Success in science

The report evaluates the strengths and weaknesses of science in primary and secondary schools between 2004 and 2007. Standards in science have not improved substantially in the last three years. This report identifies the reasons for this and provides examples of schools where young scientists excel. It also discusses issues at the heart of science teaching today.

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Executive summary

This report draws on the results of visits by inspectors to 90 primary and 105 secondary schools between 2004 and 2007. It also draws on the outcomes of subject conferences organised by Ofsted and work which Her Majesty's Inspectors (HMI) have done with educational organisations nationally.

Over the last three years, standards in science as measured by statutory tests and teacher assessments have not changed substantially at Key Stages 1 and 2. Nine out of ten pupils at the end of Key Stage 1 attain Level 2 or above and one in four achieve at least Level 3. At the end of Key Stage 2 almost nine out of ten pupils attain Level 4 or above and almost one half attain at least Level 5. Ofsted inspections of science show that standards and achievement in primary schools are good or better in around three quarters of the schools visited. These good standards are a consequence of good teaching and good curricular provision. However, where teaching is weak teachers often lack knowledge and understanding of science and are not confident about teaching it. This, together with the lack of continuing professional training and development for science, means that less effective teachers rely too heavily on published schemes of work which they are not able to adapt to the particular needs and interests of their pupils. As a result, the work lacks progression and gives scant attention to the practical investigation which should be at the heart of science.

Standards in Key Stage 3 science as measured by statutory tests continue to rise, often as a result of the advice and support that schools receive through the Secondary National Strategy. At Key Stage 4, however, standards as measured by GCSE performance have changed little over the last few years. Ofsted inspections show that standards and achievement of pupils are good or better in well over half the schools visited, and over 90% show standards and achievement that are at least satisfactory. In the weaker schools, in their concern to cover the GCSE specifications, science departments fail to take account of what pupils already know. As a result, the work becomes repetitive for pupils, lacks progression and leads to boredom and frustration.

At all key stages, the most stimulating teaching and most enthusiastic learning occur when teachers encourage their pupils to come up with ideas and suggestions and, in consultation with their teacher, to plan, conduct, record and evaluate their own investigations. Good formative assessment is also crucial to success. When pupils receive regular feedback on how well they are progressing and clear advice on how they can improve further, they are able to focus their energies effectively. The resulting growth in self-confidence contributes to further progress. Where they take responsibility for self- and peer-assessment, their learning becomes more focused. Although many teachers are adept at using information and communication technology (ICT) and often employ resources such as PowerPoint in their lessons, they do not provide enough opportunities for pupils to use ICT in science lessons.

The science curriculum provides opportunities to make connections to other subjects and to pupils' everyday lives. However, in weaker schools these connections are too often missing, especially at Key Stage 4 where the focus on tests and examinations and a lack of emphasis on scientific enquiry results in weaker conceptual development. The experiences and insights gained through scientific investigations and good quality explanations and demonstrations help to bring about good conceptual development. The changes in the National Curriculum and GCSE specifications have increased the choice and range of courses, but too few secondary schools have taken the opportunity provide a broad range of courses and pathways for 14- to 19-year-olds.

Although the quality of leadership of science was good in over half the primary schools visited, in schools where management and leadership were weaker, too few coordinators had received sufficient training to prepare them for the role. At secondary level, the quality of leadership and management was variable. The best departments used thorough self-evaluation to identify the most successful teaching and learning and had effective strategies for disseminating their best practice. At all key stages, the most effective planning occurred when teachers worked on it together.

Part B focuses on key issues relating to science today, including the importance of scientific enquiry in the curriculum; science's contribution to promoting literacy, numeracy, and spiritual, moral, social and cultural development; post-16 provision; and the training and recruitment of science teachers.

Key findings

- Outcomes of tests and public examinations in science have not changed substantially over the last three years at either primary or secondary level. While being satisfactory, there is clear scope for improvement.
- Of the schools visited, those with the highest or most rapidly improving standards ensured that scientific enquiry was at the core of their work in science. Pupils were given the opportunity to pose questions and design and carry out investigations for themselves.
- Teaching and learning were at least satisfactory in almost all of the schools visited. However, within this generally positive picture, there were recurring weaknesses, particularly in planning and assessment.
- Too often, in planning science activities, teachers did not take sufficient account of what pupils had already learned in previous key stages and did not give them clear advice on how to improve their work further. As a result, pupils lost interest and made insufficient progress.
- Most primary teachers had limited opportunities for continuing professional development to enhance their expertise in science, partly because their schools did not see the subject as a priority for development.

- In too many primary and secondary schools, teachers were mainly concerned with meeting narrow test and examination requirements and course specifications. This led them to adopt methodologies which did not meet the needs of all pupils or promote independent learning.
- The secondary schools visited were beginning to develop programmes of study that gave 14- to 19-year-olds access to vocational and academic pathways in science, suited to their needs and interests. However, progress in this area was too slow.

Recommendations

The Department for Children, Schools and Families (DCSF), the Department for Innovation, Universities and Skills (DIUS) and the Qualifications and Curriculum Authority (QCA) should:

- broaden the test requirements at Key Stages 1 and 2 to give greater weight to assessing pupils' understanding of how science works
- provide funding for continuing professional development for primary teachers and subject leaders that focuses particularly on science knowledge and understanding and progression in learning
- encourage secondary schools to provide the necessary range and choice of science courses to meet the needs of all pupils continuing beyond the age of 16 in education, training or employment
- promote the sharing of good practice between phases and sectors to ensure more effective transition for pupils between key stages.

Secondary schools should:

- collaborate with associated schools to ensure continuity and coherence in pupils' science education as they move from one key stage to the next
- provide a range of courses matched to pupils' needs and relevant to a life of continuing education in a technological age
- ensure that the science curriculum is engaging, relevant to pupils' needs and not constrained by an undue focus on meeting examination requirements.

Primary schools should:

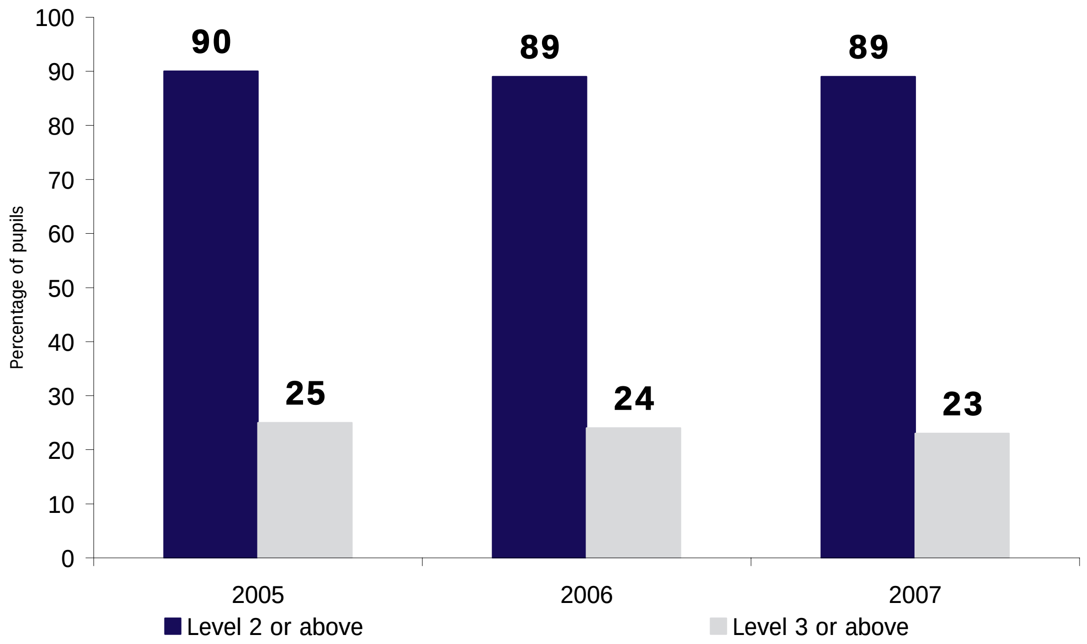
- make provision of effective continuing professional development part of school improvement planning to support and extend, where necessary, teachers' knowledge and understanding of science and their confidence in teaching it
- ensure that pupils receive a balanced programme of science education that includes a significant focus on scientific enquiry
- ensure that a focus on meeting test requirements does not detract from the breadth and balance of the science curriculum.

Part A. Science in schools and colleges

Achievement and standards in primary schools

1. At Key Stage 1, standards and achievement in science are measured by teacher assessment. The outcomes of these assessments have not changed substantially over the last three years (Figure 1). Around 90% of pupils achieve the National Curriculum target grade of Level 2 in science.

Figure 1: Percentage of pupils achieving Level 2 or above or Level 3 or above in Key Stage 1 science teacher assessments, 2005 to 2007



Figures for 2007 are based on provisional data. Figures for all other years are based on final data.
Source: DCSF, *National Curriculum assessments at Key Stage 1 in England 2007 (provisional)*, SFR26/2007.

2. Girls have consistently performed better than boys by three percentage points at Level 2 or above. However, their results at Level 3 or above have been two percentage points below those of boys (Table 1). It is unclear what accounts for the differences in performance between boys and girls. This would merit further investigation.

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Table 1: Percentage of pupils achieving Level 2 and 3 or above in Key Stage 1 science teacher assessments by gender, 2005 to 2007

	Boys			Girls			All pupils		
	2005	2006	2007	2005	2006	2007	2005	2006	2007
Level 2 or above	88	88	87	91	91	90	90	89	89
Level 3 or above	26	25	24	24	23	22	25	24	23

Figures for 2007 are based on provisional data. Figures for all other years are based on final data.
Source: DCSF, *National Curriculum assessments at Key Stage 1 in England 2007 (provisional)*, SFR26/2007.

3. Ofsted's inspections confirm that standards in science have remained static in recent years. They also show that achievement is greatest in schools that ensure continuity in pupils' learning. When teachers across year groups plan together, pupils make better progress because their prior experiences and achievements are taken into account in a way that is less likely to happen if each member of staff plans alone.

4. Raising standards and achievement in science is a significant challenge for many primary schools. It is achieved through the interaction of a number of factors, as in this school:

> The teachers recognised that standards in science at Key Stage 1 were too low. They re-examined the National Curriculum attainment targets and used guidance from the QCA to ensure that they were expecting enough of their pupils. They then set targets so that attainment at the end of Key Stage 1 would rise each year and be developed further in Key Stage 2.
>
> Using the QCA materials as a source of ideas rather than a scheme of work, they redesigned the curriculum. This ensured that pupils revisited areas of study, such as forces, several times during the key stage, exploring them in greater depth at each point. Lessons now focused on problem solving and scientific enquiry, and on developing pupils' understanding, rather than just transmitting knowledge. Previously, teachers had worked on science in one block of time a week. Now they adopted a more flexible approach and taught it at different times, for different purposes, linking it more closely to other subjects.
>
> The science curriculum at Key Stage 2 was also revised so that it built on pupils' earlier learning and avoided repetition. Each class was given 18 hours of support from a teaching assistant. 'Booster' classes were also used in Year 6 to help raise the attainment of pupils at Levels 3 and 4 and to challenge the more able.

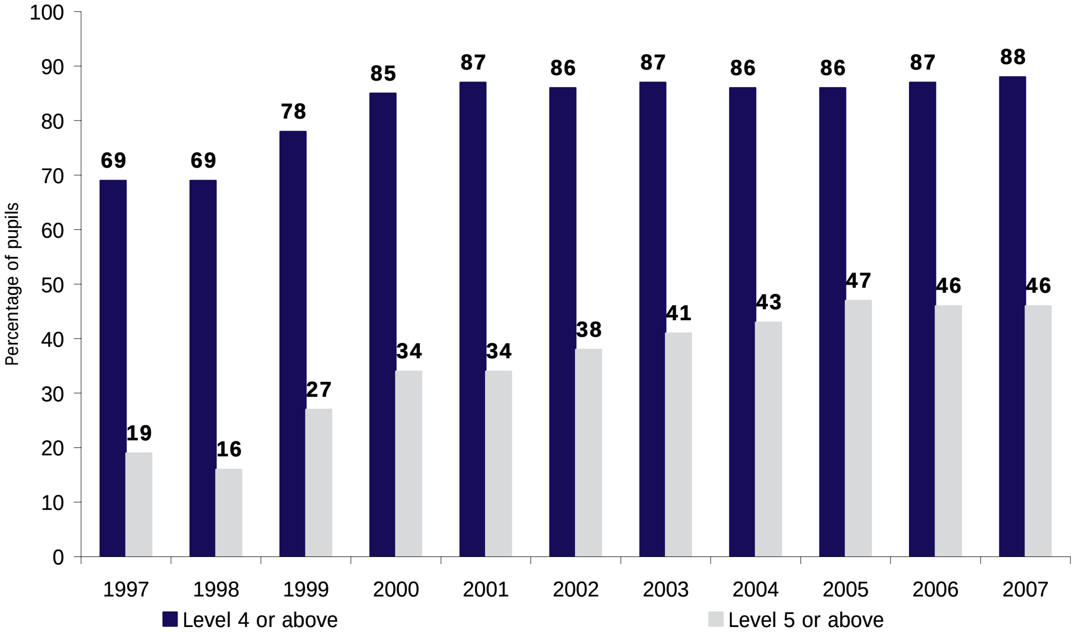
As a result, standards and achievement improved from significantly below average in 2003 to significantly above average in 2005 and 2006. Inspectors' scrutiny of pupils' work and observation of lessons showed that this level of performance was being maintained.

5. It is easy to underestimate what pupils can do in the early stages of science education. The natural curiosity of young children leads them to ask a wide range of questions about the world. With the help of an interested teacher, they can develop these into ideas to be tested and can arrive at explanations for phenomena observed.

Pupils in Year 2 were working in pairs on exploring movement in toys, ranging from model cars to jack-in-the-boxes. The teacher asked whether they could spot anything that was always true when the toys moved. In response to this very sophisticated question, they made a range of observations such as: 'Sometimes it's quick and sometimes it's slow'; 'They don't always go in a straight line'; 'Some go on for ages and some stop quickly'. These were all valid responses but focused on differences and therefore did not answer the teacher's question. She accepted their observations but kept posing the original question. The pupils' ideas become more and more refined and included comments such as 'the bigger the push the faster it goes', which identified relationships referred to in the criteria for Level 3 in attainment target Sc4 (physical properties). As they continued their explorations, they recorded what happened, using a range of methods they had devised. One girl and boy drew a table to record how far each toy travelled when pushed. They told the teacher that they had tried to push each toy in the same way, thus showing that they had clear notions of fair testing, one of the criteria for Level 3 in attainment target Sc1 (scientific enquiry). After further discussion, they came up with a generalisation: 'All the toys move because of pushes and pulls. When these change they move differently'. In doing so, they reflected a degree of cognitive development consistent with Level 3 in Sc4. This had been achieved because, instead of giving the answer, the teacher had persisted in stimulating the pupils' curiosity and rewarding their efforts with positive responses.

Attainment at the end of Key Stage 2 is measured principally using national tests. Figure 2 shows the notable increase in the proportion of pupils attaining Level 4 and above and Level 5 and above after 1997. However, it also shows that attainment did not rise further in the period covered by this report. Around 90% of pupils are achieving the end of key stage target grade of Level 4 in science.

Figure 2: Percentage of pupils achieving Level 4 or above or Level 5 or above in Key Stage 2 science tests, 1997 to 2007



Figures for 2007 are based on revised data. Figures for all other years are based on final data.
Source: DCSF, *National Curriculum assessments at Key Stage 2 in England 2007 (revised)*, SFR41/2007.

6. At the end of Key Stage 2, the difference between boys' and girls' performance is smaller than at the end of Key Stage 1. For the last three years, girls' results have been one percentage point above those for boys at Level 4 or above. In 2007, there was no difference in the proportion of boys and girls gaining Level 5 or above in the national tests (Table 2).

Table 2: Percentages of pupils achieving Level 4 or above and Level 5 in Key Stage 2 science tests by gender, 2005 to 2007

	Boys			Girls			All pupils		
	2005	2006	2007	2005	2006	2007	2005	2006	2007
Level 4 or above	86	86	87	87	87	88	86	87	88
Level 5	48	45	46	46	46	46	47	46	46

Figures for 2007 are based on revised data. Figures for all other years are based on final data.
Source: DCSF, *National Curriculum assessments at Key Stage 1 in England 2007 (revised)*, SFR41/2007.

7. Ofsted inspections show that standards and achievement in science primary schools are good or better in around three quarters of the schools visited. These good standards are a consequence of good teaching and good curricular provision. However, the levelling out of standards seen in the chart raises the

question of what is hindering further improvement. The present survey identified some possible factors including weaknesses in teachers' knowledge of the subject; a narrow range of teaching methods; insufficiently high expectations of pupils; and weaknesses in assessing pupils' skills, knowledge and understanding. Only one third of pupils had a good understanding of how they could improve. The leadership and management of science were good or better in only just over half of the schools visited.

8. The National Curriculum makes it clear that pupils should have a range of experiences in science, including being involved in investigative work. In this survey, the schools with the highest or the most rapidly improving standards were those where scientific enquiry was at the core of their work. Pupils in these schools were enthusiastic about the subject and had the confidence and skills to plan investigations and collect, present and evaluate evidence.

> Through a variety of activities, many involving ICT, pupils in one school had been taught how to formulate their own questions. They were now designing investigations to find answers to them. Some were of a practical nature whilst others involved internet searches. Pupils in Year 2 were very enthusiastic about the investigations they had undertaken to find out where electricity came from. These went a long way beyond National Curriculum requirements and involved extensive consideration of the application of science to their lives and experiences. This investigative approach permeated the school, with almost every class being involved.

9. Effective practical work requires detailed planning and additional time in the curriculum but leads to better learning and sustained application from pupils, as in this example from a primary school:

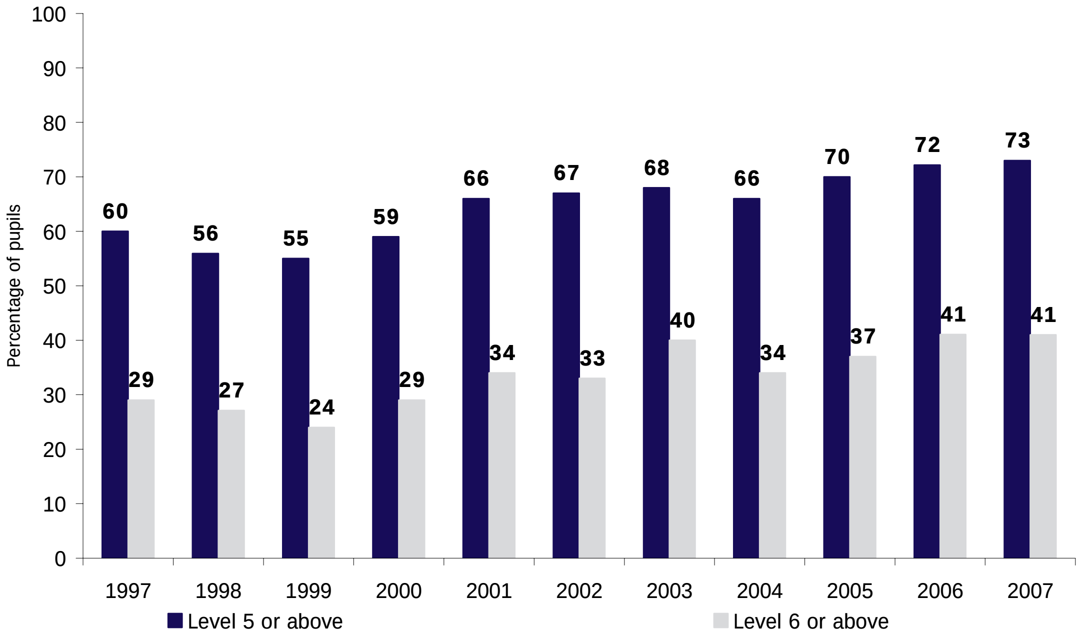
> Standards and achievement were well above average at the end of both key stages. Since the previous inspection, significant improvements had been made in the key scientific skills of planning, conducting and reporting on experimental work. All pupils were able to extend their thinking and understanding by turning their ideas into tests and by conducting experiments, collecting evidence, reporting the results and drawing conclusions from their investigations. The impact of this on their performance was reflected in the increasing numbers attaining the higher levels in the national tests.
>
> Year 5 pupils had worked on an ecology project. Through discussion, they began to understand that different areas of the school grounds were likely to have different communities of plants and animals. To establish whether this was the case, they organised themselves into groups to see what they could find in specific parts of the grounds, each group taking firm control of planning and recording its own investigation. They ensured fair testing, for example by assessing the living things in plots of land with the same surface area or collecting samples within the same period of time. They

took the specimens back to the classroom and used a range of instruments, including hand lenses, digital cameras and a digital microscope, to look at the fine detail of what they had collected. Some captured digital images of the mini-beasts to display on the electronic whiteboard. To identify them, they used printed materials as well as computer-based resources and internet sites. They discovered that a range of ecological factors tied different creatures to different habitats. For example, woodlice were found in shady damp environments. In displaying and describing their findings, the pupils used their newly acquired science language accurately.

Achievement and standards in secondary schools

10. Figure 3 shows the uneven upward trend, over the last few years, in attainment at the end of Key Stage 3. The proportion of pupils reaching Level 5 is now approaching three quarters of the cohort while two fifths are attaining Level 6. This improvement in achievement and standards was also reflected in the survey visits.

Figure 3: Percentage of pupils achieving Level 5 or above or Level 6 or above in Key Stage 3 science tests, 1997 to 2007



Figures for 2007 are based on revised data. Figures for all other years are based on final data. Source: DCSF, *National Curriculum assessments at Key Stage 3 in England 2006/07 (revised)*, SFR06/2008.

11. Both boys' and girls' performance has improved by three percentage points at Level 5 or above. However, at Level 6 or above, girls' performance rose at a faster rate than that of boys from 2005 to 2006, and this improved performance was maintained in 2007. Girls have improved by five percentage

points while boys have made an improvement of only three percentage points. In 2007, girls' performance was one percentage point ahead of that of boys at Level 5 or above and equal at Level 6 or above (Table 3).

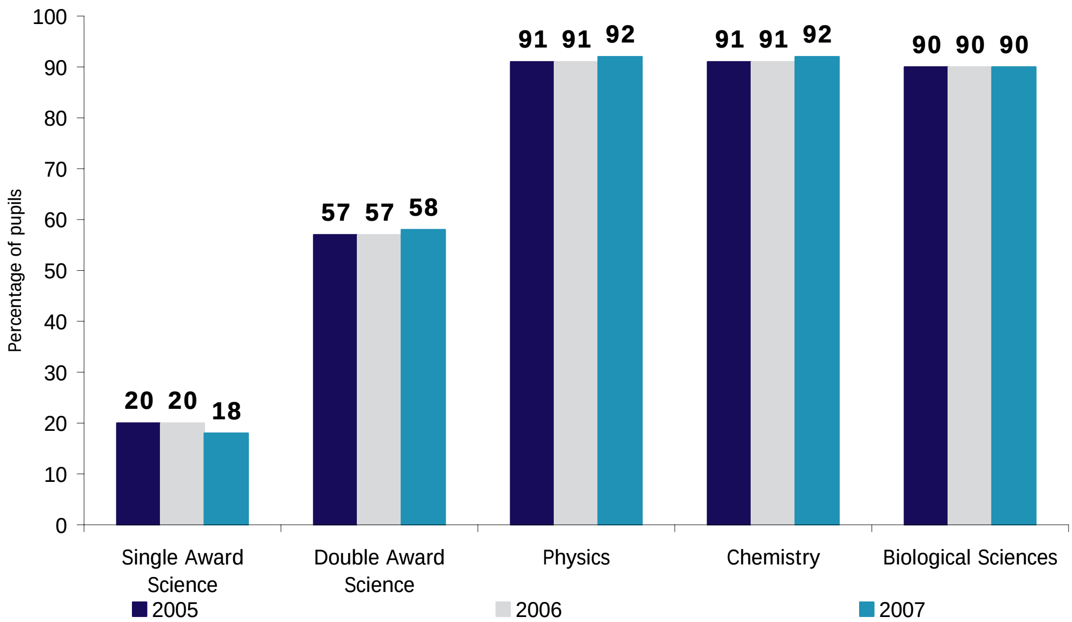
Table 3: Percentages of pupils achieving Level 5 or above and Level 6 or above in Key Stage 3 science tests by gender, 2005 to 2007

	Boys			Girls			All pupils		
	2005	2006	2007	2005	2006	2007	2005	2006	2007
Level 5 or above	69	71	72	70	73	73	70	72	73
Level 6 or above	38	41	41	36	41	41	37	41	41

Figures for 2007 are based on revised data. Figures for all other years are based on final data. Source: DCSF, *National Curriculum assessments at Key Stage 3 in England, 2006/07 (revised)*, SFR06/2008.

12. Attainment at Key Stage 4 has shown little change over the past few years.[1]

Figure 4: Sciences: percentage of pupils achieving A*–C grades at GCSE, 2005 to 2007



Figures for 2007 and 2006 are based on revised data. Figures for all other years are based on final data.

[1] The data for 2005 and 2006 are based on the pupils at the end of Key Stage 4 for all secondary schools. Results before 2005 are based on the GCSE achievements of 15-year-old pupils in maintained secondary schools.

Sources: *DCSF, GCSE and equivalent examination results in England 2006/07 (revised)*, SFR01/2008; *GCSE and equivalent examination results in England 2005/06 (revised)*, SFR01/2007; *GCSE and equivalent results and associated value added measures in England 2004/05 (final)*, SFR26/2006.

13. Unlike at other key stages, pupils at Key Stage 4 choose which courses to follow. Other than for single award science, the difference in the proportion of boys and girls attaining grades A*–C at GCSE is only one percentage point. The three separate sciences of physics, chemistry and biology are most often chosen by higher ability pupils – hence the higher proportion of pupils gaining grades A*–C at GCSE.

Table 4: Percentage of pupils achieving A*–C grades in sciences at the end of Key Stage 4

	Boys			Girls			All pupils		
	2005	2006	2007	2005	2006	2007	2005	2006	2007
Single Award Science	18	18	16	23	23	20	20	20	18
Double Award Science	56	56	58	58	58	59	57	57	58
Physics	92	92	92	91	91	91	91	91	92
Chemistry	91	91	91	91	91	92	91	91	92
Biological Sciences	90	90	90	90	89	90	90	90	90

Figures for 2007 and 2006 are based on revised data. Figures for all other years are based on final data.
Sources: DCSF, *GCSE and equivalent examination results in England 2006/07 (revised)*, SFR01/2008; *GCSE and equivalent examination results in England 2005/06 (revised)*, SFR01/2007; *GCSE and equivalent results and associated value added measures in England 2004/05 (final)*, SFR26/2006; *GCSE and equivalent results and associated value added measures for young people in England 2003/04 (final)*, SFR25/2005.

14. Schools where pupils' achievement in science is higher than in schools which are otherwise similar have some common features, one of which is the focus on developing pupils' investigative skills. Asked why she enjoyed science so much, one Year 11 pupil said that it was because 'you can do what you want'. She explained that, in practical work, pupils were able to decide what and how to investigate, which she found motivating. By contrast, in another school, where success rates in GCSE science were well below those for other subjects, a pupil described how she loved history lessons because she could discuss ideas and events and give her own opinion; in science, however, no account was taken of her views and the main focus was on taking notes and learning for tests. Carefully planned experiences of 'how science works' led to pupils' increased enjoyment and engagement and helped them gain skills, knowledge and understanding more effectively. As one Year 9 boy said, 'When we do practicals, it helps me understand better'.

15. Attainment at Key Stage 4 continues to be lower than it should be because too little account is taken of pupils' prior learning.[2] Too often, pupils repeat work that they have already covered reliably at Key Stage 3. Furthermore, the investigative work at Key Stage 4 is often too narrowly confined to activities required for GCSE assessment rather than being used to promote effective learning.

16. The following examples show how investigative work can be used effectively:

> Year 8 pupils had discussed how a grandfather clock worked. They were now involved in devising their own experiment to find out what affects the speed of a pendulum. They decided what parameters to change, for example using different string lengths and different masses. When the results table issued by the teacher did not quite tally with what they were doing, there was much debate. This was a good example of how, with guidance, pupils can take control of devising their own experiments and carry them out competently.
>
> In another lesson, Year 9 pupils used ICT effectively to create a graph of predator/prey populations using Excel. This was printed in colour and used real data. Some pupils spent too much time typing the questions that they were required to answer rather than actually working out their answers. However, those who answered the questions clearly had a sound understanding of the relevant concepts.
>
> In an excellent Year 10 lesson on the conservation of energy, the teacher captured the class's attention with his lively, enthusiastic exposition and effective use of questions and answers. This led to very good practical activity involving a wide range of items, including a candle, a kettle, a Van der Graaff generator, drums, an electric fan and a video player. In pairs, the pupils examined the items, discussed the source of energy and, in each case, what energy it transferred into. They recorded their findings as they moved around the class. The teacher also moved around the groups and, through his very effective questioning, helped the pupils to think through their observations and come up with their own ideas. Very good behaviour management and tight time limits for completing tasks ensured that the pupils worked quickly, safely and in a focused way. The lesson finished with a successful plenary session in which the pupils participated fully and with much enjoyment. They had a sound grasp of the concepts involved and were clearly thinking very thoroughly about energy transfer.

[2] *The Annual Report of Her Majesty's Chief Inspector of Schools 2004/05,* Ofsted, 2005; http://live.ofsted.gov.uk/publications/annualreport0405/4.2.15.html.

The quality of teaching and learning

Primary school teaching

17. Teaching and learning were at least satisfactory in almost all of the schools visited. Around three quarters of the lessons were good and just over one in 10 were outstanding. However, within this generally positive picture, there were some imbalances. Most importantly, teachers were more skilled at teaching knowledge and understanding of science than scientific enquiry. This often led to minimal ‘risk taking’ with a heavy reliance on worksheets and on telling pupils what to do rather than encouraging them to make decisions for themselves. In Year 6 in particular, narrow teaching to the tests meant that pupils were becoming bored with and demotivated by science.

18. Teachers who trusted pupils to come up with ideas and suggestions reaped the rewards of their engagement and enthusiasm.

> In a Year 3 class, the teacher started the lesson with a lively session of questions and answers to establish what the pupils already knew about light and how it travels. They talked about light rays, shadows, darkness, torches and beams of light. Most pupils were very keen to answer and the teacher directed questions skilfully to involve the less confident pupils in the discussion. This was followed by role play where individuals pretended to be different materials interfering with light. During this, they used words like ‘opaque’, ‘transparent’ and ‘translucent’ in context. As a result, they developed a firm understanding of their meaning and increasing confidence in applying them.
>
> The teacher used the interactive whiteboard effectively to capture ideas, aid learning and maintain a good pace. She also organised the pupils into pairs so that they could discuss and generate their own ideas. In planning an investigation into the best material to use as a blackout for the room, they showed a clear understanding of the principles of fair testing. They carried out their practical investigation systematically and responsibly. A well-run plenary session ensured that they were all confident in understanding light and the properties of materials.

19. Not infrequently, pupils misunderstood key concepts because the teacher did not understand them well enough to give a clear explanation or respond accurately to questions, as in this example:

> The enthusiasm of a class of Year 1 pupils to ‘find out’ was infectious. The teacher showed them how different objects in a tray responded when a bar magnet was moved near them. She then challenged them to work in pairs to decide how they could show their findings to other pupils. A short discussion to capture their ideas led to the printing of recording sheets from the interactive whiteboard. The investigation began with pairs of

pupils moving around the room and testing objects by touching them with a magnet to see if they 'stuck'. They used the recording sheet effectively and began to identify possible patterns in what they saw. When they came up with the idea that 'magnets attract shiny things', the teacher challenged them to see if they could find anything shiny that did not 'stick' to the magnet, and they did. Bit by bit, item by item, they built up their understanding of the materials and their properties. A boy approached the teacher holding two two-penny coins and said, 'These look the same but they can't be'. When the teacher asked him to show her, he touched each coin in turn with a magnet. One was attracted to it, the other was not. The teacher's response was to say, 'What a funny magnet'. She was clearly uncertain how to respond, did not have an explanation for the phenomenon and, rather than using it as a spur to further investigation, closed down discussion with the pupil.

20. Another common weakness was teachers' insufficient understanding of how promoting skills of scientific enquiry contributes to conceptual development. Such understanding was clearly evident in the following example:

> In all the lessons seen in the school, the teachers' subject knowledge was secure. In several instances, this gave them the confidence to give clear explanations and to help Key Stage 1 pupils to develop a better understanding of subtle scientific terms used to describe materials, such as soft, smooth, bendy, rigid, rough, hard, brittle, transparent and translucent. This helped them to sort out materials according to their properties and to suggest ways in which they could be used.
>
> The teachers used a good variety of strategies for teaching and class management. They were skilled in exposition and using questions and answers to check on learning. They encouraged everybody to be involved and challenged them appropriately. As a result, the pupils showed interest, participated well and developed good levels of knowledge, skills and understanding.

Secondary science teaching

21. Around 95% of the lessons seen were at least satisfactory. Overall, teaching and learning in science were good in 66% of the schools and were outstanding in around 7%. As in the primary schools, these figures conceal some imbalances. Given the extensive subject knowledge of most secondary science teachers, much teaching paid scant regard to what and how pupils were learning. In many lessons, teachers simply passed on information without any expectation of pupils' direct engagement in the process. The objective appeared to be to get notes into books, and then leave the learning to the pupils.

22. Progress in science was seen when teachers:

- had a clear understanding of what knowledge, understanding and skills were to be developed
- understood how development in scientific enquiry promotes effective learning
- understood the relationship between concepts and the cognitive demand they make
- were clear about what pupils already knew, understood and could do.

23. Progress was also seen when pupils:

- understood clearly the standards they had achieved, knew what they needed to do to improve and were involved in self and peer evaluation
- took part in decision-making, discussion, research and scientific enquiry
- were engaged in science that had relevance to their lives.

24. Some weaker aspects of teaching could be explained by the fact that the teachers were working outside their own science specialisms. As in primary schools, this led to the overuse of textbooks or commercially produced worksheets and 'teaching to the test'. In these circumstances, the teachers often adopted ways of teaching that did not cater for the needs of all pupils, did not promote independent learning and did not engage them sufficiently. A teacher's own lack of understanding of the area of science to be taught can lead them to operate in 'safe' mode. This involves telling pupils facts, requiring them to copy notes and avoiding activities that would require discussion and the possible revelation of their own lack of understanding. This was all too clearly demonstrated in this Year 10 lesson:

> The pupils arrived and sat quietly in their places in the laboratory. The teacher did not greet the class or ask any questions. Instead, for 30 minutes, he described the relationship between forces, work and power. There was little exemplification based on contexts familiar to pupils and no questions to draw on their experiences or establish what they already knew. The pupils copied from the blackboard, took dictated notes and adopted their expected passive role with an air of resignation. Their exercise books contained identical notes, identical red ticks, no written comment to speak of, and no evidence of independent work or of scientific enquiry. The teacher asked no questions to check their understanding at the end of his exposition, and moved on to instruct the pupils on which example questions they were to tackle for the rest of the lesson. He was surprised that HMI judged the lesson to be inadequate.

25. Significantly, the quality of teaching in the example above was very different from that seen in other science lessons in the same school. It was clear that, as a consequence of weak leadership and management, no agreement existed within the department about good practice and there was no mechanism to evaluate and ensure consistency in the quality of teaching. Within-school variations in quality were also seen elsewhere:

A school's Key Stage 3 test results were well above the national average. Pupils were engaged in a range of activities including discussions, research, role play, scientific enquiry and practical work. In discussions during the inspection, they made it clear how much they enjoyed science. The outcomes at Key Stage 4 were considerably less positive with results for GCSE double award science around the national average. Key Stage 4 lessons contrasted strikingly with those in Key Stage 3. In GCSE courses, pupils were actively involved in scientific enquiry only when they were being assessed. Teaching and learning tended to be limited to a narrow range of activities, much of it involving making or taking notes. One teacher introduced a lesson with, 'This is not a very interesting part of science but we have to do it because it is in the specification' – not words likely to inspire any pupil.

26. In good science lessons, teachers ensured that pupils understood the purpose of activities and that they were closely involved in discussing their work and testing out and refining their ideas. Their good quality feedback identified what had been achieved and how improvements could be made. In doing so, they helped pupils develop more responsibility for their own learning. In the schools that focused clearly on individuals' needs, pupils and teachers related well to each other. In the best situations, pupils could describe what they had learned, how they had improved and what they needed to do to build on this.

27. Teaching had improved in the schools which had used the Secondary National Strategy's science programme effectively. The focus on tracking pupils' achievement and providing better feedback had been particularly beneficial. The majority of schools were now better at tracking pupils' achievement in terms of their knowledge and understanding of science. However, they paid less attention to developing their understanding and skills of scientific enquiry. Where the quality of provision was even across the different areas of the programme of study, pupils' knowledge and understanding improved, as in this secondary school:

The teachers had good subject knowledge across all the areas of science. In Years 7 and 8, science was usually taught by one teacher who covered biology, chemistry and physics. In Year 9, pupils were almost always taught by three teachers, one for each discipline. The specialist teaching was lively and enthusiastic, involved an appropriate range of activities and used demonstrations successfully to engage pupils' interest and illustrate concepts.

In introducing Year 9 pupils to the idea of diffusion, a teacher used a Petri dish on an overhead projector to show potassium permanganate diffusing through water. As the whole class watched its purple colour spread out from the crystals, she sprayed perfume in one corner of the room. As they sensed the perfume, pupils put up their hands so that there was an ever-widening area of the classroom where there were hands in the air. One pupil compared what she saw to the ripples spreading out from a stone thrown into a pond. The teacher built on this image and asked pupils to suggest what was happening in all the examples experienced. They arrived at a good understanding of the diffusion of particles through different media and began to consider how rates of diffusion were affected by temperature, density and particle size.

28. In science departments where teachers used ICT successfully this helped pupils to think far beyond their own experiences. For example, in a Year 8 lesson, a DVD about the importance of a good diet included clips of a baby with kwashiorkor.[3] In a Year 10 lesson, an animation was used to show the changes of gravitational potential energy and kinetic energy during a pendulum swing. This made a difficult concept more understandable.

29. In most lessons, teachers had high expectations and focused clearly on scientific enquiry and how science works. They questioned pupils effectively to check on their prior knowledge, to involve them and to encourage them to think for themselves. The materials used in lessons were of excellent quality, clearly laid out and used in a structured way that helped pupils develop their understanding further.

30. Effective use was made of individual targets. Pupils knew the levels or grades they were aiming for and what they needed to do to achieve them. Written work was marked regularly and included helpful comments on how it might be improved. The pupils also received summary feedback sheets noting their strengths and areas for improvement. They valued these and responded well to the advice.

31. Although most teachers were adept at using ICT and often employed resources such as PowerPoint in their science lessons, pupils generally used it too little. They drew on it more often for homework than for classroom activities. Many schools had data-logging equipment but it was rare to see it being used in practical work. The next example shows how ICT can support learning effectively when it is used well:

Year 8 pupils, working in small groups, had carried out an investigation of their own design on the factors affecting the rate of reaction between acids and calcium carbonate. They had used a variety of ways, including data-loggers, to gather data which they captured in tabulations on their laptops. One pupil volunteered to collate the information on the teacher's laptop, gathering it by wireless connection and displaying it on the interactive whiteboard. The class was immediately involved in scrutinising the data, identifying correlations, spotting anomalies and discussing

[3] Common in developing countries with a high incidence of malnutrition, kwashiorkor is a severe protein deficiency in infants, resulting in retarded growth, lethargy, oedema and a swollen abdomen.

possible explanations for variations. The quality of learning was very high, as were the pupils' levels of engagement and enthusiasm.

Assessment in science

32. A common characteristic of the schools in which pupils achieved well was the quality of assessment and the effective use of data to support learning. Teachers drew not only on written tests but also on evidence gathered in other ways. For example, they used concept- or mind-mapping at the start of topics or lessons to establish what pupils already knew and to identify any misconceptions. They also used open-ended questions effectively, in some cases combined with small whiteboards or 'traffic light' cards, to determine levels of understanding. Strategies such as these, combined with the detailed marking of work, gave a clear picture of pupils' attainment and what they needed to learn next.

33. Teaching and learning were most effective when teachers used the assessment information to plan lessons that met the needs of all the pupils in the class and provided varying levels of challenge and support. In too many schools, however, particularly secondary schools, attainment was measured primarily through end-of-topic tests. Teachers rarely used this summative assessment information to identify strengths and weaknesses in learning, to inform future lesson planning or to provide pupils with advice on how to improve.

34. Many science departments had taken on board the advice and guidance of the Key Stage 3 and Secondary National Strategies and had improved their practice by using assessment for learning better. These departments were focusing increasingly on sharing learning objectives and success criteria with the pupils. The more they understood the purpose of the lesson and what they needed to do to be successful, the greater their sense of involvement in their learning. This was not a matter of asking them to copy objectives from a board but, rather, a systematic use of objectives as part of initial explanations, as points of reference during lessons and as a means of evaluating the progress being made. It involved the pupils in contributing their views, clarifying what they had already achieved and what remained to be done.

35. Some schools involved pupils in assessing their own work through using progression strands that showed what they had to know, understand or do to achieve particular levels. They also discussed mark schemes and assessment criteria with the pupils. Where pupils have and understand the assessment criteria, they can evaluate each other's work successfully and bring about improvements collaboratively. Such effective peer assessment in science was still relatively rare in schools. Some schools used science learning logs or progress files that enabled pupils, teachers and parents to identify what progress had been made and the learning needs of individuals.

36. The quality of marking varied considerably between and within schools. Inconsistencies in this very important aspect highlighted weaknesses in a department's monitoring of its work. Marking was most effective when comments written in pupils' books made clear what they had done well and what they needed to do to improve.

37. Most secondary science departments were effective at monitoring data and reviewing patterns of performance; they were less successful in responding to individual pupils' needs. Too many departments confined assessment to tests at the end of a teaching sequence. Many made little use of this data to inform planning, analyse the effectiveness of teaching or to provide individual pupils with advice on how to improve. Even when departments did have policies on marking and providing written feedback, in practice there was often too much variation, and inconsistent monitoring rarely identified it.

38. The most successful schools focused on assessment for learning:

> In science lessons pupils regularly marked each other's work and then, as a class, discussed key points. They also assessed their own work against individual targets set for the end of unit, end of year or end of key stage. At each point, they reflected on their progress, identified their next goal and wrote what they needed to do to improve, plotting their progress on individual charts. Because they knew how they learned best and what progress they were making, they were able to challenge the teachers if they felt that they were being presented with unsuitable materials or activities. The teachers were supported by a scheme of work in which all lessons included a section on how to assess and provide formative feedback. The end of each unit included a plenary session to assess progress and identify and correct any misconceptions. The head and deputy head of department monitored assessment carefully and provided focused support for and advice to their colleagues.

39. Analysis of assessment data from the primary schools should play an important part in improving transition between primary and secondary schools, but too often this was weak. Good examples exist of transition projects involving investigative work that pupils begin in Year 6 and continue in Year 7. These provide secondary teachers with good evidence of individuals' prior learning and attainment. Where such projects were used successfully, staff from both phases had a good understanding of the teaching methods used in the other phase and modified their teaching to improve continuity. This enhanced pupils' confidence because, from the start of secondary school, they were challenged appropriately. However, some secondary teachers continued to damage pupils' enthusiasm by dismissing what they already knew.

> In a Year 7 science lesson, the laboratory assistant wheeled in a trolley of low voltage supplies. One boy, recognising the equipment, shot up his hand and wanted to tell the teacher what he had done at primary school.

The teacher showed no interest and said that whatever the pupil had done in the past, he was now going to 'do properly'. It was difficult to see how this would motivate him to offer his views in future or to understand why the teacher did not want to know about pupils' prior learning so he could plan appropriately. This was a recipe for purposeless repetition, tedium and demotivation. It did not establish the climate of mutual respect and understanding needed for effective teaching and learning.

40. At times, preparation for national tests and examinations at the end of Key Stages 3 and 4 inhibited pupils' enjoyment of science, particularly when it led to fewer opportunities for practical work and discussion. From observing and interviewing pupils during the survey, it was clear that they had far greater interest and understanding when they continued to be involved in scientific enquiry and the exploration of 'how science works'. Such activities helped them understand scientific concepts and gave them a vehicle for testing their ideas in the context of practical work, research and debate.

Quality of the curriculum

41. All the primary schools visited were providing at least a satisfactory curriculum in science. Of these, around two thirds were good and more than one in 10 outstanding. There was good coverage of the National Curriculum requirements, and teachers were less reliant than in the past on the QCA scheme of work or other publications.

42. Increasingly, teachers were using such publications as resources, dipping into them and adapting them to suit their pupils and circumstances. Where this was done, the science experiences provided were often better suited to the school's context and more relevant to the pupils and their community. It also helped to ensure that there was more time available for pupils to be involved in scientific enquiry and to reflect on topics. The most successful science curricula made effective cross-curricular links to literacy, numeracy, ICT and subjects such as geography.

43. Curricula that did not reinforce links with other subjects hampered pupils' opportunities to get the most out of their science studies. In some cases teachers' rigid adherence to the content of the National Curriculum did not always allow them to respond to pupils' increasing interest in environmental matters, such as global warming and climate change, which provide ideal opportunities for linking subject areas.

44. The most effective primary schools ensured that children had excellent opportunities to be involved in science investigations from the beginning of the Foundation Stage and to build on these experiences in subsequent key stages. They also ensured that there were good resources to support learning across the age range. Some schools, for example, made good use of the internet to enable pupils to find out more about their science topics, or organised science

clubs where pupils could extend their enjoyment and learning beyond the classroom.

45. In these schools, the teachers planned collaboratively, producing schemes of work that met pupils' needs; showed clear progression in knowledge, understanding and skills; and included opportunities for the investigative work that is crucial to learning.

46. None of the primary schools visited had an inadequate science curriculum. However, in a small minority (one in 20), it was too narrow and relied too heavily on worksheets. Year 6 pupils particularly were too often involved in practising responses to national test questions rather than engaging in exciting science work; they did not develop a thorough understanding of the subject and their interest and enthusiasm were low.

47. The curriculum was satisfactory in almost all the secondary schools in the sample. It was good in over a half and outstanding in one in 20. Good curriculum provision included thorough planning which ensured that scientific enquiry was a persistent and consistent element. In the very few schools where the curriculum was inadequate, only one science course was provided and that failed to meet the needs of all pupils. In one school, for example, several Key Stage 4 pupils missed two hours of the GCSE double award science course each week to attend a course at college. This need not have happened had they been able to take a single science course.

48. The past three years have seen great changes in science curricula in secondary schools. Many of these reflect increasing concern that insufficient numbers of students take courses post-16 to ensure that recruitment to science degree courses is adequate to meet the country's needs. The Government has made a commitment to 'achieve year-on-year increases in the number of young people taking A levels in physics, chemistry and mathematics' and to 'make science a priority in schools by including science in the Schools Accountability Framework'.[4] The changes to examination specifications and the National Curriculum are intended to tackle these concerns and to make the subject engaging and exciting.

49. The new programme of study for Key Stage 4 led to the introduction of new GCSE courses in September 2006, a year before other subjects. The full impact of these changes is yet to be seen, although some secondary schools have responded positively to them.

50. As well as fulfilling the requirements of the National Curriculum programmes of study and external examinations, a good science curriculum should also focus on the Every Child Matters outcomes. For example, it can make a major

[4] *Science and innovation investment framework 2004–2014: next steps,* HMSO, 2006.

contribution to pupils' understanding of what is to 'be healthy', what constitutes a balanced diet and which foods provide the necessary elements. It provides opportunities to teach about the negative effects of alcohol, solvent and drug abuse. It enables pupils to learn how the growth and reproduction of bacteria and the replication of viruses can affect health and how the body's natural defences may be enhanced by immunisation and medicines. It can also focus on human reproduction and on the physical and emotional changes that take place during adolescence. Being aware of potential dangers of using materials and equipment and 'staying safe' are key when working in science. Group work is often a requirement. This gives pupils the opportunity to 'make a positive contribution' to the successful working of teams whilst also enabling them to 'enjoy and achieve'.

51. The fact that the Government has made such a clear commitment to increasing the number of graduates in science also shows the subject's potential to contribute to the wealth of the country. This 'economic awareness' is another area that can be developed through the science curriculum. Some new GCSE specifications offer greater opportunities for such enrichment of science. Currently not many schools are taking full advantage of such opportunities to build in such links to their schemes of work for science.

52. In the very large majority of schools, pupils in Key Stage 4 can follow courses that lead to two GCSEs in science. Around 90% of all pupils attempted at least one science GCSE in 2006 with around half gaining a grade within the range A*–C. The programme of study for Key Stage 3 has been revised to complement the changes in GCSE and will be implemented in September 2008. A-level GCE specifications are being revised for implementation in September 2008.

53. In the Key Stage 4 curriculum, vocational pathways are developing alongside appropriately challenging academic pathways. Science departments are expected to provide courses that fulfil at least two purposes: first, to provide a science education that will equip individuals to live in an increasingly technological world and to understand the science that they encounter in their lives; second, to provide a course of study that will prepare pupils for further education or training in science beyond the age of 16. Schools should ensure that the range of courses available meets the needs of all pupils.

54. Ofsted's science inspections in 2006/07 focused on whether the courses schools offered met these requirements. Some schools had met the challenge well. They had analysed their pupils' needs carefully and offered them a good choice, including core and additional science that provided a balanced education and a suitable preparation for studying the subject at advanced level GCE; applied science with clear vocational elements that prepared pupils for further education, training and the world of work; and three separate sciences for pupils wanting to develop a particular specialism post-16. Schools that chose

Twenty First Century Science did so because they believed that studying science in a contemporary context would engage pupils more successfully.[5]

55. In collaboration with further education providers, some schools were widening their 14 to 16 curriculum to give pupils access to a variety of vocational part-time courses such as agriculture, engineering and other applied science areas. This was increasing the numbers continuing with their education beyond 16. Teachers had explained to pupils and parents what courses were available, what each course involved and how it would be assessed. They had helped the pupils to identify how they worked best and to identify the most suitable course.

56. In the most successful departments, the teachers used curriculum change effectively to extend the opportunities for discussion in class and to plan a wide range of relevant and stimulating activities. Their enthusiasm and skills in planning and delivery were crucial in ensuring the success of the innovations.

57. Another feature of the best science curricula was the focus on ensuring that what was taught drew on, and was relevant to, the pupils' own lives and experiences. The school in the next example recognised how science could be enriched by linking it with other curricular areas, in this case environmental studies and aspects of geography:

> In an area of significant limestone outcrops, Year 8 pupils had planned and carried out an investigation into the effects of acid rain. They had identified what parameters to measure, the variables involved and the techniques to use. This resulted in an impressive range of PowerPoint presentations on their research and a rich source of data for analysis. Researching the impact of acid rain on the water supply, public buildings and habitats in the immediate locality had clearly engaged and motivated them.

58. The best lessons seen made natural and mutually advantageous links between subjects. Thus, for example, pupils were able to consolidate their learning in mathematics by applying it in a scientific context. The highest performing specialist schools used such links particularly effectively and were able to use their specialisms to enhance the whole curriculum, as in the following example:

> A specialist college for mathematics and science had very well-developed links between science and other curriculum areas. These were made explicit in the scheme of work for each term and year group, as in these plans for a term:

[5] Twenty First Century Science is a set of flexible GCSE courses developed to meet the needs of both those who will go on to be professional scientists and those who will not. For further details, see www.21stcenturyscience.org.

- Year 7: links with history to explore the Black Death, science in the Islamic world, the Crusades
- Year 8: links with art on the effect of light and perspective
- Year 9: links with geography on weathering and erosion, tectonic activity, global environment issues, data handling and analysis
- Year 10: links with performing arts – a half-term drama workshop on the environment
- Year 11: links with art on scale and proportion, light in still life drawings, photo silk screens using ultraviolet light
- Years 12 and 13: links with business studies on sampling and interpretation of data, supply and demand calculations, evaluation of money sharing.

Through such activities, staff shared good practice and also helped pupils extend their understanding of how they learned.

The award of specialist status had enabled the school to offer new courses. For example, extra resources and staff training had been made available to support the introduction of Cognitive Acceleration through Science Education (CASE) into Years 7 and 8. The school had also been able to introduce the three separate sciences into Key Stage 4 earlier than originally planned by funding teachers to teach during 'twilight' time after the end of the school day. This was helping to challenge the most able pupils and to recruit larger numbers to study A-level sciences in the sixth form. Applied science had been introduced at GCSE and at A level to provide a vocational route from 14 to 19. Core and additional science GCSE courses were also part of the curriculum.

59. Despite such positive developments, too many of the schools visited failed to meet the full range of pupils' needs. In choosing new GCSEs, the weakest departments focused on identifying courses that were most similar to those offered previously, even when success rates had been low. Vocational pathways did not exist or developed too slowly. The main focus was on meeting the needs of the most academic pupils without any serious attempt being made to adapt the content and teaching of courses to meet the needs of a wider range of pupils. The schemes of work were too narrow, did not relate to pupils' experiences and did not link science to other areas of the curriculum.

Quality of leadership and management in science

60. In just over half the primary schools visited, the quality of leadership and management in science was good. In over a quarter, it was outstanding and it was inadequate in only one school.

61. In the schools where science was thriving, the coordinator had good support from senior management, was well organised and had a very clear understanding of the strengths of provision and the areas for development.

Good team work and critical reflection resulted in well-produced schemes of work which took careful account of new initiatives. Resources were deployed well and used effectively to make lessons interesting and relevant. Data on pupils' performance were collected and analysed systematically and used for planning. The following shows how one school moved towards this position:

> The school had been inspected by Ofsted and by local authority staff. The inspection team had identified the need to raise standards in science and to improve teaching and learning. The newly appointed headteacher evaluated standards and drew up a plan for improvement which included appointing an advanced skills teacher for two terms. During her tenure, she provided in-service training in knowledge and understanding of science and the skills of scientific enquiry. With the collaboration of the staff, she wrote a scheme of work that set out clear progression in all the attainment targets throughout the primary phase. She introduced a system for monitoring pupils' performance and for setting targets. She also led team-teaching sessions to introduce her colleagues to best practice and help them develop their own understanding and practice in a safe and supportive environment.

62. The better schools used lesson observations and the scrutiny of pupils' work effectively in order to monitor teaching and learning. Too often, however, the headteacher carried out the monitoring and the coordinator was not sufficiently involved to be able to identify and help to improve areas of specific concern.

> At a primary science conference attended by HMI, the coordinators were asked if they were involved in monitoring the lessons of other teachers and the standards of science education. A third said they did not see other teachers teach. One exasperated coordinator described how her headteacher saw her role as about no more than keeping the equipment in good order and making sure there were enough worksheets for science activities.

63. In many primary schools, the science coordinator's responsibilities were limited to overseeing day-to-day tasks rather than providing incisive leadership and management. This was partly because science was rarely a priority for improvement and therefore limited time was allocated to its management. However, where headteachers recognised the need to raise standards in the subject, the quality of monitoring and evaluation improved significantly, and included the direct observation of teaching and learning. The insights gained led to sharing good practice, identifying professional development needs and changes to individual teachers' practice.

64. In just over half the secondary schools in the sample, the quality of leadership and management in science was good. In one in seven, it was outstanding. In the small minority of schools where management and leadership were inadequate, clear evaluation of effectiveness was lacking. Monitoring of

teaching and learning was poor or non-existent and there was insufficient gathering and analysis of performance data to measure progress.

65. Well-organised and successful science teams in secondary schools often enjoyed effective support from senior managers. Strong departmental leadership produced a clear rationale for curriculum development, with good implementation of key national strategies and initiatives. Good team work amongst teachers resulted in well-produced schemes of work, coherent curriculum planning and a firm focus on improving teaching and learning and sharing good practice. Data on pupils' attainment and progress in relation to their prior performance were collected systematically and analysed thoroughly. Assessment was well-organised and consistently completed. Target-setting, for pupils and the teachers themselves, was thorough and led to improved outcomes. The effective tracking of progress and analysis of data resulted in accurate departmental self-assessment reports.

> The head of department in a secondary school could demonstrate clearly how standards had improved over the previous three years. He had ensured that all the science staff had been involved in a thorough analysis of data which resulted in an accurate assessment of the strengths and areas for improvement within the department. They had identified appropriate priorities including raising the achievement of higher performers in Key Stage 3; improving assessment for learning and self- and peer-assessment; improving the tracking of pupils' progress; and making increasing use of ICT.
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> The scheme of work was strong, well written and supportive; it gave teachers the opportunity to be innovative and to share good practice. It ensured that teachers planned for ICT, literacy and numeracy and also identified opportunities for spiritual, moral, social and cultural development. Planning was collaborative, with individuals taking responsibility for different units of the courses offered. Similarly, policies were thoroughly discussed and implemented by the whole department. There were plans to build further on this strong climate by introducing peer observation, in addition to the monitoring of teaching already being carried out by the head of department and senior staff.

66. In the best science departments, resources were organised well and supported pupils' high achievement. Teachers were well qualified and largely taught their own science specialisms. Monitoring of teaching and learning was thorough and helped to raise standards.

67. In the least successful departments, there was insufficient monitoring of teaching and learning. Lesson observation was not rigorous enough and managers did not have a clear idea of the strengths and weaknesses in their teams. Where there were several heads of department for the different branches of science, there were often significant variations in practice.

Accommodation and resources in science

68. In 2005, data from Ofsted's inspections showed that accommodation for science was good or better in around two fifths of secondary schools, and unsatisfactory in around a quarter.[6] This supported the findings of the Consortium of Local Education Authorities which indicated that, of the science laboratories in maintained schools in England, only 35% could be graded good or excellent. Of the remainder, 25% were either unsafe or unsatisfactory. This report also identified under-provision of 3,518 laboratories in schools.[7]

69. Unsatisfactory accommodation hinders teaching and learning in a number of ways. For example, classes not taught in specialist rooms have limited opportunities to conduct investigations or take part in practical activities. A mixture of specialist and non-specialist accommodation can lead to problems of timetabling and make it difficult for teachers to plan lessons which ensure continuity of learning.

70. The Government is committed to improving science buildings so that 'they reflect the latest thinking on what is required to ensure effective interactive teaching'.[8] It has made additional funding available for this, including money from the Building Schools for the Future and the Academies programmes.[9, 10] In addition, the DCSF has set up Project Faraday, the brief for which includes ensuring that designs for science:

- make use of the whole school building and its grounds, not just the laboratories themselves, to enable and enhance innovative and interactive methods of teaching science
- fully reflect the requirements of the new science curriculum
- are practical, affordable and replicable in other schools
- are developed in close collaboration with the demonstration schools.

71. In the current survey, the best teaching and highest standards were found in schools where staff drew on a rich range of resources to support a wide variety

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[6] *The annual report of Her Majesty's Chief Inspector of Schools 2004/05*, Ofsted, 2005; http://live.ofsted.gov.uk/publications/annualreport0405/4.2.15.html.
[7] CLEAPSS, *Laboratories, resources and budgets; a report for the Royal Society of Chemistry on provision for science in secondary schools,* 2004; http://chemistry.rsc.org/Education/Policy/Laboratories2004.asp.
[8] *Science and innovation investment framework 2004–2014: next steps,* HMSO, 2006.
[9] Building Schools for the Future is a major programme of capital investment which, through rebuilding, remodelling and upgrading, is intended to ensure that 'every child will be educated in a 21st century environment within 15 years' (www.number-10.gov.uk/output/Page5801.asp); www.teachernet.gov.uk/management/resourcesfinanceandbuilding/bsf/.
[10] Academies are publicly funded maintained ? independent schools, established by sponsors from business, faith or voluntary groups working with central Government and local education partners. For further information, please see: www.standards.dfes.gov.uk/academies/.

of activities. These were carefully planned to match pupils' needs and stimulate their interest. Where resources were limited, the pupils were involved in a restricted range of activities, few of which were matched to their abilities and interests or enabled them to pursue independent investigations. This was particularly evident in schools which relied almost exclusively on a single published scheme of work.

Good practice in schools and colleges post-16

72. Between October 2006 and April 2007, Ofsted conducted a survey of good practice in post-16 science education. The work was published by Ofsted as *Identifying good practice: a survey of post-16 science in colleges and schools*.[11] The survey involved visits to 18 schools and colleges where science had been judged good or outstanding in the previous inspection report.

73. In 12 of these schools and colleges, achievement and standards were outstanding, examination pass rates were high, and many students went on to study science in higher education. A range of enrichment activities helped them examine science from a variety of perspectives and to see the range of career opportunities it offered. However, there were few opportunities for them to take sciences at Levels 1 and 2, and progression routes to Level 3 courses were unclear.[12]

74. In eight of the institutions visited, the quality of teaching and learning was outstanding. The vast majority of science teachers were subject specialists. Some had valuable industrial or vocational experience and many had been external examiners. They made particularly good use of practical work, giving students direct experience of the laboratory and analysis techniques relevant to each discipline and balancing this carefully with theory and written work. They asked direct, probing questions and stimulated discussion about 'big questions' in science, including ethical issues. They were also making increasing use of assessment for learning, which was beginning to have an impact on students' learning. Subject-based workshops and peer mentoring were highly effective in helping students to improve. Year 12 students appreciated support from older students who, in turn, spoke very positively about the unexpected benefits of immersing themselves in a topic in order to help someone else.

75. The vast majority of the science laboratories seen during the survey were modern and well equipped, providing good environments for learning. Many included electronic whiteboards and data projectors. The teachers used a range of ICT effectively, including PowerPoint, video clips and web downloads. Some courses made extensive use of learning materials on CD-ROM or on the World

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[11] *Identifying good practice: a survey of post-16 science in colleges and schools* (070027), Ofsted, 2008; www.ofsted.gov.uk/publications/070027.
[12] For an explanation of the differences between levels, see www.qca.org.uk/qca_6631.aspx.

Wide Web. In physics and electronics lessons, students regularly used data-logging software to capture data and process information. However, they rarely did this during practical work in physics and chemistry. Despite their evident skills in this area, students used ICT more outside the classroom than within it.

76. In 11 of the colleges and schools visited, the quality of leadership and management was outstanding. In the best instances, science teams were very well led and self-assessments were comprehensive, evaluative and honest. However, school staff were less self-critical than their college counterparts, partly because self-assessment had been established for longer in colleges.

Initial Teacher Education

77. Ofsted has a continuing programme to inspect the quality of teacher training in England. This includes a focus on how well trainees are prepared to teach specific subjects.

78. Trainees for primary teaching are generally prepared well to meet the required standards for teaching science and most providers have good mechanisms for tracking the progress they make.

79. Overall, primary trainees spend too little time on relating the teaching of science to what is known about the way that pupils learn at various stages of their development. Therefore, although they have a good knowledge of the standards for the award of Qualified Teacher Status and what is required to meet them, their understanding of how to plan and sequence activities in a way that will help pupils progress is limited. As a result, they rely too heavily on published schemes of work without adapting them to their pupils' particular needs. During their blocks of school experience, they also spend too little time working with science coordinators.

80. Those preparing to teach science at secondary level are not given enough opportunities to work with pupils across the full age and ability range. Their experiences of teaching the most able pupils are particularly limited.

81. There is not enough emphasis on training new teachers to use science to promote the core skills of numeracy and literacy. Some good links are made between science and ICT but these tend to be limited. For example, ICT is not used well in monitoring and control in carrying out practical work.

Enhancement courses in physics and chemistry

82. The Training and Development Agency for Schools (TDA) funds pre-initial training courses for graduates who are interested in teaching but who need to enhance their subject knowledge so that they can teach secondary pupils. Among the subjects offered are physics and chemistry. Trainees enrolled on these 26-week courses receive a bursary to support them during their studies.

They are required to have experience of the subject to at least A-level standard through holding an A level in the subject, having an element of it in their initial degree course and/or through occupational experience. The scheme is intended to encourage a wider pool of people to enter teaching and to create a better balance in the subject specialisms of teachers between the three sciences.

83. The DCSF asked Ofsted to monitor these enhancement courses. Overall the courses are meeting the challenge of enhancing trainees' knowledge and understanding of physical sciences as a preparation for training to be science teachers. The following summarises the findings from inspection visits to four providers.

84. Common strengths of the courses included the following:

- The bursary had made it possible for trainees to enrol. Without it, the large majority of trainees would not have applied.
- Trainees showed high levels of commitment to the enhancement courses and to entering initial teacher education for physical sciences.
- The content of courses related closely to the specification set down by the TDA.
- Course leaders and tutors felt that the meetings organised for them by the TDA offered good opportunities for communicating with other providers and ensuring that work was well coordinated across institutions.

85. Common weaknesses included the following:

- Quality assurance procedures were not well developed and were not applied consistently.
- Assessment procedures lacked clarity, including arrangements for resits, their timing, and whether they could be used to improve performance rather than simply to achieve a pass grade.
- Self-assessment and peer assessment were underdeveloped. Trainees often did not have a clear understanding of tools such as learning logs. Assessment was understood as being done to them rather than involving them.
- The rooms in which the courses were taught often limited the work that could be done and reduced tutors' flexibility in structuring and sequencing activities.

Part B. Issues in science

Scientific enquiry and how enquiry works

86. Preparing pupils to behave like scientists is a focus of successful teaching and learning in science. It is a key component of the National Curriculum programmes of study and forms the basis of 'scientific enquiry' at Key Stages 1 and 2 and 'how science works' at Key Stages 3 and 4. At primary and

secondary level, the highest achievement in science occurs most often where pupils have frequent opportunities for experimentation, investigation and analysis.

'Forensic scientists' were arriving after their playtime. As they entered the room, they were very careful not to disturb anything and to preserve any evidence. For many, this was their first time at the scene of a crime. The 'officer in charge', the class teacher, described what had been found and invited observations, comments and questions. It was quickly established that the white powder found near the body had also been found on the clothing of the victim. The scientists suggested the murderer worked with powders and had inadvertently left the powdery deposit while attacking the victim. This could be the link to the murderer. The officer in charge had identified four people who worked with four different white powders. She had gathered samples of these powders and had made them available to the forensic scientists who worked together in groups to share their observations and to come up with suggestions for their work. They decided that, if they could match the white powder from the body with one of the four white powders collected from the four suspects, they would be one step nearer the murderer. They knew that one white powder can look very much like another so they needed to identify more characteristics which might be matched with it. Would it dissolve in water? Would it react with an acid? What would happen when it was heated?

Throughout this activity it was the pupils who raised the questions and decided how they would test their ideas. It was the pupils who took turns to speak, who listened carefully to the ideas of their collaborators and who made sure everyone joined in. They sorted out what they would do to ensure their tests were fair and, when the teacher asked about their plans, they readily provided appropriate information. One group asked to use the digital microscope and computer. They used the interactive whiteboard to display the images of the powder found next to the body and a sample of each of the four known powders from the suspects. They captured and printed images of the powders to help other groups in their enquiries. All this was accomplished without direct intervention by the teacher. By the end of the session, the pupils had experienced around two hours of intense science work. The intensity was not imposed by the teacher but resulted from the pupils' high levels of involvement. Their commitment and engagement in the scientific enquiry reflected the way they had been taught. They expected not only to take part but also to take decisions on how to carry out their enquiries. Importantly, they saw themselves as scientists. The activity in which they were taking part was much richer and far more stimulating than simply carrying out a practical procedure by following instructions.

87. The results of this survey show that schools are now placing greater emphasis on learning through investigative work and this is having a very positive impact on pupils' understanding and enjoyment of science. However, there is still some way to go before it is a regular part of every pupil's experience.

88. In some schools, practical work is too heavily directed by teachers and there is too much reliance on work sheets. In these circumstances, practical activities are often used to illustrate points rather than to give pupils the opportunity to plan and conduct their own investigations. Some secondary schools place too much emphasis on transmitting knowledge about science rather than also developing pupils' scientific skills and conceptual understanding. In some cases, this reflects weaknesses in the teacher's subject knowledge and a lack of the specialist expertise needed to teach scientific enquiry well.

> A teacher introduced a Year 7 class to practical work where they were going to extract vegetable colour from a beetroot and use it to determine whether solutions were acid or alkali. In her introduction, she used the terms 'macerate', 'extract', 'mortar', 'pestle', 'indicator', 'pH', 'acid', 'alkali' and 'filtration' but at no time did she explain what any of these meant. She then gave out a worksheet where pupils were required to use these words, plus various measurements they had made, to fill in gaps in the text. One girl decided that it was 'a bit like cooking'. She bashed her beetroot into a pulp and carried out the instructions on the worksheet. She realised that she had to fill in the gaps and set about doing so by asking the teacher for the answers or by copying from others. She almost completed the gap-filling but could not say why she had used specific words in particular places. In talking to the inspector at the end of the lesson, she and many others showed that they did not understand what they had done or why and their grasp of the new vocabulary was very insecure. Therefore, although they had, as they put it, 'done things with stuff', they had learned very little.

Continuing professional development

89. In 2006/07, Ofsted's science inspections focused on the challenges that primary teachers face in teaching science, the continuing professional development they have received and what they consider they need to be more effective. These issues were also discussed at a number of conferences for those engaged in primary science education.[13] The views of teachers and the outcomes of the conferences were consistent with the inspection evidence about the quality of science in primary schools.

[13] These conferences were supported by Ofsted and a range of other organisations including the QCA, the National Strategies and the National Advisers and Inspectors Group for Science.

90. Where teaching in science is weaker teachers often have limited knowledge of science. However, little training is available, beyond that which their school provides. The extent and quality of in-school training depend very much on the effectiveness of science coordinators. Some are successful in extending their colleagues' skills, knowledge and understanding. To be effective they need the support of their headteachers but this is not always forthcoming.

> A coordinator in a primary school reported that, as part of workforce reform, her headteacher had instructed the class teachers only to teach the programmes of study for Sc2 (life processes and living things), Sc3 (materials and their properties) and Sc4 (physical processes). To free time, they would not teach Sc1 (scientific enquiry); this would be covered by a supply teacher who would come in from time-to-time. The decision had been taken without considering how pupils' scientific enquiry skills would be secured or how pupils' knowledge and understanding would develop effectively if Sc1 were divorced from the rest of the programmes of study.

91. In areas where local authority science networks are good, coordinators are given the leadership training to help them improve teaching and learning and disseminate good practice. However, such networks are not widespread.

92. Since 2004, in collaboration with the Wellcome Trust, the DCSF has established a network of Science Learning Centres to provide high-quality professional development for all those involved in science education in primary and secondary schools and further education.[14] Their mission is broad, embracing psychology, earth science, astronomy, citizenship and other areas, in addition to the three traditional sciences. The intention is to improve subject knowledge and awareness of the impact of science in society, and encourage inspirational and innovative teaching. Reflecting this mission, all centres have close links to higher education institutions and have a wide range of partners from industry and the professions, as well as schools and local authorities.

93. Too few schools in the survey, however, took advantage of these centres. Some were aware of the courses they offered but did not apply for them because of financial constraints and the distance from their nearest centre.

94. The vast majority of primary schools visited did not know that the centres existed and were also unclear about what other sources of professional development were available. Secondary schools had a better understanding of the training opportunities the centres offered, and most of those who had used them had found the support helpful.

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[14] There are nine regional centres in England (funded by the DCSF) and a National Centre at the University of York (funded by the Wellcome Trust) to serve all the United Kingdom.

95. The in-service training offered through the Key Stage 3 Strategy and, more recently, the Secondary National Strategy has helped to improve the teaching and learning of science. However, its impact depends very much on the skills and capabilities of the head of department. Opportunities are often missed to share good practice or use peer observations to improve practice. In too many schools, there has been very little recent continuing professional development in science.

96. There is a need to ensure that headteachers and senior staff are aware of the opportunities for continuing professional development in science and have a good understanding of what contributes to effective teaching and learning. Continuing professional development which is well focused can have a positive impact on raising standards, as this example shows:

> In a school with specialist science and mathematics status, the applied science coordinator was a lead practitioner for the Specialist Schools and Academies Trust. She was also an advanced skills teacher, deployed to give advice and continuing professional development in other schools as well as her own. She had established extensive links with the local community and ran regular events, clubs and professional development for linked primary schools which promoted good transition from Key Stage 2 to Key Stage 3. The school had been recognised for its good practice in the use of interactive whiteboards. London Challenge therefore funded the installation of further interactive whiteboards which enabled the school to offer continuing professional development on using them to other schools in the area.[15]

Separate sciences and specialist teaching

97. Since the introduction of the National Curriculum, pupils have been required to follow a course of balanced science in Key Stage 3. It has also been the expectation that, at Key Stage 4, pupils would follow a course of study leading to double award science at GCSE.[16] In setting this target, the Government recognised that a minority of pupils would wish to follow only a single award balanced science course in order to pursue specialisms in other subject areas.[17]

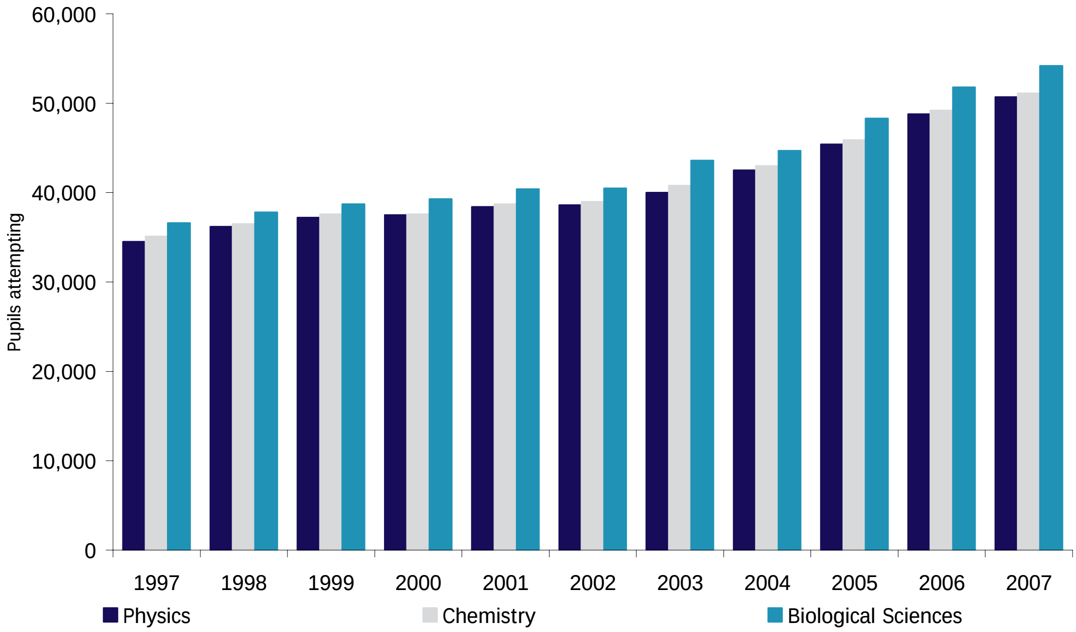
98. In 2004, the Government published a 10-year investment framework for science and innovation which included a range of ambitions, including ensuring 'a strong supply of scientists, engineers and technologists'.[18] In response to

[15] City Challenge is a five-year partnership between the Government, schools and boroughs to raise educational standards in London's secondary schools. www.teachernet.gov.uk/wholeschool/london/.
[16] Double award science is the combined study of biology, chemistry and physics that leads to two GCSEs. Those passing GCSE in double award science can progress to study science at A level.
[17] Single award science combines the study of biology, chemistry and physics. A pupil cannot easily progress to study a science subject at A level if single award science is chosen for GCSE.
[18] *Science and innovation investment framework 2004–2014: Next steps,* HMSO, 2004.

this, the DCSF put a strategy in place to increase the number of schools that offer the three separate sciences of biology, chemistry and physics (triple award science) at GCSE.[19]

99. Double science equips pupils with the necessary knowledge, understanding and skills to study science A levels. However, evidence from the DCSF and qualitative evidence from Ofsted suggest that those who study three separate sciences are more likely to choose to study science at A level and degree level. The Government is encouraging all schools to make triple science an entitlement for all pupils attaining Level 6 at the end of Year 9. Currently, some 52% of specialist schools and about 20% of maintained comprehensive schools offer their pupils triple science. Figure 6 shows the increases in the numbers of pupils studying separate sciences at GCSE level.

Figure 5: Number of pupils entered for GCSE physics, chemistry and biological sciences, 1997 to 2007



Figures for 2007 and 2006 are based on revised data. Figures for all other years are based on final data.
Sources: DCSF: *GCSE and equivalent examination results in England 2006/07 (revised)*, SFR01/2008; *GCSE and equivalent examination results in England 2005/06 (revised),* SFR01/2007; *GCSE and equivalent results and associated value added measures in England 2004/05 (final)*, SFR26/2006. *GCSE and equivalent results and associated value added measures for young people in England 2003/04 (final)*, SFR25/2005.

[19] Success criteria include all pupils achieving Level 6 at Key Stage 3 being entitled to study triple science; all specialist science schools offering triple science; and all schools being encouraged to make triple science available to their pupils.

100. Encouraging schools to offer triple science could be seen to conflict with other government statements advocating greater curriculum flexibility. On the other hand, offering triple science to pupils who would benefit is entirely compatible with the aim of ensuring that the curriculum is sufficiently flexible to meet pupils' needs. Since some schools may find it difficult to implement this change, the Government is encouraging them to collaborate with other schools, further education colleges and universities to extend the resources available to them.

101. The move to increase the availability of triple science has clear implications for staffing. In 2006, the National Foundation for Educational Research published a report on staffing for mathematics and science departments in secondary schools.[20] This showed that, of the science teachers in England, 44% had a specialism in biology, 25% in chemistry and only 19% in physics. The Government recognises the need to increase recruitment in shortage areas and its aim is that, by 2014, 25% of science teachers should have a specialism in physics and 31% a specialism in chemistry.[21]

102. Both the DCSF and Ofsted consider that qualified science teachers are competent to teach effectively across the three subjects at Key Stage 3. Therefore, there is no shortage of qualified teachers at this level.

103. In schools which offer triple science at Key Stage 4, Ofsted's inspectors have not noted significant numbers of staff teaching an area for which they are not qualified. Schools make it a priority to allocate specialist staff to teaching A level and separate sciences at GCSE. Around 90% of A-level teaching is done by those with a degree in the relevant science. Data provided by the DCSF show the least specialist teaching occurred in GCSE double award science, where only two fifths of teachers of chemistry had studied it at degree level or during initial teacher education. The situation in physics was worse, with only a third of the physics elements being taught by staff with a physics degree or qualified in the subject through their initial training.

104. In 2005, the last year for which such data were collected, science inspectors made judgements about the match of teachers to the curriculum and related this information to the judgements on the quality of teaching, standards and achievement. As Figure 5 shows, the better the match of teachers to the curriculum, the higher the achievement of pupils.

Figure 6: Relationship between achievement and the match of teachers to the curriculum in science (percentage of secondary schools 2004/05)

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[20] *Mathematics and science in secondary schools: the deployment of teachers and support staff to deliver the curriculum,* National Foundation for Educational Research, 2006; www.nfer.ac.uk/research-areas/pims-data/summaries/mathematics-and-science-in-secondary-schools-the-deployment-of-teachers-and-support-staff-to-deliver-the-curriculum.cfm.
[21] *Science and innovation investment framework 2004–2014: Next steps,* HMSO, 2006.

The key shows the achievement of pupils. Percentages are rounded and may not add up to 100%. Figures are derived from Ofsted's section 10 inspections in 2004/05.

105. This relationship was also seen in the primary and post-16 phases. Subject knowledge alone is not a measure of effective teaching. However, where it is combined with enthusiasm and effective teaching, it makes a major contribution to raising pupils' achievement.

Recruitment of students to science post-16

106. In school sixth forms and sixth form colleges, the majority of science courses offered are at level 3, that is, at GCE, AS and A level.[22] Most schools can offer biology, chemistry, physics and psychology, and class sizes are often small. In sixth form colleges, the range of courses is usually wider, including, for example, electronics, environmental science and geology, and class sizes are larger. Interestingly, both in schools and colleges, the number studying physics remains relatively small while the number choosing psychology has increased markedly in recent years.[23]

[22] The National Qualifications Framework supports the qualifications system. Level 1 qualifications include National Vocational Qualifications (NVQ) and the Business and Technician Education Council (BTEC) Introductory Award. Level 2 qualifications include GCSE, General National Vocational Qualifications (GNVQ) and the BTEC First Diploma. Level 3 qualifications include A level, Vocational Certificate of Education Advanced Level and the BTEC National Diploma. www.qca.org.uk/14-19/qualifications/116.htm.

[23] Psychology is classified as a science by the Learning and Skills Council subject sectors but is often regarded as a social science in schools and colleges.

107. Schools and sixth form colleges use a variety of post-16 syllabuses. Some use Salters and Nuffield courses in chemistry, biology and physics as alternative syllabuses.[24] A few try to broaden their students' understanding by offering AS courses in public understanding of science or perspectives on science. The students who take these courses enjoy the breadth of topics and the ethical and philosophical discussions they entail.

108. General further education (GFE) and tertiary colleges offer AS and A-level courses alongside vocational options, such as BTEC courses in applied science, forensic science, ophthalmology and dispensing pharmacy. These courses attract a wider range of students than the science courses offered by schools and sixth form colleges. GFE colleges also offer level 2 courses (usually BTEC diplomas) as progression routes to level 3 studies. Enrolment on level 2 vocational courses is not high. In schools and sixth form colleges the progression to level 3 is usually through GCSE. Vocational science courses at levels 2 and 3 are rare. Sixth form colleges make some provision for level 2 sciences, usually in the form of opportunities for students to repeat GCSE courses. Here again, numbers are not high and progression routes from level 1, through level 2 on to level 3 sciences are underdeveloped. Improved collaboration between providers could help promote better progression routes.

109. Sixth form colleges and GFE colleges successfully offer access to higher education courses in a variety of sciences, including nursing and psychology. These attract mainly adult students who have returned to study. The numbers tend to be small but the success and progression rates are high.

110. The Government has identified a shortfall in the number of students taking science post-16 and has therefore set new ambitions, including to:

- achieve increases each year in the number of young people taking science A levels so that, by 2014, there are 35,000 entries in physics (currently 24,200); 37,000 in chemistry (currently 33,300); and 56,000 in mathematics (currently 46,168)
- continually increase the number of pupils gaining at least Level 6 at the end of Key Stage 3 (11- to 14-year-olds)
- continually increase the number of pupils achieving A*–B and A*–C grades in two science GCSEs.[25]

111. Where the numbers recruited to A-level sciences are low, the students often talk about how it is more difficult to attain higher grades for entry to university in sciences (particularly physics and chemistry) than in other subjects. Where the numbers recruited to post-16 science courses are increasing, several factors

[24] For further information on these courses, see www.salters.co.uk/institute/curriculum.html and www.nuffieldcurriculumcentre.org/.
[25] *Science and innovation investment framework 2004–2014: Next steps,* HMSO, 2006.

come into play, the most frequently mentioned being the enjoyment gained from the subject and the enthusiasm of particular teachers.

> A 13–18 school had a comprehensive intake. Over the years, the science department had maintained high levels of attainment across the year groups. Close collaboration with Key Stage 2 and middle schools to moderate assessment and agree standards, as well as to identify the most relevant courses for Year 9, had led to an increase in Key Stage 3 results. At GCSE, AS and A2 the students were given very positive experiences and they repeatedly cited enjoyment as a reason for choosing to study science beyond the age of 16. There were now 47 A-level physicists, 31 chemists and 24 biologists in the sixth form, a remarkable achievement set against the national picture where physics recruits fewer students than any other subject and has the lowest numbers of entries for A level.
>
> The success of science in this school resulted not only from the teachers' energy and enthusiasm but also from the belief in the importance of students' active involvement. There was a strong focus on giving them opportunities to discuss, consider data, plan and carry out practical tasks, and analyse results. Most lessons maintained a brisk pace and high levels of engagement through well-directed questions, a variety of modes of learning, changes of activity and a good range of teaching and learning styles well matched to individuals' needs. The department had introduced courses in the three separate sciences for higher ability students who wished to take them. Staffing levels allowed subject specialists to teach the separate sciences, whether as part of the GCSE courses in separate science or as modules within the combined science course. The study of separate sciences served students well and was a further factor which contributed to high levels of recruitment to AS and A2 courses.

Literacy in science

112. Science, like other subjects in the curriculum, has an important role in developing pupils' literacy skills. Planning, conducting and reflecting on investigations provide excellent opportunities for pupils to express their own opinions, to listen to those of others, and to develop and refine their ideas. Discussion also provides opportunities for teachers to identify and challenge misconceptions and to help pupils clarify their own thinking and to work together to find solutions to problems.

113. Having talked through and clarified their ideas, the pupils are in a better position to write coherently about the activities in which they have been involved. Through science, pupils can be involved in a range of different types of writing, including extended writing.

114. Science provides opportunities for pupils to extend their understanding by reading about a wide variety of topics ranging from the seen to the unseen,

from the immediate to the universal, from the individual to the global. It also enables them to develop their research skills by integrating information from different sources. As well as giving pupils access to a rich range of non-fiction writing, it can be a spur for them to develop their imagination through exploring the rich range of science fiction writing available for all ages.

115. The Ofsted *Secondary subject report 2000/01: science* showed that the most effective development of literacy skills to support teaching and learning in science involved:

- reinforcement of the meaning and use of terminology by pupils in context
- a reduction in routine written descriptions of practical activity and more writing about pupils' own understanding and interpretation of information
- extended writing for other purposes such as 'ideas and evidence'
- reading about issues in science as well as reading for information.[26]

116. In 2004, as part of the Key Stage 3 Strategy, the then Department for Education and Skills published guidance on how schools might make better use of literacy in science.[27] In the three years since its publication, there has been an increased focus on literacy development in science. It is now common for teachers to have strategies to help their pupils deal with scientific terminology and to focus on the purpose of their writing. Even so, in the secondary schools inspected, the reading activities were too often confined to worksheets and focused too much on copying out notes, an approach that was particularly ineffective for pupils whose reading skills were weak and that resulted in poor attitudes and misbehaviour. The most positive responses were seen in science lessons which provided a good range of experiences, including recording and reporting, discussing and presenting. Pupils enjoy writing about science in their own words. Too often, however, they are required to write to a prescribed pattern which limits their thinking and learning. The following is a quite unusual example of writing by a Year 8 boy whose science teacher had asked him to write creatively about weathering.

> Douglas the rock was sitting around quite happily when all of a sudden he was picked up by some horribly rude child and thrown very hard into the sky, where he flew in a curve until he bounced off a tree and landed in a pond. He was petrified. Nothing like that had ever happened to him before. As he bounced off the tree, he had lost a small chip of himself, into which water was slowly seeping. And it was getting dark.
>
> Later that night, Douglas awoke to find a searing pain in his head, all around the chip. He tried to turn around to look, but found he couldn't

[26] *Secondary subject report 2000/01: Science* (HMI 371), Ofsted, 2001; www.ofsted.gov.uk/assets/2887.pdf.
[27] *Literacy in science,* DfES, 2004.

move. And this wasn't how he normally couldn't move (due to him being a rock), but he was surrounded by frozen water! Suddenly part of his head exploded. He blacked out.

The next morning he woke up to find part of a plant stuck in him. Luckily the plant had lifted him slightly out of the water, so he could see himself. Douglas saw that the part of his head that had exploded was around where the original chip was. He deduced that water had got in and expanded, which smashed part of him away. That force must have also blasted him backwards into a plant, which got stuck in him. Then the water level receded. But because he was stuck on a plant it left without him, so he was lifted into the air. Of course, that was just his theory but it made sense.

He hung there miserably for years, getting cold at night, then warming up each day. He noticed that bits of him were crumbling off. Douglas thought why this could be and came up with another theory. He theorised that, as he was made up of a few different types of mineral, they must be expanding and contracting at different rates when the temperature changed. Therefore, they were no longer connected as strongly and were falling apart.

He stayed on the plant for almost two years, before someone came and picked up the plant and carried it off, with Douglas still on it! He turned and twisted and eventually saw it was the horrid child who had first thrown him at a tree. Douglas instantly wished that the child was dead. He knew it was a terrible thing to wish, but he didn't care, he wanted the kid to suffer as much as Douglas himself had.

The child eventually stopped and threw the plant and Douglas into another pool. At least this one was warm. Too warm, it was contaminated with industrial acid. Douglas's last vision was of a child waving before he dissolved into nothingness.

117. This boy has brought a range of science concepts to bear on his moving account of Douglas's demise. His writing shows that literacy development in science need not be confined to key word lists, displays and the development of scientific vocabulary, but can be a vehicle for promoting and enriching imaginative and cognitive development.

Spiritual, moral, social and cultural development

118. The spiritual, moral, social and cultural development of pupils has a significant part to play in science education. However, inspectors rarely see science lessons that are designed specifically to foster it. Where it does occur, it tends to result from the flair and creativity of individual teachers:

In a Year 11 science lesson, the teacher had set a challenge for pupils to plan a rearing regime for a beef calf. The target was to bring about a good profit on the calf but also to take ethical and moral issues into account. They were asked to log the actions they would take and their consequences and implications. They had worked up their plans and the justifications for their choice. A wide range of issues arose including the confinement of calves to maximise growth and minimise energy dissipation; the use of antibiotics which would protect calves but possibly have an impact on the human food chain and people's response to antibiotics; the use of land for meat production when the same area of pasture could produce so much more food through arable cultivation; the inclusion of waste material such as beer slops from a local pub in the calves' diets; society's responsibility to ensure sufficient food for the world's population, even if this is at the expense of luxurious western lifestyles. The pupils were fully committed to the work and clearly enjoyed explaining their strategies. When asked about their enjoyment and commitment to science, their responses centred on the inspirational nature of the teaching; the way that their views were valued, listened to and never dismissed; the fact that matters discussed were so often relevant to their lives; and the opportunities they were given to plan and take part in lessons, rather than simply carrying out instructions or copying materials for notes.

119. Having a sense of awe and wonder is the experience of any human being, and it is a human attribute to be curious about the questions of life, its origins and its future. Sir Isaac Newton (1642-1727), mathematician and physicist, was one of the foremost scientific intellects of all time, whose work was hugely significant in founding our modern understanding of the world through science. In late editions of his scientific works, he expressed a strong sense of God's providential role in nature. His work challenges any assumptions that matters of faith and of science are intrinsically antagonistic. More recently, Albert Einstein wrote: 'Science without religion is lame, religion without science is blind'.[28]

120. Skilled science teachers are sensitive to what their pupils believe, take on their ideas and offer their own and others' opinions too. In this way, they enhance their pupils' understanding of the contribution of science to life and society.

Schools with specialist science status

121. During this survey, inspectors visited 11 schools with specialist science status. Provision for science overall was outstanding in only one of these:

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[28] *Science, philosophy and religion, A symposium,* Conference on Science, Philosophy and Religion in Their Relation to the Democratic way of Life Inc., 1941.

Of the six lessons seen, three were good and three were outstanding. The lessons had clear objectives which took careful account of the range of pupils' abilities and made close links to other areas of the curriculum. The teaching was of high quality with teachers using a wide range of resources effectively, including ICT, to explain and reinforce the objectives.

The scheme of work was detailed and supportive but provided plenty of scope for teachers to develop their own ideas and improve provision. Staff were knowledgeable and shared good practice and expertise, ensuring a good balance across the three science subjects.

The department was working hard to raise individual pupils' performance. Much additional support was provided in class and through out-of-class activities, such as booster sessions and revision groups.

The department knew itself well. Pupils were regularly involved in monitoring each other's work and the head of department had established an effective annual cycle for reviewing all pupils' books. The department had collected a portfolio of evidence on standards which provided a good basis for developing greater consistency in accurate assessment. Technicians made a significant contribution to the quality of the department's work.

122. The curriculum provision was good in nearly two thirds of the specialist schools as opposed to just over half of the schools without specialist status. The specialist schools also offered a greater number of science courses. The best schools provided an enriched curriculum in Key Stage 3 and a broad range of courses in Key Stage 4 and post-16.

In one very effective school, all the science courses covered the National Curriculum and examination requirements fully and were presented in a way which made them highly relevant to pupils' lives. The school had introduced Cognitive Acceleration in Science Education into Key Stage 3, which had impacted positively on the achievement of pupils. Staff were keen to get hold of the new programmes of study for that key stage so that they could be used to enrich and improve their current scheme.

The school had put a great deal of effort into ensuring that the pathways for 14- to 19-year-olds met the full range of needs. In Key Stage 4, around half of them were following a triple science course with considerable success. In Year 11, they could follow both applied and additional routes. A high proportion chose post-16 courses which included health and social care and applied science as well as traditional A-level courses.

A major strength of the department was the way that staff ensured that science was not treated as a separate entity but constantly related to other areas of the curriculum. They also provided pupils with many opportunities to extend their understanding of science through involvement in a wide range of extra-curricular activities, including clubs, meetings, booster classes and visits.

123. The quality of leadership and management of science was good in around two thirds of the specialist schools visited, compared to around a half of other maintained schools. However, in most cases, it was not clear how the science specialism was being used to promote higher standards in the rest of the school. Only in a small minority did the head of science have a clear role in disseminating good practice. There was generally little contact between the head of science and the head of mathematics, the other subject contributing to science specialist status.

124. Schools had used the additional money that came with specialist school status in a range of ways, including refurbishing laboratories, purchasing resources and investing in additional staffing. Several schools had increased staffing at middle management level in order to improve monitoring and evaluation, tracking and target-setting. Specialist schools are required to meet additional targets in the particular subjects contributing to their status. However, these were not very challenging. Staff in these schools could not describe what new knowledge or skills they had acquired as a result of the award of specialist status. The heads of science felt that, in this respect, the Secondary National Strategy had been more influential.

125. The findings of this survey support the view that the curriculum and leadership and management in specialist status schools are better than in other maintained schools. This might be because schools apply for specialist status because their own evaluation indicates that science is a leading subject. However, analysis of inspection evidence describing teaching and learning suggests that specialist schools have made insufficient progress in these areas and more needs to be done to ensure that specialist status is linked to higher achievement in science.

Notes

This report is based on evidence gathered as part of section 10 and section 5 inspections of schools during the period 2004 to 2007. It draws on survey work carried out by Ofsted on good practice in post-16 science education and on the provision for initial teacher education. Evidence has been gathered through the subject survey programme for science carried out by HMI and Additional Inspectors to a national sample of primary, middle and secondary schools. Inspectors visited 90 primary and 105 secondary schools between 2004 and 2007.

The report is also informed by evidence gathered through conferences, some of which have been organised by Ofsted in collaboration with organisations such as the Qualifications and Curriculum Authority, the Secondary National Strategy, Science

Learning Centres, and the National Advisers and Inspectors Group for Science. HMI have also gathered information and views from a range of organisations concerned with science education. These include the Association for Science Education, the National Advisers and Inspectors Group for Science, the Royal Society, the Royal Society of Chemistry, the Institute of Physics, the Institute of Biology, the Earth Science Teachers' Association, and the Consortium of Local Education Authorities for the Provision of Science Services (CLEAPSS).

Further information

Association for Science Education (ASE)
This is the UK's largest science association dedicated to the teaching of science which has over 25,000 members worldwide.
www.ase.org.uk

Consortium of Local Education Authorities for the Provision of Science Services (CLEAPSS)
CLEAPSS is an advisory service providing support in science and technology for a consortium of local authorities and their schools including establishments for pupils with special needs. Independent schools, post-16 colleges, teacher training establishments, curriculum developers and others can apply for associate membership.
www.cleapss.org.uk

Department for Children, Schools and Families (DCSF)
The Department for Children, Schools and Families leads work across government to ensure that all children and young people:

- stay healthy and safe
- secure an excellent education and the highest possible standards of achievement
- enjoy their childhood
- make a positive contribution to society and the economy
- have lives full of opportunity, free from the effects of poverty.

The main website is found at:
www.dcsf.gov.uk

In 2004, the then Department for Education and Skills collaborated with Her Majesty's Treasury, the Department of Health and the Department of Trade and Industry to produce a discussion paper concerned with the position of science in education and the economy: *Science and innovation investment framework 2004–2014: next steps*. This presents the next steps in taking forward the Government's science and innovation investment framework in 2004–2014. Against the background of increasing global competition for knowledge-intensive business activity, it presents the next steps in five key policy areas: maximising the impact of public investment in science on the economy through increasing innovation; increasing research councils' effectiveness; supporting excellence in university research; supporting world-class health research; and increasing the supply of science, technology, engineering and mathematics (STEM) skills. The document is available from www.berr.gov.uk/dius/science/science-funding/framework/next_steps/page28988.html. This page includes a link to the framework document that preceded it.

Department for Innovation, Universities and Skills (DIUS)
The Department for Innovation, Universities and Skills brings together functions from two former departments: science and innovation responsibilities from the Department of Trade and Industry; and skills, further and higher education from the Department for Education and Skills. The department draws together the nation's strengths in colleges, research, science and universities.

DIUS is working with partners from the commercial, public and voluntary sectors to:

- Accelerate the commercial exploitation of creativity and knowledge, through innovation and research, to create wealth, grow the economy, build successful businesses and improve quality of life.
- Improve the skills of the population throughout their working lives to create a workforce capable of sustaining economic competitiveness, and enable individuals to thrive in the global economy.
- Build social and community cohesion through improved social justice, civic participation and economic opportunity by raising aspirations and broadening participation, progression and achievement in learning and skills.
- Pursue global excellence in research and knowledge, promote the benefits of science in society, and deliver science, technology, engineering and mathematics skills in line with employer demand.
- Strengthen the capacity, quality and reputation of further and higher education systems and institutions to support national, economic and social needs.
- Encourage better use of science in government, foster public service innovation and support other government objectives which depend on the DIUS's expertise and remit.

www.dius.gov.uk

Earth Science Teachers' Association (ESTA)
The aim of the ESTA is to advance education by encouraging and supporting the teaching of Earth sciences at all levels, whether as a single subject such as geology, or as part of science or geography or other courses.
www.esta-uk.org/main.html

Institute of Physics (IoP)
The Institute of Physics runs a schools and colleges web resource. This provides information about their latest curriculum development initiatives, the Affiliated

Schools Scheme and professional development courses, as well as resource links and information about the various support networks available.
www.iop.org/activity/education/index.html

Institute of Biology (IoB)
The Institute of Biology's Education and Training Department works to improve biology education in schools, colleges and universities. It offers advice on science education issues in collaboration with other learned societies.
www.iob.org/general.asp?section=education_careers

Lifelong Learning UK (LLUK)
Lifelong Learning UK (LLUK) is the independent employer-led sector skills council responsible for the professional development of all those working in community learning and development, further education, higher education, libraries, archives and information services, and work-based learning across the UK. It represents the interests of over one million individuals working in lifelong learning in England, Northern Ireland, Scotland and Wales and is the voice of employers in this sector on skills issues.
www.lifelonglearninguk.org/2760.htm

National Advisers and Inspectors Group for Science (NAIGS)
NAIGS is the subject group for science inspectors, advisers and consultants, and is affiliated to and administered by the Association for Science Education. Its role is to provide continuing updating of information and developments in science, professional development and networking opportunities. It has close links with schools in all phases to support and advise staff on issues relating to science education.
www.ase.org.uk/htm/membership/naigs.php

Qualifications and Curriculum Authority (QCA)
The QCA is committed to building a world-class education and training framework. Its role is to regulate, develop and modernise the curriculum, assessments, examinations and qualifications.
www.qca.org.uk

The curriculum section of the QCA's website sets out all aspects of curriculum design, timetabling and monitoring, including details of the national curriculum and schemes of work.
www.qca.org.uk/qca_104.aspx

The Quality Improvement Agency (QIA)
The Quality Improvement Agency (QIA) has been set up to spark fresh enthusiasm for innovation and excellence in the further education sector. It is leading the challenge to those involved in teaching, learning and training to lift their performance and implement the government's reforms for learning and skills.
www.qia.org.uk

Royal Society
The Royal Society, the national academy of science of the UK and the Commonwealth, is at the cutting edge of scientific progress. The Royal Society is keen to support scientists of the future and to help us all gain the scientific understanding we need in order to make effective decisions, be active citizens and ensure the UK remains competitive and prosperous. The teachers' section of the website is found at:
http://royalsociety.org/landing.asp?id=10

Royal Society of Chemistry
The education activities of the Royal Society of Chemistry cater for chemical scientists of all ages. The organisation produces a wide range of resources for teachers, lecturers and students, provides training and continuing professional development courses, maintains professional registers and contributes to education policy.
http://rsc.org/Education

Secondary National Strategy
The Secondary National Strategy for school improvement is part of the Government's major reform programme for transforming secondary education to enable children and young people to attend and enjoy school, achieve personal and social development and raise educational standards in line with the Every Child Matters agenda.
www.standards.dcsf.gov.uk/secondary/?version=1

Science Learning Centres
Science Learning Centres provide continuing professional development for everyone involved in science education, at all levels. There is a network of 10 centres across the country.
www.sciencelearningcentres.org.uk