to re-train as teachers, and encouraged enrichment and other schemes to attract more graduates into teaching in the sciences and mathematics. The Blair Government reached a workload agreement with all of the teacher unions bar the NUT in 2003.

7.10 The present government has emphasized the importance of teaching. Its first White Paper (DfE, 2010) was called just that. It has added to the diversity of routes into teaching, introduced a generous bursary scheme for top graduates, and clarified the powers of teachers and schools in relation to pupil behaviour. It is too soon to know

[32] Jane in *Man and Superman* (1903).

what the outcomes will be. The Graduate Teacher Programme has been reconstituted as School Direct (salaried). A similar school-based pathway has been created for recent graduates. The Graduate Teacher Programme did boost science and mathematics teacher recruitment (Smithers and Robinson, 2012), but currently there are fears that the transition to School Direct is not going smoothly (Garner, R., 2013). The early evidence shows that recruitment has fallen in 2013, and this has been attributed to School Direct, but it could also be associated with other changes. Generous bursaries and scholarships[33] of £20,000 have been brought in for graduates with first-class honours degrees in shortage subjects to train as teachers, but these taper to nothing for those with less than a 2.2 (DfE, 2013b). The bursaries could be off-putting to those with moderate degrees, rather than bringing in many more with top degrees.

7.11 But this is where The Royal Society will have to start from in pursuing its ambition for a future world-class, high performing science and mathematics education system. As well as deciding what steps it wishes to take towards getting more good teachers into schools, on which we have made recommendations, it will also have to consider the impact on teacher retention of current accountability arrangements for schools. Many teachers are dissatisfied with having to drive up examination grades at all costs. This would be fine if it reflected a better grasp of the essentials, but it seems clear from the pattern of entries and results that it is more about test taking than improved understanding (JCQ, 2013b). A parallel review will be advising on accountability.

7.12 The chances of recruiting good teachers in the physical sciences and mathematics would be increased if there were more graduates in these subjects. Physics, in particular, seems to be in the grip of a negative feedback loop: the graduate pool is small; there are not enough good teachers; pupils in secondary school encounter inspirational teachers more often in other subjects; pupils are drawn to these subjects; not enough come through to expand the graduate pool. To break into this cycle there needs to be radical action. We have recommended two measures to The Royal Society. First, undergraduate teaching training for the primary phase should be re-designed to incorporate specialisms, which would include the sciences and mathematics, to be taught by the subject departments of the universities, as is the case in Finland. Secondly, the teaching certificate should include the age range and subjects for which the holder is qualified to teach. If the Royal College, as envisaged, did come into existence, it would be able to set out requirements for membership and fellowship, which could incorporate the specification of specialisms. The fellowship could also be used to catalyse the systematic professional development of teachers.

7.13 Adopting these measures would break into the negative feedback loops in several ways. More expertise in the primary school would be a better foundation for secondary education, identifying specialisms would make for a better balance in science teaching in secondary schools, and better training and professional development prompted by a Royal College would make for better teachers. The numbers studying the subjects at university could be expected to rise, so there would be a bigger pool from which the teachers could be drawn.

7.14 The prospect has to be faced that it may never be possible to get enough good teachers in some of the sciences and mathematics. The pleasures of impersonal subjects, like physics and mathematics, are so different from continually being with children in the

33 The government has funded subject associations, like the Institute of Physics, to award competitive scholarships of £20,000 to teacher trainees with a first or upper second in physics, chemistry, mathematics and computer science.

classroom that relatively few of the graduates in these subjects are attracted to teaching. Studying these subjects to degree level is also beyond the compass of many people. The frontiers are now so far beyond the comprehension of the majority of the population, it not surprising that, once a popular pastime, it is now remote from everyday life.

7.15 Good teaching thus becomes as much a matter of deployment as recruitment. By deployment we mean bringing together the pupils with the ability and interest to study a subject in depth with teachers having the necessary expertise and enthusiasm. In Chapter 6 (paragraph 6.15) we discuss three possible ways of doing this: forming teams of subject specialists to serve school partnerships; genuinely specialist schools; and a new course in the public understanding of science at Key Stage 4 as an alternative to the sciences themselves.

7.16 Of these, the first is most in tune with the school system as it is emerging. A variety of formal school partnerships are coming into being including academy chains, federations and teaching school networks. All are in a good position to create teams of, say physics teachers, who could teach across the partnership rather than in just one school. There are already some excellent examples, including the Cabot Learning Federation in Bristol. Physics teachers at the present time can find themselves as the only one in the school and the whole weight of physics falls on their shoulders. If they are newly qualified, there will no experienced teachers in their subject from whom to learn and little opportunity to experiment to find their own teaching style. Being dropped in the deep end is why some of these scarce teachers leave in the early stages of what could have been their career. Putting together subject teams not only provides mutual support and a chance to improve, but also ensures there are specialists available to a consortium of schools, some of which may have not been able to recruit a single teacher in the subject.

7.17 The other options could fall foul of a reluctance to differentiate between pupils in education at the present time. A number of countries, including Singapore, South Korea and the United States, have very successful specialist science schools. In some countries, like the Netherlands and Australia, there are specialist science schools associated with universities. The experience with science schools in England, which were in name only, will have dented the prospect. But a bigger barrier is that they would involve some form of selection which is an anathema to the current educational establishment. Nevertheless, the Government has provided funding for specialist mathematics schools post-16 (which seems to us to be too late in the day) and is supporting Kenneth Baker's technology schools from the age of 14.

7.18 The idea of an array of science pathways post-14 is likely to run into similar opposition. But to introduce a public understanding of science course at 14 would not only meet The Royal Society's aim of educating engaged and informed, but would release subject specialist teachers to be deployed on teaching the sciences *per se*. Mathematics and computing pose different problems, but again deployment is an issue to be addressed.

7.19 The Royal Society (2012) has already conducted a major inquiry into computing in schools which makes a number of important recommendations that we assume are being taken forward. It is not going to be easy to secure sufficient high quality teachers any time soon. The confusion about what the school subject actually is has not helped. But there is very strong competition from industry for the best people, and too few are coming through A-level and university to meet demand. Independent schools pay some of the highest premiums to attract computing teachers. Computer science is a young subject compared with the other sciences and mathematics, and wrapping up its problems with theirs in STEM takes the eye off the ball.

7.20 Good technicians are essential to the pursuit of many aspects of science in research, industry and schools, yet they are grossly undervalued. The teaching of science in schools through practical work has been constrained by the lack of technical support. The Gatsby Charitable Foundation is taking a keen interest in the recruitment of technicians, their training and qualifications, and has helped to establish a Technician Council. This covers all technicians, not just those in schools. In school statistics, science technicians tend to be grouped with other support staff. The Royal Society published a study of school science technicians with the Association for Science Education in 2002, and it should consider conducting a new inquiry to unravel the current situation. More and better science technicians in schools would not only improve science education, but also make it easier to recruit and retain science teachers who are not infrequently put off by, or lost through, the burdens of unsupported practical work.

7.21 In this report we have distilled from the evidence what we think would be the most promising approaches to securing the Vision Project's aims. Chief among them is for The Royal Society to put its weight behind helping the profession establish a Royal College of Science and Mathematics Teaching. We suggest that graduate output in the sciences and mathematics could be increased by clearer pathways through school, training specialist teachers for primary schools, certificating teachers for science and mathematics specialisms, and more systematic professional development of teachers. There are likely to be continuing shortages of teachers in some subjects and we recommend The Royal Society should consider how best to deploy those that there are, including options such as: subject teams serving school partnerships; specialist schools; and alternative pathways from the age of 14, including 'public understanding of science'.

7.22 We further recommend that The Royal Society should seek to engage the Department for Education in discussions about the planning model for science and mathematics teachers with a view to improving it through consultation; consider whether to advocate greater freedom for schools to pay higher salaries in shortage subjects; and work with the Gatsby Foundation to provide a clearer picture of where we are with school science technicians. We have assumed that The Royal Society is progressing the recommendations of its 2012 computing inquiry, which provide a basis for improving teaching provision in this subject. In its deliberations, we suggest that The Royal Society focuses on the subjects rather than STEM, since the situation for each is different.

7.23 Taking the education system forward so that it is inspirational and better at delivering "both more scientifically and technologically informed citizens and appropriate numbers of qualified people who wish to take up science and technology-based careers"[34] is a major undertaking. We offer these thoughts for the future as steps along the way.

[34] Sir Martin Taylor FRS, Chair of the Vision Committee, http://royalsociety.org/education/policy/vision/

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Appendix A: Teacher Shortages in PISA and TIMSS

A.1 Calculation of country averages produced figures somewhat different from OECD average, but we nevertheless stuck to the OECD's figure. Confidence limits were calculated and applied to published OECD and International averages. In the case of PISA the 95% confidence interval ranges from 24.0% to 11.6% and TIMSS from 23.8% to 14.4%.

Table A.1: Science and Mathematics Teacher Shortages in OECD

Country	Science Teachers	Mathematics Teachers	Average
Turkey	76.5	79.4	78.0
Luxembourg	57.5	77.9	67.7
Germany	41.6	28.3	34.9
Netherlands	30.9	30.7	30.8
Chile	29.9	31.5	30.7
Belgium	26.1	34.2	30.1
Australia	24.3	30.0	27.2
Mexico	27.0	26.3	26.6
United Kingdom	14.6	26.3	20.4
Israel	18.7	21.0	19.9
New Zealand	14.0	22.0	18.0
OECD Average	**17.7**	**17.9**	**17.8**
Norway	17.7	17.8	17.8
Switzerland	20.6	13.0	16.8
Iceland	20.8	7.6	14.2
Italy	11.9	15.9	13.9
Canada	11.3	11.5	11.4
Czech Republic	13.5	8.9	11.2
United States	9.8	11.4	10.6
Estonia	12.0	7.4	9.7
Ireland	8.7	9.5	9.1
Austria	10.8	5.8	8.3
South Korea	9.1	7.2	8.2
Denmark	12.8	1.9	7.4
Greece	8.3	3.8	6.0
Sweden	8.5	2.8	5.7
Hungary	5.2	5.2	5.2
Japan	4.2	4.0	4.1
Slovak Republic	5.3	2.4	3.8
Finland	3.6	2.5	3.1
Poland	3.4	0.6	2.0
Portugal	1.3	1.8	1.6
Slovenia	1.7	0.6	1.2
Spain	1.2	1.0	1.1

1. France did not provide these data.

Source: OECD PISA (2009) Database.

Table A.2: Science and Mathematics Teacher Shortages in PISA Partners

Country	Science Teachers	Mathematics Teachers	Average
Thailand	44.6	46.5	45.5
Kyrgyzstan	47.7	43.4	45.5
Jordan	46.1	41.0	43.6
Kazakhstan	41.5	43.1	42.3
Miranda-Venezuela	41.8	42.1	41.9
Trinidad and Tobago	27.0	42.3	34.6
Shanghai	33.8	32.2	33.0
Macao	23.7	30.0	26.8
Liechtenstein	26.3	26.3	26.3
Uruguay	21.2	29.0	25.1
Russian Federation	24.2	22.5	23.3
Peru	25.7	18.6	22.2
Colombia	20.0	21.6	20.8
Brazil	21.1	19.1	20.1
Indonesia	21.8	17.8	19.8
Croatia	16.9	20.8	18.8
Taiwan	20.4	15.7	18.1
OECD Average	17.7	17.9	17.8
Costa Rica	18.2	17.4	17.8
Albania	17.3	13.9	15.6
Azerbaijan	20.0	9.2	14.6
Qatar	14.8	12.9	13.9
United Arab Emirates	14.2	12.3	13.3
Moldova	11.8	14.7	13.2
Panama	15.3	9.0	12.1
Tamil Nadu-India	10.5	13.4	12.0
Malaysia	12.0	9.5	10.7
Argentina	13.2	7.8	10.5
Montenegro	3.4	14.9	9.1
Serbia	4.7	9.1	6.9
Himachal Pradesh-India	7.0	6.6	6.8
Singapore	8.2	4.9	6.6
Malta	9.2	2.0	5.6
Mauritius	4.2	6.4	5.3
Georgia	6.4	3.6	5.0
Latvia	5.8	3.1	4.4
Lithuania	4.7	3.4	4.0
Hong Kong-China	1.9	4.9	3.4
Tunisia	2.1	1.5	1.8
Bulgaria	0.7	1.2	1.0
Romania	0.7	0.7	0.7

Source: OECD PISA (2009) Database.

Table A.3: Difficulty of Filling Vacancies (TIMSS, 2011)

Country	Science	Mathematics	Average
Thailand	51	58	54.5
Australia	39	41	40
Israel	41	29	35
England	31	37	34
New Zealand	22	44	33
Qatar	37	28	32.5
Bahrain	31	33	32
Ghana	33	30	31.5
Indonesia	33	26	29.5
Syrian Arab Rep	30	29	29.5
Jordan	24	30	27
Oman	25	26	25.5
Norway	27	22	24.5
Sweden	26	23	24.5
United Arab Emirates	23	26	24.5
Iran	22	24	23
Lebanon	26	19	22.5
Morocco	21	23	22
Chile	20	20	20
Turkey	18	22	20
International Average	**19**	**19**	**19**
Saudi Arabia	15	20	17.5
Chinese Taipei	22	11	16.5
Canada	14	14	14
Korea	11	17	14
Kazakhstan	11	16	13.5
United States	14	12	13
Japan	14	11	12.5
Malaysia	10	10	10
Macedonia	10	8	9
Russian Federation	10	8	9
Finland	6	11	8.5
Georgia	10	6	8
Italy	8	8	8
Tunisia	6	9	7.5
Hong Kong-China	6	8	7
Palestinian Authority	5	8	6.5
Ukraine	8	3	5.5
Slovenia	3	6	4.5
Romania	2	4	3
Singapore	4	2	3
Lithuania	3	1	2
Armenia	2	1	1.5

1. Eighth grade – mainly 14 year-olds.

2. Hungary did not provide information for science.

3. Canada is average of Alberta, Ontario and Quebec.

Source: TIMSS published reports on science and mathematics.