raising standards
improving lives

Maintaining curiosity

A survey into science education in schools

The report sets out the findings of a new survey of science in 91 primary and 89 secondary schools, which was carried out between 2010 and 2013. This report will support schools in implementing the new National Curriculum.

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Executive summary

Physicians take an oath that commits them to 'first do no harm'. The best science teachers, seen as part of this survey, set out to 'first maintain curiosity' in their pupils. The most successful schools visited during this survey had adopted this as a key principle in teaching science and this not only fostered enthusiasm for the subject in their pupils but helped them to fulfil their potential.

We need better science education to secure a strong foundation for a successful and technological society. The new National Curriculum for 2014 sets out why we teach science in schools:

> 'A high-quality science education provides the foundations for understanding the world through the specific disciplines of biology, chemistry and physics. Science has changed our lives and is vital to the world's future prosperity, and all pupils should be taught essential aspects of the knowledge, methods, processes and uses of science. Through building up a body of key foundational knowledge and concepts, pupils should be encouraged to recognise the power of rational explanation and develop a sense of excitement and curiosity about natural phenomena. They should be encouraged to understand how science can be used to explain what is occurring, predict how things will behave, and analyse causes.' [1]

This report highlights the importance of teaching science for understanding. For pupils to achieve well in science, they must not only acquire the necessary knowledge, but also understand its value, enjoy the experience of working scientifically, and sustain their interest in learning it. Pupils in schools need to discover the concepts revealed through observing scientific phenomena and conducting experimental investigations for themselves. Then they are more likely to continue to study science and use that learning for work, for family, and to contribute as informed citizens.

The report also reflects and explores the concerns often voiced by employers, higher education, and the scientific community's professional bodies, that too many school leavers are not well-enough equipped scientifically with practical, investigative and analytical skills. These are vital if young people are to flourish in a technological world and to contribute to economic development. The government's review of GCSE and A-level qualifications provides a timely opportunity to ensure that the skills of scientific enquiry are assessed as an integral part of these qualifications.

The report is set out in three sections. Part A describes primary provision, Part B secondary provision, and Part C explains evidence-based factors that promote achievement in science. Inspectors visited 91 primary and 89 secondary schools,

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[1] National Curriculum in England: science programmes of study, Department for Education, 2013; www.gov.uk/government/publications/national-curriculum-in-england-science-programmes-of-study.

including 53 with sixth forms, and six special schools, between summer 2010 and spring 2013. The best teaching in these schools:

- was driven by determined subject leadership that put scientific enquiry at the heart of science teaching and coupled it with substantial expertise in how pupils learn science
- set out to sustain pupils' natural curiosity, so that they were eager to learn the subject content as well as develop the necessary investigative skills
- was informed by accurate and timely assessment of how well pupils were developing their understanding of science concepts, and their skills in analysis and interpretation so that teaching could respond to and extend pupils' learning.

The majority of the teachers observed were skilful in teaching interesting science lessons and inspectors judged the majority of the lessons (69%) they saw as good or outstanding. However, a minority of the secondary schools visited were preoccupied with test and examination results as ends in themselves at Key Stage 4, rather than aiming to establish pupils' understanding and application of scientific ideas through practical enquiry-based approaches to learning.

Where disadvantaged pupils study academic GCSEs, they achieve as well as other pupils when teachers hold the same high expectations for all. GCSEs provide the greatest range of routes for pupils to access further science study at 16. However, too few 16-year-old girls continue studying physics nationally. Not enough subject leaders analyse why pupils of both genders either continue or stop studying science subjects after the age of 16. Uninspiring teaching was one reason pupils gave to inspectors to explain why they did not wish to continue studying science. Another was not seeing the purpose of what they were studying, other than to collect examination grades.

There were common weaknesses in a significant minority of lessons in both the primary and secondary schools visited:

- activities did not match each pupil's prior learning, so that some pupils wasted time or did not complete work
- pupils became disengaged from learning and more able pupils in particular were not given work that was challenging enough
- teachers failed to provide pupils with feedback that really helped them to improve their work.

In nearly half of the primary schools visited senior leaders were not setting targets for science and were not tracking pupils' progress in the subject. This was because they no longer saw science as a priority, despite its place as a core subject in the National Curriculum.

A very low proportion of the subject leaders in the survey had received specific professional development in providing leadership for science. However, schools that had provided science-specific professional development were much more likely to be judged as outstanding in their overall effectiveness of science.

Key findings

- In the best schools visited, teachers ensured that pupils understood the 'big ideas' of science.[2] They made sure that pupils mastered the investigative and practical skills that underpin the development of scientific knowledge and could discover for themselves the relevance and usefulness of those ideas.
- Attainment in science up to 2012 has risen year by year at all key stages, and girls attained better than boys at all key stages. Despite this, too many girls do not continue to study physics or related subjects at 16.
- Leaders in the schools visited were not monitoring and evaluating the reasons why their pupils, both boys and girls, pursued routes other than science at 16.
- Science achievement in the schools visited was highest when individual pupils were involved in fully planning, carrying out and evaluating investigations that they had, in some part, suggested themselves.
- Although the quality of teaching was at least good in the majority of the schools visited, lessons in both primary and secondary schools often lacked sufficient differentiation to allow pupils, especially the more able, to build on their prior learning and make good progress.
- The quality of feedback to pupils on how they might improve their science understanding was a common area for improvement in the primary and secondary schools visited, regardless of the school's overall effectiveness in science.
- Teachers who coupled good literacy teaching with interesting and imaginative science contexts helped pupils make good progress in both subjects.
- A significant minority of leaders in the primary schools visited were failing to ensure full coverage of the science National Curriculum. They did not track pupils' progress in science effectively and were not setting challenging targets for improvement in science. For these leaders, science was no longer a priority.
- The effectiveness of science in both the primary and secondary schools visited was much more likely to be outstanding when teachers and subject leaders had received science-specific training. However, most of the primary teachers had not received such training, and most of the science leaders in both phases had not received leadership training that was specific to science.

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[2] For a useful, school-level cataloguing of the 'big ideas', see: W Harlen (ed) *Principles and big ideas of science education*, Association for Science Education, 2010; www.ase.org.uk/bookshop/books-for-subject-leaders/.

- Timetables in a significant minority of the primary and secondary schools visited did not allow enough time for teaching science through regular, enquiry-based learning. This limited pupils' opportunities to develop the practical skills necessary for future work in science, technology or engineering. This included restricting science to irregular 'science days' in primary schools, and limiting the teaching time for the three separate science GCSEs to the same amount as for a double science award in secondary schools.
- In most of the schools visited, pupils from Key Stage 1 to Key Stage 4 had limited opportunities to work independently, particularly to develop their individual manipulative skills in practical work, because teachers only required them to work in pairs or small groups.

Recommendations

The Department for Education (DfE) and The Office of Qualifications and Examinations Regulation (Ofqual) should:

- ensure that qualifications include assessment of the skills needed for scientific enquiry.

School leaders, including governing bodies, should:

- provide sufficient weekly curriculum time and, in secondary schools, laboratory space so that individual pupils develop good scientific enquiry skills as well as the knowledge they need to pass examinations
- provide subject-specific continuing professional development for subject leaders and teachers that improves the quality of assessment and feedback for pupils in science.

Science subject leaders should:

- in primary schools, monitor pupils' progress in science regularly to ensure they are supported effectively to reach their potential
- in secondary schools, monitor and evaluate the progression of different groups of pupils and their continuation to science-related pathways in education, employment or training, against the national proportions for those groups
- develop literacy through using science as a motivating context for pupils.

Science teachers should:

- use assessment effectively to plan lessons that build on individual pupils' prior knowledge and provide feedback that genuinely helps pupils to improve their work in science

- allow pupils enough time to secure their understanding of the science concepts they are studying and complete their investigations.

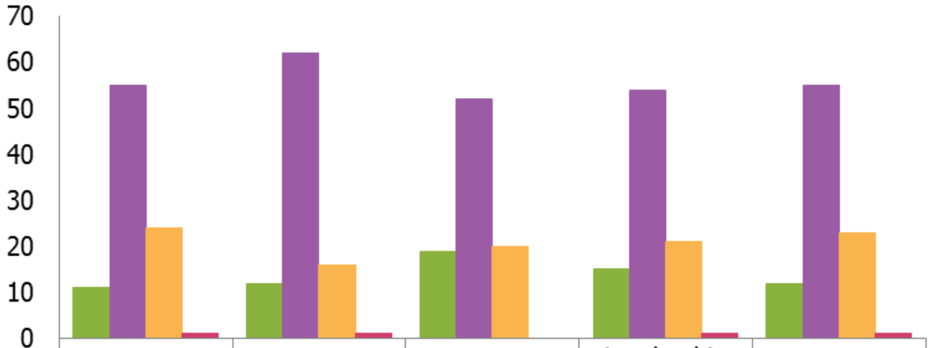
Part A: Science in primary schools

Overall effectiveness

1. Science is not taught every day in most primary schools. When Ofsted notifies a school of a science survey visit, the headteacher often organises a special, and therefore atypical, day of science teaching. This allows inspectors to base their judgements on having seen some science teaching in every year group, therefore drawing from as wide an evidence base as possible. But it may be that these atypical lessons are not fully representative and that routine teaching of science is not always as good as the lessons seen during the inspectors' visits.

2. The overall effectiveness of science was good or outstanding in the majority of the 91 primary schools visited, including the three special schools. This is similar to the findings of the previous triennial report (*Successful science*), although the proportion of outstanding science has not improved (about one in 10 primary schools) since then.[3] Figure 1 shows the distribution of inspection judgements for overall effectiveness, as well as the key aspects of achievement, teaching, the curriculum, and leadership and management.

Figure 1: Science judgements in the primary school sample (by number of schools)



	Achievement	Quality of teaching	Curriculum	Leadership and management	Overall effectiveness
Outstanding	11	12	19	15	12
Good	55	62	52	54	55
Satisfactory/requires improvement	24	16	20	21	23
Inadequate	1	1	0	1	1

3. The criteria that inspectors use for judging achievement give considerable, although not exclusive, weight to the attainment of pupils and their progress

[3] *Successful science* (100034), Ofsted, 2011; www.ofsted.gov.uk/resources/100034.

over time, using each school's own teacher assessments.[4] Working scientifically (Sc1) is given more weight than scientific knowledge (Sc2, 3 and 4). Given the evidence from inspectors' observations during the survey of relative weaknesses in pupils' skills of scientific enquiry, the National Curriculum levels recorded through teacher assessment for all schools appear to be too high (see paragraph 4). Some of the outstanding schools visited considered that the materials available to help teachers to judge National Curriculum levels in science (a process known as 'levelling') were not demanding enough to fully meet the criteria in the National Curriculum, and the levels awarded did not meet the expectations of subsequent secondary school users. These schools were working closely with other partners, including secondary schools, to moderate their judgements to make sure that the levels awarded represented pupils' achievement in science securely and could be relied upon to inform subsequent planning.

Achievement

4. Headline figures on pupils' achievement in science have risen marginally since the previous report. National Key Stage 2 teacher assessment data for 2012 show that 86% of 11-year-olds gained Level 4 or above; this is one percentage point higher than in 2011. In 2012, girls attained three percentage points higher than boys, although the proportions of boys and girls gaining the higher Level 5 were identical at 36%. This was also one percentage point higher than in 2011. But these overall figures mask a wide range of science achievement in individual schools, differences between different groups of learners, and a disparate approach to assessing and recording science achievement across schools. These increases are at odds with a general decline in attention to science in about half of the primary schools visited.

5. In the schools visited, the teachers that took science assessments seriously felt that the optional tests did not challenge pupils and did not allow an accurate assessment of a pupil's understanding in science. International tests have shown a relative decline in the performance in science of 10-year-old pupils in England.[5] This coincided with the end of statutory assessments in science in 2009. Most teachers in the schools visited no longer provided pupils with time to revise and review their science knowledge, and most prioritised English and mathematics above science, which is still a core subject in the National Curriculum. This is a worsening of science provision since 2011, with about half of the school leaders in the survey citing the removal of SATS as the main reason they no longer paid as much attention to science. The few schools visited that were outstandingly

[4] *Generic grade descriptors and supplementary subject-specific guidance for inspectors on making judgements during subject-survey visits to schools* (20100015), Ofsted, 2013; www.ofsted.gov.uk/resources/20100015.
[5] M O Martin, I V S Mullis, P Foy, and G M Stanco, *TIMMS 2011 international results in science*, Chestnut Hill, MA: TIMSS & PIRLS International Study Center, Boston College, 2012; http://timssandpirls.bc.edu/timss2011/international-results-science.html.

effective at science retained a programme of monitoring, evaluation and intervention for science that was as robust as it was for the other two core subjects.

6. Invariably, achievement was highest where pupils were involved in planning, carrying out and evaluating investigations that, in some part, they had suggested themselves. They learnt best when they could see how the science they were studying linked to real world experiences, revealed more about the 'big ideas' in science, and connected with and supported their learning of other subjects, including English and mathematics. Learning in this fashion engages and enthuses pupils, develops their natural curiosity, and motivates them to find out more.

7. Explicit connections between science and literacy, when teachers made them, showed clear evidence of better science and literacy outcomes for pupils. Imaginative teaching allowed pupils to use their science work as a purpose for their reading and writing, in effect doubling the time available to teach both subjects. Given that the vast majority of primary teachers of science also teach English to the same pupils, they know how to improve reading, writing, speaking and listening alongside the science work itself. There were exceptions, however, where some pupils and teachers saw science as a 'relief' from English and as a subject where pupils 'did not need to write much'.

8. Although there were no significant differences in outcomes between groups of pupils in three quarters of the primary schools visited, too many groups of pupils were still not achieving as well as others in the same school. The most common difference was the lower achievement of boys in science and the most common reason for this was their relatively weaker literacy skills. This hampered their reading about science, their discussion of their ideas, and their recording and reporting of their investigations. One sign of this was teachers' frequent comments to pupils about incomplete work. Teachers were tempted to short-cut any writing tasks in lessons, anxious that pupils moved on to practical work. This reinforced the idea in pupils' minds that clear planning and subsequent recording of observations and results were not important parts of science practical activities. At its worst, inspectors heard pupils say: 'We like science because we do not have to write anything.'

9. In a quarter of the schools visited, higher ability pupils were not given enough challenge.[6] This often occurred alongside poor opportunities for pupils to plan, carry out and evaluate investigations independently. This sometimes related to teachers' lack of understanding of the purpose of scientific enquiry and of the value of constructing activities that lead pupils to discover the scientific ideas for themselves.

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[6] Ofsted has reported on this in more detail in *The most able pupils: are they doing as well as they should in our non-selective secondary schools?* (130118), Ofsted, 2013; www.ofsted.gov.uk/resources/130118.

10. Where achievement was rising over time, the improvements could be traced to these six features– in no particular order:

- increasingly accurate assessment
- a high profile accorded to science in the school
- coverage of the full science National Curriculum programmes of study, rigorously monitored
- staff who were confident in teaching pupils how to work scientifically
- strong links between literacy and science
- very good, regular monitoring of achievement in science for individuals and groups of pupils.

11. The following shortcomings were found where achievement was weaker:

- lack of monitoring of pupils' progress in a way that was timely enough to drive improvement in science
- topic-based approaches that did not cover all of the content and skills of the science programmes of study
- reduced teaching time for science
- practical work restricted to a series of formulaic instructions for pupils that inhibited their independence.

12. A majority of the primary schools visited gave pupils opportunities to develop some independence and research skills through scientific investigations. When those opportunities were missing, pupils had no chance to raise their own questions, devise experiments to find out answers, or evaluate their work to see if their results were fair, reliable and accurate. This happened when teachers limited pupils' thinking by doing most of the planning for them. Pupils were then not making decisions about what they studied or the questions they needed to find answers for. Their teachers lacked understanding of the need for pupils to make key decisions based on prior knowledge and understanding, not just on a sense of 'Guess what you think will happen'. Teachers who showed pupils how they could ask their own questions and set up investigations that would help to reveal answers to those questions experimentally showed that this could be done well.

13. In about a third of the primary schools visited, pupils knew how well they were doing and what they needed to do to improve. This proportion is not high enough and contrasts with the generally good information that the same pupils had about their work in English and mathematics, almost always from the same teacher. The proportion is much lower than in the secondary schools visited, where about two thirds of the pupils knew what they had to do to improve in science. In the best practice seen, each pupil had a tracking sheet showing what she or he needed to do to achieve the different levels of science

investigation. This was supported when teachers annotated pupils' work to point out which targets were being met. The pupils were also clear about the level they were aiming to achieve.

14. An inspector's notes below sum up how opportunities were being missed to involve pupils in practical work:

> 'One or two pupils were involved in demonstrating their understanding of a nutritionally balanced meal by assembling a meal on a plate from a selection of different food types while the rest [of the pupils] just sat on the carpet and watched and drifted away. Others had to record the results of a teacher demonstration that took 25 minutes, recording (but not measuring for themselves) a temperature every minute! Pupils were well capable of following instructions, working cooperatively, taking responsibility for carrying out and recording. But they could be passive when teaching did not require them to be thinking and participating. They enjoyed hands-on practical opportunities, although at times the purpose of these activities in supporting pupils' knowledge and understanding of science was not made explicit by the teacher.'

15. Pupils' behaviour was good or outstanding in almost all the primary science lessons seen. In general, the more responsibility that pupils were given, the better they learnt, the more they enjoyed their discoveries and the better they behaved. When teachers talked for too long, or limited the challenge, pupils tended to be passive; even then, most remained patient.

The quality of teaching

16. Analysis of 327 lessons in the primary schools visited showed that the best teaching took place in the Early Years Foundation Stage: inspectors judged 89% of lessons in the Foundation Stage to be good or outstanding. Teachers focused on giving each child the time and resources she or he needed to explore and investigate the physical world. Children became engrossed in whatever activity they were doing; teachers capitalised on their interest as they steered activities towards developing children's basic skills.

17. There was little difference between the quality of science teaching at Key Stage 1 (67% good or outstanding) and Key Stage 2 (73% good or outstanding).

Teachers' subject knowledge

18. Teachers' subject knowledge was good or outstanding in three quarters of the primary schools visited, and adequate in the rest.

19. Despite concerns raised by various government agencies and professional associations about the lack of science subject specialists in primary schools, the evidence from this survey indicates that this was not a serious barrier to pupils' achievement in terms of teachers' knowledge and understanding:

according to national figures, attainment in primary science has risen, generally speaking, over time. Most primary teachers are not subject specialists – nor have they been in the past.

20. There were individual examples of teachers not spotting errors in pupils' work or of occasional inaccuracies in terms of technical explanations, but these were not seriously hampering pupils' learning. Teachers of science in the survey knew the limitations of their subject knowledge; they also knew how to find out information to support their teaching: through their subject coordinator or through partnerships and contacts in other schools. They prepared the content of science lessons conscientiously, even when they were not too familiar with the science concepts involved.

21. When things went wrong, it was more often to do with teachers thinking they knew the science involved when actually they did not, or attempting a lesson that was too difficult or too easy for the pupils, given their abilities and prior knowledge. The latter occurred when teachers had an insufficient understanding of progression in the curriculum, both in general terms, and in the specific experiences of their pupils. In a few cases, insecure subject knowledge led to insecure assessment of standards, as the following illustrates.

> Teachers were not sure about what pupils' performance at different levels looked like. They knew how pupils learnt and used those strategies in their teaching, but they lacked confidence in the higher levels of science and this was hindering their assessment of those levels. The teachers gave pupils feedback on the quality of the work in terms of its presentation, but gave less feedback on the academic standards, so the pupils did not know what National Curriculum levels they were working at or what they could do to improve.

22. Not every teacher, even in the effective schools, was convinced by – or confident enough about – scientific enquiry as the most effective way for pupils to learn about science. This was evidence of the failure of science leadership in the schools to ensure that, first and foremost, teachers meet the overarching aims of the National Curriculum for science. These aims spell out clearly the central role of scientific enquiry in developing pupils' ideas, skills, knowledge and understanding in a way that sustains their natural curiosity.

23. The consequences of this failure are that teachers go straight to the detail of a particular lesson, drawing ideas and activities from published frameworks without considering how the teaching might meet the wider aims of science education or the pupils' individual learning needs. Some of the teachers were keener to cover the content than to develop pupils as independent, inquisitive young scientists. It also explains why many lessons were controlled by the teacher, with detailed, step-by-step instructions. All pupils attempted the work, regardless of their prior knowledge, and often without any opportunity

to plan the investigation for themselves. There was a strong tendency towards worksheets that, ostensibly, 'scaffolded' the activity, but more frequently were preventing the pupils from thinking for themselves about the experimental method.

24. Occasionally, teachers did not really recognise whether an investigation needed to repeat rigorously the familiar stages of a 'fair test'. Some investigations are, essentially, practical experiences that reveal scientific phenomena, enhance pupils' dexterity and measuring skills, and allow opportunities for pupils to observe carefully and record; quite simply, some investigations might not be testing a particular hypothesis. In addition, when a 'fair test' was actually required, some teachers allowed pupils to suggest too many (spurious) variables that would not result in the concept of a fair test being illustrated. Teachers' thinking about independent, dependent and controlled variables was confused.

25. A further common weakness was that pupils had very little scope to try out their own ideas and then evaluate later whether their investigation really was fair and their results trustworthy. Teachers' undue emphasis on planning sequences of instructions rather than allowing pupils to discover ideas through enquiry and evaluation led pupils, in some cases, to think that their experiment and its results did not matter. Yet it is only when pupils come to evaluate results and examine them against those of other pupils that they begin to understand what 'fair testing' looks like and why it is necessary.

26. In addition, pupils' skills of observation, drawing, measuring, recording, analysing, and calculating were underdeveloped, because these were not consistently taught and teachers did not give the pupils sufficient time to develop them. Although the process of designing and doing investigations is important, it is just as important to learn how to do this accurately, reliably and consistently. It is also essential that pupils develop a healthy scepticism for apparently 'scientific' facts; they need to recognise that established scientific knowledge is built upon repeatable experimental observations and results, not one-off assertions.

27. Through Key Stages 1 and 2, pupils began to work in groups and while this helped to develop their collaborative and communication skills, it risked losing independent thinking, as well as the individual mastery of the necessary manipulative and measuring skills referred to above. Teachers would not consider group work for every lesson in other subjects. In a small minority of the classes seen, the groups were too large for any significant improvement in individual pupils' investigative skills.

Continuing professional development

28. There was a strong correlation between a school's provision of continuing professional development (CPD) for teaching science, and the overall effectiveness of science. Seven of the 32 primary schools in the survey that

provided CPD for science had outstanding science provision compared with five of the 58 that did not. This low proportion of schools offering CPD indicates clearly the low priority given to improving science teaching and learning. Many of the headteachers spoken to during the survey commented on this explicitly: they pointed out the removal of end-of-key stage national tests in science and were of the view that because Ofsted regarded English and mathematics alone as key, these schools were not taking science as seriously as they did before 2009.

29. Generic teaching skills and knowledge apply as much to science as other subjects, for example, planning for differentiation or managing behaviour. All the teachers from whom the information was gathered during the survey reported at least reasonable access to training of this kind.

30. Some school leaders noted reduced numbers of primary science support officers in their local authority. However, the better schools arranged training for clusters of their local schools, including working with partner secondary schools, to help fill the subject-specific vacuum that had been created.

Planning to meet pupils' needs

31. Most of the lessons seen during inspections were planned well enough to engage pupils' interest overall and met an appropriate learning intention. But a common weakness, even in the better schools, was the lack of detailed pupil-level planning that built on individual pupils' prior knowledge and experience. Typically, teachers compensated for this by using their personal knowledge of their pupils' abilities to adapt the generic plan as the lesson unfolded.

32. It was the execution of otherwise good overall plans that sometimes led to weak outcomes. The most common weakness was teachers talking too much at the start of a lesson. The majority of the lessons that inspectors saw had been planned to accommodate the range of ability in the class, usually 'by outcome', that is, all the pupils would do the same activity but the teacher expected them to perform differently. This approach works well if the more able pupils can use the more challenging material from the beginning; however, sometimes all pupils had to complete every task.

33. It was relatively rare to see pupils grouped by ability in primary science lessons, even though this would be the case for the same pupils in English and mathematics lessons (usually with the same teacher who would therefore know them). Some teachers deliberately paired more able pupils with less able partners; in this way, they hoped to enhance the learning of the more able pupils by requiring them to explain the science to their partners. But, more often, this approach meant that the less able pupils lost the chance to think through the activity for themselves, as the group leader did the thinking.

Ofsted

Assessment, including marking

34. The use of assessment to inform subsequent teaching was no better than adequate in around half the schools visited. This weakness is not unique to science, but it was still the most common area for improvement that inspectors identified in science inspections of primary schools. Some teachers tried to involve their pupils in self- and peer-assessment, but it was rare to find examples of this working effectively to raise attainment and improve pupils' understanding of science. Here is one of the outstanding examples seen.

> Assessment for learning in one of the schools visited was the strength of the outstanding teaching, because it resulted in a very good match of task to talent, swift intervention from teachers and teaching assistants if learning faltered, and high expectations coupled with supportive challenge for all pupils to go further. There was time for pupils' reflective thinking, especially as they planned their own investigations. Their skills of collaboration and researching ideas helped to make group discussions worthwhile. They relished learning in this way, and it was not just in science: the approach extended to other subjects. A key feature was the care with which teachers acknowledged good work and displayed it publicly, thereby showing pupils that their teachers held the work in high regard.

35. The day-to-day marking of pupils' science work varied in quality. It was good in just over half the schools visited. In these schools, teachers rewarded good learning, corrected errors and suggested the next steps that each pupil should take to move on. In the best examples, these steps were framed as clear and specific actions for pupils, ranging from requests for further details on a diagram to additional questions to encourage the pupil to aim for higher levels. In the weaker examples, the advice was vague and unrelated to science, such as suggestions that pupils might 'think a bit harder' or 'remember to use a pencil for diagrams next time'. Even in the best cases, however, it was uncommon to find pupils actually acting on the advice by making the suggested corrections or completing further answers.

36. Only about a quarter of the schools in the survey were using the 'Assessing Pupils' Progress' materials from the former Qualifications and Curriculum Development Agency (QCDA). Those who did so said they found the materials helped them to 'level' the Sc1 component accurately, but most of the teachers were attempting to assess every pupil in this way rather than sampling a pupil from a similar group.

37. In most of the schools visited, however, accurate levelling of any science strand depended on its teachers' ability to recognise pupils' achievements against the National Curriculum level descriptions. A minority of the science leaders moderated their judgements with colleagues in nearby primary schools. Teachers used a variety of approaches, ranging from simply their past

experience to using optional tests from the DfE or previous end of key stage national tests. This can work well, especially if teachers combine summative assessment with a systematic review of learning carried out by the pupils themselves.

> One of the schools visited used a 'scrapbook' approach. Teachers asked pupils to review and summarise a science topic some months after they had been taught it. This approach reinforced the original learning, aided their literacy and communication skills, and was used as a literacy activity to develop the pupils' skills of summary through using a familiar context. This work was part of English teaching time so it did not shorten teaching time for science. It generated some deep learning of science content that went beyond the minimum required by the National Curriculum, because pupils needed to properly understand the science they had first learnt by investigation in order to explain the ideas clearly. It also helped teachers to level the work and gave them a secure way to confirm pupils' deeper understanding of the big ideas in science.

38. The survey revealed wide variations in the rigour of determining teachers' assessments of pupils' attainment in science. Practice varied from half-termly, closely moderated summative checks on progress leading to intervention and support, to 'levelling' once a year with no quality assurance. Both extremes generated data but of different reliability, depending on the rigour of moderation rather than any lack of subject expertise among teachers. With less emphasis in some schools on refining pupils' subject knowledge and understanding in preparation for SATs, less data was available in the form of practice tests. Given that secondary schools usually receive pupils from several different primary schools, the variation in reliability resulted in some science teachers in secondary schools being unconvinced that the data bore much relation to what pupils actually knew, understood and could do.

Information and communication technology

39. About two thirds of the schools visited used information and communication technology (ICT) for science, and about half of these did this effectively to support the teaching of science. Most commonly, this was through teachers' use of presentation software, including multi-media pictures and clips of scientific phenomena. In a small minority of the schools visited, the pupils used ICT regularly for internet-based research themselves. It was unusual, however, for the teachers to use ICT to record and process evidence from experiments.

40. Opportunities were often missed to use technology to help in processing data from investigations and to give direct evidence to pupils of the underlying concepts.

A Year 3/4 class had to find out if there was a link between how far they could leap from a standing position and the length of their thigh bone. This was an enjoyable activity with an element of competition and allowed pupils to speculate from everyday experience about what the conclusion might be. They could plan for repeating results to get an average jump distance.

Given a class of 30 pupils, the experiment generated a huge amount of data, which would become tedious to process manually and even trickier for these young pupils to plot graphically. However, the teacher decided to drop the idea of a graph in favour of a bar chart in which he grouped thigh-bone lengths into arbitrary 'short', 'medium' and 'long' sets, and then attempted to work out an overall average for the three sets. This lost the continuous nature of the variables and the chance to explore exceptions to a general 'rule'. Indeed, one girl in the class had already predicted an exception, when she said her little sister could 'jump much further, because she goes to gym club'.

The teacher missed the opportunity to engage the class with discussions about this hypothesis. Given spreadsheet technology, the pupils could have collected the data, entered it jump by jump, then let the software process the numbers and plot a line graph that would have shown the trend, and all of the outliers, and allowed sensible discussion of data collection.

The quality of the curriculum

41. The science curriculum was good in around three quarters of the primary schools visited.

42. Successful collaborative work occurred with teams of staff, including teaching assistants and other interested adults with some specialist knowledge.[7] They designed and taught a curriculum that embedded science with other subjects, allowing pupils to connect scientific ideas and concepts with topical applications.

43. Teaching time for science was sometimes extended successfully when science was used as a context for literacy and, sometimes, numeracy. Teachers used science content as material for reading and writing non-fiction.

Pupils in one school visited spent 20 minutes reading in every morning registration, using material from newspapers, magazines and the internet and then summarising this current affairs information. Science featured in at least a third of the examples. Teachers adapted the original newspaper

[7] See, for example, Ofsted's *Good practice resource – innovative curriculum design to raise attainment: Middlestone Moor Primary School*; www.ofsted.gov.uk/resources/good-practice-resource-innovative-curriculum-design-raise-attainment-middlestone-moor-primary-school.

or magazine text to match pupils' reading skills. The approach gave pupils a wide knowledge of science in society and also helped them to raise their own questions about the topics.

44. A significant minority of the primary schools visited had adapted the International Primary Curriculum (IPC).[8] This includes some science topics, although it does not cover the National Curriculum content fully. However, the underpinning rationale of the IPC emphasises pupils' questioning and sets up a climate of enquiry at the start of topics by asking pupils what they want to find out. That approach is particularly effective for science, because it allows teachers to set up practical investigations to answer questions that pupils have raised, providing a motivating purpose and context for learning.

45. Science lessons took place once a week in the majority of the primary schools visited, usually in the afternoon. The length of time for a lesson varied, with the better practice allowing the lesson to extend into the next day, if this was necessary to complete the investigation. A strong feature of the Early Years Foundation Stage was that teachers allowed children to complete the activity they had chosen; the older the pupils were, the less likely it was that they had the freedom to take time to explore ideas, find solutions and get to the bottom of their enquiry.

46. Some headteachers, however, chose to run occasional 'science days' each term or to include some science content within wider topics. This meant several weeks might pass before pupils did any science, with the risk of their practical scientific enquiry skills regressing. Such arrangements usually also resulted in incomplete coverage of the National Curriculum content. There were rare exceptions where coverage of science content through a topic approach worked very well.[9] But only when:

- tracking of progress and coverage was exceptionally rigorous
- teachers were fully committed to adjusting subsequent topics to make up for shortfalls
- science was taught weekly in every topic.

Extra-curricular activities

47. Extra-curricular science activities enriched science learning very well in the schools visited. Almost all of the schools provided science-based trips, had science visitors, and offered science clubs. Some schools used science, technology, engineering and mathematics subject (STEM) ambassadors

[8] For further information on the International Primary Curriculum, see: www.greatlearning.com/ipc/.
[9] See, for example, Ofsted's *Good practice resource – innovative curriculum design to raise attainment: Middlestone Moor Primary School*; www.ofsted.gov.uk/resources/good-practice-resource-innovative-curriculum-design-raise-attainment-middlestone-moor-primary-school.

effectively to illustrate the application of science; such visits were effective in stimulating pupils to think about science careers.[10] A growing number of schools also had a substantial commitment to reducing their carbon footprint, as illustrated here.

Extra-curricular science in this rural primary school is its major strength. Its excellent, science-based partnerships with the high school result in interesting and high-quality science club activities, including sophisticated computer-aided simulation work on model car streamlining, aerodynamics and computer controlled manufacturing.

The school has a substantial array of photo-voltaic cells that supply electricity to the national grid as well as powering the school. Pupils monitor the energy generated and this gives them a real connection between theoretical energy production and the environment.

Governors lead the school in a village-wide tree-planting programme, and a large horticultural club produces food for the school and its community. Some developmental micro-electronics work with Cambridge University is about to start, using a small microprocessor project board.

Coupled with the eco-agenda, pupils have exceptionally good access to modern science experiences.

48. Teachers in such schools were well placed to connect their curriculum to important real applications. Others had embraced outdoor learning and used their outdoor learning areas to teach environmental science; again, these on-site examples allowed pupils to experience science in action, regularly and at first hand.

Leadership and management

49. The overall quality of leadership and management of science in primary schools has not changed since the previous report. Leadership in about three quarters of the schools visited was good or outstanding.

50. In the 16% of schools where it was outstanding, subject coordinators knew:

- why learning science is an essential part of pupils' education
- that science is something pupils must actually do – not just learn from what others have done
- that scientific method is the foundation for scientific knowledge
- that understanding the big ideas of science is the goal of science teaching, so that pupils can apply these ideas in new situations

[10] For further information on STEMNET ambassadors, see: www.stemnet.org.uk/content/ambassadors.

- how to enhance and maintain pupils' curiosity, equip them with the skills of scientific enquiry, and embed sufficient knowledge of the big ideas in science.

51. School leaders who recognised the likelihood of a declining profile for science were able to mitigate the risk by, for example, seeking accreditation through the primary science quality mark (PSQM).[11] The process of gaining the award brings benefits beyond the certificate, because it requires school leaders to evaluate their provision and justify their science curriculum as being fit for promoting good learning. It also connects school science leaders to other primary school leaders who have successfully raised the subject's profile in their schools.

52. Only a minority of the primary school science leaders were using challenging targets effectively enough to raise pupils' achievement. Almost half of the schools visited were not setting science targets. This emphasises starkly the decline of science, yet targets were set for English and mathematics because leaders and managers knew that this could bring about improvement in outcomes for pupils.

53. About half the schools visited were tracking pupils' progress, coupling this to some form of support or intervention in science; nothing at all was happening in about a quarter. This is a very much weaker picture than in the secondary schools visited, where almost every head of science was doing this well.

54. The rigour and effectiveness of the monitoring and evaluation of science provision were good enough to deliver improvements in about a quarter of the schools visited. But in another quarter of schools visited there was no monitoring or evaluation of science at all, primarily because most of these schools' leaders were not clear about the purpose of science teaching, and therefore could not evaluate whether what was being taught met their aims and vision for science. Science lessons were taking place, but no-one checked whether they sustained pupils' curiosity and embedded scientific knowledge, skills and understanding well enough to serve pupils in the next stage of their education.

55. Science development plans varied in quality, depending on the accuracy of the underlying monitoring and evaluation. Too often, they were not ambitious enough to drive up standards. However, some school leaders found that the process of gaining the PSQM helped to raise the profile of science. The survey found a couple of examples of rigorous science reviews led by senior staff to tackle major weaknesses in teaching, but these were concerns about the teaching of individuals rather than specific weaknesses related to science.

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[11] For further information about the Primary Science Quality Mark, see: www.psqm.org.uk/about_psqm/about_psqm.html.

56. Support and challenge for curriculum leaders were outstanding in 14 of the schools visited; they were poor in eight. The majority of the coordinators had reasonable generic support for their role, often through mentoring arrangements for middle managers and, sometimes, from national professional development programmes for middle leaders.[12] However, school managers sometimes assumed that coordinating involved just coordinating resources rather than also exercising leadership of science.

57. Effective training for leadership rarely took place. Of the 91 coordinators in the primary schools, 17 had received science-specific leadership training. Of these 17, six had received it from a regional or the National Science Learning centres,[13] four from their local authority science conferences, and seven through attending other training events. The coordinators spoke well of the training, whatever its source. In six of the 17 schools in which the coordinators had received leadership training, science provision was outstanding, compared with only two of the 42 schools that provided no training for their coordinators.

58. The leadership of science was not effective enough in many schools. In these schools, the coordinators saw their primary role as maintaining what had gone before. Their role in monitoring and evaluating science was limited to checking that teachers were working through the schemes of work and sampling to establish that pupils' books contained some science. In other words, there was plenty of management, including of resources, but not enough leadership of the subject. This was a key reason why the profile of science in these schools was deteriorating.

Part B: Science in secondary schools

Overall effectiveness

59. The overall effectiveness of science was good or outstanding in just under three quarters of the secondary schools visited, including three secondary special schools; it was outstanding in 18. This is similar to findings from previous science reports.[14]

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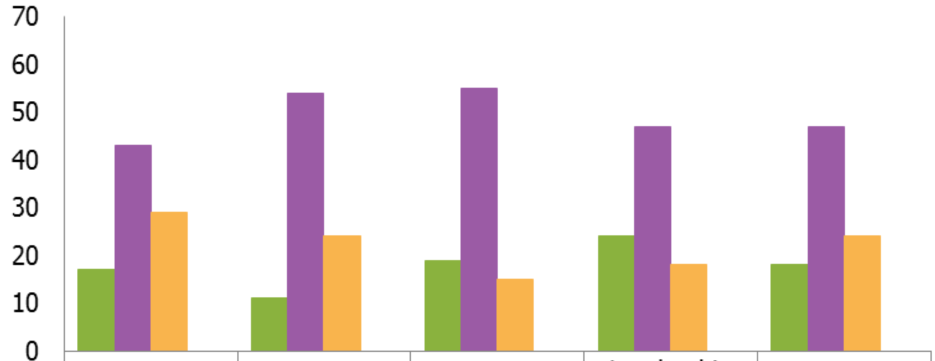
[12] For further information, see: www.education.gov.uk/nationalcollege/index/professional-development/professionaldevelopment-schools.htm%20.

[13] For further information on Science Learning Centres, see: www.sciencelearningcentres.org.uk/centres/national.

[14] *Successful science* (100034), Ofsted, 2011; www.ofsted.gov.uk/resources/100034.

Figure 2: Science judgements in the secondary school sample (by number of schools)



	Achievement	Quality of teaching	Curriculum	Leadership and management	Overall effectiveness
Outstanding	17	11	19	24	18
Good	43	54	55	47	47
Satisfactory/requires improvement	29	24	15	18	24
Inadequate	0	0	0	0	0

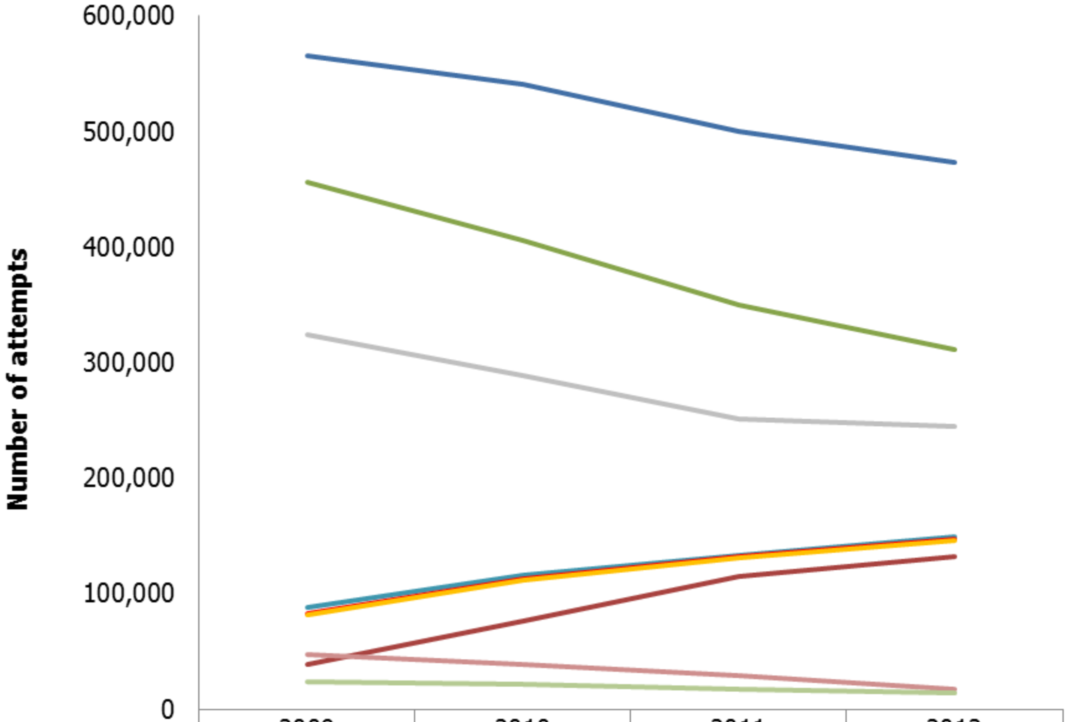
Achievement

60. Achievement was good or outstanding overall in two thirds of the schools visited. This was not the case, however, for the 53 sixth forms visited: students made good or outstanding progress in only half of the 53 school sixth forms visited. This judgement on overall progress in sixth forms is at odds with the quality of the teaching seen during the visits, which was generally better than these figures suggest, but the finding is consistent with a similar finding in further education colleges.[15] Classroom learning, of course, is not the sole factor in determining the achievement of students in advanced level science courses. Independent study and literature research by students beyond the school should make a significant contribution to their understanding.

61. The Key Stage 4 science curriculum is changing rapidly year by year in the majority of schools, including in the schools visited. In essence, fewer students nationally have been following broadly academic science courses, but more students are taking three separate science GCSEs (biology, chemistry and physics). Vocational science entries (BTEC Awards, Certificates and Diplomas, or OCR National Awards/Certificates) have risen sharply up to 2012. This chart shows the national change in numbers of attempts in these various courses over the past four years.

[15] *Improving science in colleges* (110081), Ofsted, 2011; www.ofsted.gov.uk/resources/110081.

Figure 3: Science qualification attempts for students at the end of Key Stage 4 in each of the last four years (2009 to 2012)



	2009	2010	2011	2012
All GCSE	565,300	541,500	500,500	473,800
Vocational	39,411	76,304	115,132	131,819
Core science	456,000	405,900	350,100	311,200
Additional science	324,300	288,700	251,700	244,700
Biology	88,000	115,900	133,700	149,000
Chemistry	83,100	113,300	132,000	147,500
Physics	82,300	112,200	131,100	146,500
Additional applied	47,400	38,600	29,100	17,600
Other	23,800	21,700	17,900	13,900

62. Nationally, the number of vocational entries has increased as the number of GCSE entries has declined. At the same time, entries for the three separate sciences have approximately doubled while entries for additional science have dropped sharply. Despite the large relative changes of entries between the various routes, the number of students gaining two or more science GCSEs at grades A* to C (either core plus additional science, or three separate sciences) has remained virtually constant at around 310,000. This is the main source of students who progress to A-level science. Again, the proportion of students who continue to achieve at least one science A level has also remained steady at about 25% of the pool. The total number entered for one or more A levels has increased over time; it was 77,068 in 2010 and 80,756 in 2012.

63. The trend up to 2012 of increased vocational entries appears to have peaked. Inspection of schools through both section 5 (that is whole-school) and subject-

specific inspections in the current academic year (2012/2013) reveals that many schools that had previously provided vocational science are now providing a predominantly academic Key Stage 4 science curriculum. It is likely that numbers for vocational science courses will decrease in the next year or two. This is in part because schools are responding to the new combined EBacc measure that validates only at least two science GCSEs as part of that measure; there is also a recognition by schools that progression to courses beyond 16 can be limited if students have followed a vocational course in science at Key Stage 4.

64. There is no meaningful single measure of overall standards in science at Key Stage 4, because so many different courses count towards a science qualification. The DfE's criteria for including a particular qualification change regularly and individual schools also change their courses. It is best, therefore, to look at year-on-year changes within a specific science course. These national data show stable proportions of students gaining grades A* to C at GCSE in biology, chemistry, physics (triple science) and additional science (the former 'double award'). As entry numbers have risen for the separate sciences, numbers for additional science have declined. Over 90% of grades in the separate sciences are at grade C or above – and have been for the past six years; about 70% are at grade C or above in additional science and this figure has also been similar for the past five years. More students overall are gaining higher grades as a result of following the triple science pathway and this is reflected in the increase of good GCSE grades in any science from 71% in 2010 to 77% in 2012. Preliminary data indicate that this figure has reduced slightly in 2013, as awarding organisations respond to concerns over grade inflation.

65. GCSE additional applied science appears to be a poor route nationally for students who want to study two GCSE equivalents in science: only 34% of grades were awarded at C or above. Nationally, entry numbers for this course are declining rapidly. Several leaders in the schools visited had chosen not to provide it any longer, following disappointing outcomes. Progression to Level 3 science courses from this route normally depends on whether there is a suitable further education provider nearby; one is not always available.

66. Generally speaking, girls attain better than boys nationally in all the science courses, but not by very much except in GCSE additional applied science where the gap is 14 percentage points. The gap is around five percentage points in core and additional science, but only one point in the separate sciences. Girls also attain better than boys in AS and A-level sciences; the greatest gap is for girls in physics.

67. This gender difference is also apparent from national Key Stage 3 teacher assessment data.[16] In 2012, 52% of boys attained Level 6 or better compared with 56% of girls.

68. Students' progress nationally from their starting points in GCSE science varies substantially, depending on the course. The proportion of students making the expected three levels of progress in the separate sciences is 85% for biology, and 83% for chemistry and physics. But for core science, that figure drops to 60%, and is 61% for additional science. The proportions making four levels of progress show a similar mismatch, as follows: 54% for biology and chemistry, 52% for physics, but only 21% for core science and 25% for additional science. These differences are evident at every starting 'level'. The conclusion is that making good progress is more likely through the separate science route and the chances of gaining higher grades are also greater.

69. In the schools visited where science achievement had recently improved, one or more of the following factors was found:

- robust review by senior leaders, leading to a reduction in weaker teaching
- the recruitment of permanent science specialist teachers where previously there were none
- examination preparation and well-structured revision programmes that were well attended, including the use of ICT to support learning beyond lessons
- more time for triple science by starting in Year 9
- the empowering of teachers to inject experimental science into lessons to make science interesting.

These factors are explored below.

Progression in science

70. Getting the grade is not the same as 'getting' the science. Too frequently, GCSE grades indicated that students were doing well but they were not enjoying science. Because the subject is a statutory requirement to 16 in local authority maintained schools, and is made compulsory by the academies visited, most students have no choice but to continue studying science at Key Stage 4, and most want to do their best. But once they can choose other courses at 16, most students drop science completely. Despite some 316,000 students nationally achieving two or more good GCSE grades in science in 2010, only 80,000 went

[16] Statistical First Release: Provisional GCSE and equivalent results and national curriculum teacher assessments at key stage 3 in England: academic year 2011 to 2012, DfE, October 2012; www.education.gov.uk/rsgateway/DB/SFR/s001094/index.shtml

on to study one or more advanced level sciences in 2012. This represents a major loss of science talent.

71. The drop-out from GCSE is alarmingly high for girls in physics nationally, and continues between AS and A2 level physics. In 2010, there was a potential pool of 159,745 girls gaining two good GCSE grades in science. In 2011, the number of girls attempting AS physics was 11,390, representing 7.1% of the pool. Only 6,452 of these girls then attempted A-level physics in 2012; a very low 57% of those who started AS physics, and only 4% of the potential Key Stage 4 pool. For comparison, 37,689 boys (24% of the potential pool of boys gaining two good GCSE grades in 2010) went on to study AS physics in 2011. Of these, 64% continued to A level, 15.5% of the original pool. Others have also drawn attention to this and analysed the differences in take-up between types of schools.[17]

72. These progression rates are averaged over England. In many schools, therefore, very few or even no girls continue to study physics beyond Key Stage 4. Inspectors were not able to find reliable information about progression to post-16 courses in most of the schools visited. For the 11 to 16 schools, the information relies on students' intentions prior to leaving school, as much as hard evidence of their course take-up at 16. Schools with sixth forms know about students who continue into the sixth form, but often do not know exactly what those who leave at 16 have chosen. The information regarding post-18 destinations is equally partial. School governors, at the very least, should set a target so that progression in their school matches the national proportion of students progressing to AS and A-level science; they should monitor this and require action to tackle any shortfall.

Pupils' views about science

73. Inspectors held discussions with students and sixth-form students to see what factors might be deterring some from a science-based future. The reasons they cited for their post-16 choices varied, but the main influences came from their homes, families and local culture. A separate report by Ofsted has considered the choices that girls make.[18]

74. Common to all students studying science at 16 was their enjoyment of 'getting it': solving problems, understanding a difficult concept or discovering a phenomenon directly. As their understanding deepened, they began to explain and connect hitherto apparently disparate facts. Hard work and good recall might allow them to achieve the grades at GCSE level, but these do not cement understanding. For the science curriculum to do this, teachers must themselves

[17] *It's different for girls: the influence of schools – an exploration of data from the National Pupil Database looking at progression to A-level physics in 2011 from different types of school at Key Stage 4*, Institute of Physics, 2012; www.iop.org/publications/iop/2012/page_58292.html.
[18] *Girls' career aspirations* (090239), Ofsted, 2011; www.ofsted.gov.uk/resources/090239.

know the big ideas of science well, know the progression and development of that idea through the key stages, and have access to a wide range of resources that they can adapt. Schools with the best science provision helped students to explain, from an early age, phenomena and concepts. These schools insisted on extended spoken and written communication. Learning was extended beyond the examination specification, allowing students to follow leads they had suggested themselves to satisfy their curiosity.

75. The second factor that students raised in the discussions was the extent to which their teachers were able to make links across the content and big idea of a science concept, the practical work used to reveal it *and* the usefulness of the idea to explain how the world works. If this did not happen, then, as one girl put it, she 'didn't see what physics was for or how the practical helped explain the theory'. Some sixth formers said they had not liked the lack of relevance of Key Stage 4 science and that this was why they did not choose physics – or, for some, any science – at 16.

Differences between groups of pupils

76. Nationally, the proportion of secondary students eligible for free school meals (FSM) is 16% and the proportion of these students following vocational science courses is 21%. In half the schools visited, there was very little difference between the school's overall proportion of FSM students and the proportion of FSM students within the different qualification routes at Key Stage 4. In other words, the same proportions of FSM students studied triple science or additional science as followed vocational routes.

77. But in the other half of the schools visited, the proportion of FSM students who were studying vocational courses was much higher than the school's overall proportion. These students' access to A-level science was being disproportionally limited.

78. In the schools visited, the most common difference in the performance of groups was between boys and girls: boys were doing less well in 10 schools; girls were doing less well in three. Pupils receiving the Pupil Premium lost ground in five of the 89 schools. The schools concerned cited a poor match of the curriculum to the students' needs as the reason for this, implying that vocational routes would have been more successful in terms of students attaining GCSE equivalent qualifications.

79. In six schools visited, the progress of higher ability students slipped relative to their peers nationally. This was because of a lack of sufficient challenge for these students in lessons, and a lack of opportunity for independent research.

80. In most of the secondary schools visited, students knew how well they were progressing in relation to the targets that had been set for them, because their teachers tested them frequently and provided feedback in terms of levels or grades. In this respect, the teachers were tracking their pupils thoroughly.

81. In about a third of the schools visited, however, the students were not sure exactly what they had to do to meet their targets. This is not just a problem in science; in many schools, diagnostic feedback is not a strength. However, science teachers sometimes rely too heavily on summative tests. Multiple choice questions or those requiring short statements for answers do not give students enough opportunity to show their understanding of a scientific principle. As a result, their teachers do not know precisely enough what students do not understand and so cannot offer sufficient direct guidance to help them improve.

The quality of teaching

82. Analysis of 638 lessons by key stage in the secondary schools visited shows that inspectors judged sixth-form lessons more favourably than those in any other key stage: 89% of the lessons seen were good or outstanding. This is at odds, however, with the overall judgement that the progress of sixth-form students in science was only adequate in nearly half of the schools. The mismatch between lesson quality and progress over time indicates the important contribution of individual study beyond the classroom. The best sixth forms provided good advice to students on how they should study for themselves. A few found that the Extended Project Qualification (EPQ) provided a useful framework for developing independent learning, and brought additional UCAS points to students' overall examination scores.

83. Teaching in Key Stage 3 was weaker than in Key Stage 4. At Key Stage 3, 59% of the teaching was good or outstanding, compared with 68% at Key Stage 4, although the same teachers were usually teaching across both key stages. The lower proportion of good teaching at Key Stage 3 is consistent with this survey's inspection findings of slightly poorer progress in science of students in Key Stage 3 compared with those in Key Stage 4. This may reflect the removal of the national end of key stage tests at Key Stage 3.

84. The best teaching took place in upper ability sets, where 74% of Key Stage 3 and 78% of Key Stage 4 teaching was good or outstanding. The weaker teaching took place with average-ability sets. Only 50% of the teaching for these students at Key Stage 3 was good or outstanding and 57% at Key Stage 4. These figures raise concerns about equality of provision for students of different abilities.

Teachers' subject knowledge and their deployment

85. In all but five of the secondary schools visited, teachers' subject knowledge supported students' achievement strongly, and even where inspectors noted the need for some improvements in subject knowledge, this was not hampering students' progress. National figures continue to show that a relatively low proportion of teachers of physics (and, to some extent, chemistry) hold first degrees in these subjects. But this is not reflected in student performance data at Key Stage 4, where results for all three separate sciences are equally good.

86. School managers used a range of staffing models. Some deployed separate subject specialists from Year 7; others deliberately deployed their teachers to teach across nominal subject boundaries – at least as far as Key Stage 3, and often beyond. Either way, the choices appeared to make no impact on GCSE grades. By the sixth form, in the schools visited science was taught by separate-subject specialists who had very good subject knowledge. In that respect, the high drop-out rate of girls from AS physics to A2 referred to earlier is a concern nationally, not least because these girls are probably being taught by the most expert physicists a school has.

Continuing professional development

87. When they identified the need, school leaders in the schools visited made good use of subject knowledge enhancement courses. Three quarters of the schools visited were also providing science-specific professional development, much of which tended to be technical training related to examination board specifications. Responding to recent changes in specifications absorbed most available training funds. Of the 64 schools where teachers had access to science-specific training, 17 schools were outstanding. This contrasts with the 25 schools where no recent science training had taken place; only one of these was outstanding. This is important evidence that correlates the quality of science provision with the existence of science-specific training for teachers. It suggests that schools which invest in professional development at a subject level have a culture that successfully seeks continuous improvement.

88. Only five science leaders said they had not heard of their regional or the National Science Learning Centre. Thirty-four leaders had used these centres themselves and all of them reported favourably on the impact of the training on science provision in their schools.

Planning to meet pupils' needs

89. Most lessons are planned with every intention of engaging students with activities that ought to deliver the learning intentions, although they are not necessarily executed quite as effectively. When shortfalls do occur, usually this is because the task does not challenge all students well enough from the outset of the lesson, especially the more able, and the teacher does not respond effectively to that situation. Planning considers different groups of learners effectively in two thirds of lessons, and adequately enough in all.

90. Many of the teachers observed were skilful in teaching science in a way that helped students to become real scientists. As often as possible, they used scientific enquiry to teach the content, ideas and understanding that were needed, and they made students' independence and involvement in learning a priority. In just over half the schools visited, students' involvement in raising questions for research or practical investigation was good. They enjoyed learning science when they were finding out answers to their own questions.

91. However, despite the attainment data available from frequent topic tests and from earlier stages, too many lessons in the schools visited did not take enough account of what students had already learnt and where they needed further teaching. In a third of the lessons seen, the activities provided for some did not match their learning needs well enough to ensure that they made good progress. In practice, despite the widespread 'differentiation by outcome' seen in the survey schools, once students began work, teachers adjusted their teaching quickly. It would make a significant difference to raising expectations if teachers assigned all students to the most challenging tasks from the outset, before adjusting them if they turned out to be too demanding. The general assumption, however, was that 'pupils can't', rather than 'pupils can'. This was seen to be most damaging at the start of Year 7. Too many teachers disbelieved the students' attainment levels reported by their primary schools. This survey notes differences in the rigour of science assessment between primary schools and the contrast between international tests and national assessment data; but to discount all primary school information completely leads to poor planning, repetitive and undemanding activities for many Year 7 students, and is disappointing for them.

92. By Key Stage 4, most teachers were relying on setting to differentiate by ability. However, almost half the lesson planning seen at this key stage made no attempt to personalise activities based on a particular student's prior knowledge, or how much progress students had made in the previous lesson.

Differentiation can be done exceptionally well. In the best lessons in one of the schools visited, students worked on tasks that had been differentiated well to meet their needs. In a Year 7 mixed ability lesson, students worked on three tasks that were similar but pitched at three different levels.

- The more able had a worksheet with some challenging questions. These involved them in discussion as a group and extended writing.
- The middle ability students were given questions that were slightly more closed and support was provided for them.
- The less able students were given help sheets to support them if they needed it.

The teaching assistants had spoken to the teacher before the lesson and knew how they should support the students with whom they were working. One of the science technicians was also a higher level teaching assistant. She helped the teacher to perform demonstrations during the two lessons observed and also provided very effective support for the students with whom she worked.

Assessment, including marking

93. Students were increasingly taking an informed part in peer- and self-assessment, compared with previous triennial report findings, which is a welcome indication that this strategy is developing. However, the approach is not universally good as yet, because students in some classes have not been trained effectively enough in assessing their own and others' work. For example, without effective training, students tended to praise the quality of presentation, rather than the depth of understanding of science concepts that they were assessing. In the few schools where this was done well, teachers and students were very positive about how this enhanced students' progress.

94. In about half the schools visited, teachers provided good diagnostic feedback so that students knew how they could improve their work. This was a major factor in driving high achievement. The practice was exceptionally good in one of the schools visited. Teachers gave consistent diagnostic and instructional feedback that students responded to consistently. This was a major reason why the school's teaching over time was outstanding, even though discrete lessons were generally good rather than outstanding.

95. In the other schools visited, inspectors regularly saw perfunctory marking which was little more than comments about underlining titles, putting dates on work or using pencils for diagrams. Occasionally, the marking was so uncritical that incorrect work was ticked and praised, suggesting that the teacher had not read it. The most ineffective comments related to unfinished work; this was disappointingly common. Sometimes students do not complete a report or record enough results to make any scientific conclusion valid, and there may well be a good reason why that is the case. But repeating the remark 'Finish this off' suggests that neither the student nor the teacher was taking any notice of the marking.

96. The main difficulty is choosing what is worth marking diagnostically. Too often, students are set tasks or make notes that do not really allow them to reveal their understanding of a science concept or idea. Teachers should consider longer written activities, maybe taking several days, which allow students to research, think about and then apply their understanding of a science idea through a summary explanation.

Information and communication technology

97. In half the schools visited, ICT was used well to enhance science learning with good use of projection, multi-media and – more rarely – effective use of interactive whiteboards.

98. Students generally had good access to ICT for research and revision. Data-logging was rare (seen in five schools of the 89) and hardly ever carried out by students themselves. Most of the secondary schools visited had sophisticated instrumentation that students needed to become familiar with as early as

possible, so that they were prepared to use similar equipment at work or in further study, but the schools did not train their students in its use. More demanding investigations that require high-quality data should feature in routine experimental work. Inspectors visited only two schools where ICT deployment was outstanding in bringing about learning of science that could not be undertaken more effectively in any other way.

The quality of the curriculum

99. The quality of the curriculum was good in 61% of the secondary schools visited and outstanding in 22%.

100. The majority of the schools began Key Stage 4 schemes of work at some point in Year 9. There was no discernible difference in students' achievement at GCSE, however this was organised. Many teachers had discovered, however, that an earlier start to Key Stage 4 reduced time pressures, especially for triple science. The approach appeared to be working well for students in terms of maintaining their curiosity because they had more opportunities for illustrative enquiry work in science.

101. Most of the schools visited taught triple science in the same time allocation as double award science. This is too short a time if the courses do not start until Year 10: open-ended scientific enquiry and opportunities for independent learning are limited and students often find themselves attending after-school sessions to keep up. Although they attend, they do not want to repeat the approach in the sixth form, so motivation to study science in the future and take-up both decrease.

102. Most science teachers wanted to use practical activities to engage and interest students, but many of them, as well as subject managers, described the challenges they faced. Time in the laboratory was the most pressing concern. Those attempting to squeeze triple science GCSEs into less than 20% of a week's timetable, starting in Year 10, faced this problem most acutely. In these situations, any practical work that students did was the necessary minimum for controlled assessments. As a result, opportunities for illustrative and investigative scientific enquiry were limited, and so was the achievement of students. They achieved their GCSE grades but not the science practical skills they needed at the next stage. Sixth-form teachers told inspectors that this lack of practical skill is revealed starkly for many students at A level, as they try to catch up with the demands of accurate, individual practical and experimental work.

103. A small but important minority of secondary schools had limited laboratory space, forcing science lessons into ordinary classrooms. This was the case in two brand-new schools that had been built without regard for the needs of investigative science. This limited the amount of practical work that could be

planned and also eliminated opportunities for teachers and students to illustrate new ideas that emerged spontaneously through class discussion.

104. In the secondary schools visited for science it is common practice for practical work to be done in pairs. In other subjects with a practical base, such as design technology or art, individual work is the norm. Although working in pairs may help to develop students' skills of teamwork and collaboration, it curtails personal initiative and independence, and can allow some students to avoid practical manipulations altogether. Inspectors observed boys doing practical work in larger, mixed-sex groups while the girls did the recording. It was unusual to see larger groups of four or more students working effectively at a practical investigation. Where it did work well, teachers had chosen the groups, and explained the roles for each student within the groups.

105. Working in pairs may be one reason why so many post-16 and post-18 students struggle with the demands of advanced science practical work when they have to do it by themselves. Teachers should consider providing regular opportunities for students to work independently in Key Stages 3 and 4. Although teachers cited the lack of apparatus as a reason for students not working individually, in practice they had not thought through alternative classroom organisations as a solution. There is no reason why every student in a class has to do the same experiment at the same time; working through a series of investigations as a 'circus' and taking several lessons to complete the series should resolve any equipment shortfall.

106. The best science leaders had carefully planned opportunities to develop students' independence. Some of these leaders had started to use the EPQ for sixth-form students as a way of validating independent research, with science projects often featuring as the source material. In these schools, science contributed to a whole-school mission to develop independent learning, and other employability skills. This allowed students to see the purpose of science learning and its enquiry-based skills within a wider context applicable to future careers.

107. In 78 of the 89 secondary schools visited, schemes of work were planned collaboratively. This usually meant teams of teachers reviewing and revising science topics to accommodate changes to examination specification or to teach new courses. In these schools, science teachers had access to a range of detailed suggestions for lessons and were expected, in theory, to choose activities from these resources that met the learning needs of their students. However, in practice, teachers were using common lesson plans across a range of ability groups or sets. It was rare to see a standard lesson plan adjusted to take account of the previous lesson.

108. Most teachers were trying to develop students' literacy and numeracy through science and they sought to connect science with technology and mathematics. In the best practice, science teachers applied their school's literacy policies to marking students' written work and correcting their spoken responses. This was

not common, however, because some teachers had focused too narrowly on scientific literacy, such as the correct use of technical terminology. This led to restricted written work, for example learning a list of science definitions. Teachers can assess students' current levels of understanding and suggest the next steps only when students have the opportunity to write and talk at length about their understanding of a scientific idea or concept. Activities that merely ask students to insert a word into a gap in a pre-prepared paragraph (where the words are usually listed on the worksheet) require hardly any thinking about science.

109. In the best practice, teachers asked students what they would like to find out about a topic and then used the responses to shape a sequence of lessons. They explained the connection between the science in the lesson and the bigger learning journey. Sometimes, teachers explained the sequence of learning at the start of each lesson so that the students could see where they were going and, indeed, could accelerate if they had already understood parts of the work.

In one excellent example from a school visited, students were becoming students of science history, often having the opportunity to repeat a fundamental experiment for themselves. For example, sixth-form physics students individually investigated the effect of temperature on air pressure by changing the temperature of a sealed flask connected to a pressure gauge. By plotting a graph of temperature against pressure, they could then extrapolate the best fit line to predict the temperature where pressure is zero. This temperature, called absolute zero, is a fundamental constant and could have been simply described by the teacher. But by discovering it for themselves, students shared the experience of the first scientist who did that experiment and the rather disturbing realisation that there is no colder temperature. They were not distracted by artificial notions of relevance.

There were good links with mathematics that enhanced the learning of science and allowed teachers to promote mathematics-related science theory. Literacy was also promoted strongly. Students had to write independently about their science learning rather than give single-word responses or practise multiple-choice tests. For example, in the same school, Year 11 students were set the reading task of finding out 'why Fritz Haber's second wife left him' as preparatory homework for the subsequent lesson on chemical equilibrium. This information is not a syllabus requirement and is irrelevant to the chemistry of equilibrium but is fascinating; it allowed students to see the impact for good and evil that Herr Haber's discovery of his 'Haber process' permitted. The actual process is impossible to carry out in a school laboratory. But despite the theoretical nature of the lesson, students' interest had been captured and they could understand why that particular process has made such an impact on modern chemistry and on world history.

110. However, students sometimes had no voice in what they were being taught or any idea why the topic was being taught. As one student said, 'I do not see how the practical activity is supposed to link to the science we are doing, and I cannot see what use that science has.' At worst, students were told they would need it 'for the exams'. This does not secure students' interest, although it may tap into their concerns about their future success.

111. Some teachers said they did not have enough time to allow students to work things out for themselves, but this is a consequence of not building on students' prior knowledge and experiences. Too often teachers assumed that they had to start from the beginning again and therefore repeated work that students had already done. For example, inspectors regularly saw the same few experiments repeated. A typical example was the testing of thermal insulation properties by lagging containers of warm water and recording their cooling against time. This experiment can be seen in classrooms from Reception to Year 13. This is a waste of students' time. Teachers justify such repetitions on the basis that students should be looking for more in-depth explanations or making more accurate measurements. There may be no other way than to repeat a familiar experiment, but inspectors saw few attempts at imaginative alternatives.

112. Inspectors considered how well the National Curriculum strand, 'How science works', was taught compared with the knowledge-based strands. The majority of the schools visited planned for this, with teachers wanting to use investigative science to teach the content; in general, most did this well at Key Stage 3.

113. However, as students moved to Key Stage 4, preparing for GCSE assessment tasks became all-consuming in many science departments, leading to an 'atomistic' approach to teaching the various skills required. These were without a particular purpose other than learning the skill as an end in itself. Students told inspectors they did much more practical work in chemistry, with biology the least likely place for students' practical work. That difference was at its widest in the sixth form.

Science qualifications

114. Although different courses with different assessment arrangements may appear to meet a range of learning needs, in practice it is not the course specification but the effectiveness of the teaching that engages students. It is possible for a predominantly academic Key Stage 4 pathway to meet all students' learning needs in science and enable them to progress to all 16+ science pathways, including employment or apprenticeships. In the best lessons seen, the teachers made the course content come alive and pushed learning well beyond the specifications.

Extra-curricular science

115. Extra-curricular science activities took place, to a greater or lesser degree, in every school inspected. At their best, they complemented learning by extending students' experiences with extra experiments, projects, and visits to settings that used science. The latter allowed students a chance to meet professional scientists who explained their enthusiasm for science and gave students a sense of the fascinating breadth and depth of science in action. At a minimum, all schools provided additional revision classes for students who had fallen short of expectations, or additional teaching time out of hours when school managers had not assigned sufficient timetabled lessons for a particular course.

116. In this survey, 12 of the schools were specialist colleges. Although the designation is no longer active, it is still taken seriously by such colleges.

> In one of the mathematics and science specialist colleges visited, there were three main benefits of the specialism.
>
> - The school continued to fund teachers working in the 'feeder' primary schools, as well as opportunities for pupils in Years 5 and 6 to visit the school for science lessons. Arrangements for transition were strong. The specialism also funded a mathematics and science summer school for gifted and talented students.
> - The specialism allowed the recruitment of high-quality staff and funded training for the new staff appointed. Improving teaching had a positive impact on the number of students following separate sciences in Key Stage 4 and post-16 science courses.
> - The specialism also supported the development of cross-curricular learning links with science.

Leadership and management

117. The overall good quality of leadership and management of secondary science reflects the fact that the majority of the schools visited were providing science education that was at least good. Of the 89 schools visited, leadership and management were outstanding in 24, good in 46 and at least adequate in the remainder. The high proportion of outstanding leadership was reflected in high or strongly improving achievement in science in those schools.

118. In schools with good or outstanding leadership and management of science, department leaders had the confidence of their team. They promoted a clear vision that their colleagues shared in principle, and that was expressed in the opening paragraphs of their school science policy.

119. But if significant improvement in science provision is to happen, that vision must deliver the purpose of science education as set out in the National Curriculum old and new, and not just offer a comprehensive management plan

that maintains existing provision. Very few of the science improvement plans seen measured the department's performance against that lofty goal of 'maintaining curiosity'; they played safe, and merely aimed to maintain their grades. There were exceptions, however, where the subject leader set out to raise standards and post-16 participation as well as students' engagement in science. Although they might not have arrived at that destination, and therefore might not yet be outstanding, they knew what was needed.

120. Inspectors looked carefully at the way science teachers used challenging student-level targets to raise attainment. Almost every school leadership team set targets of some sort. However, the impact of the target-setting and the data gathered on raising science attainment were not convincing. The impact was positive in 32 of the schools visited; the targets were not challenging enough in 18.

121. In the weaker cases, the information gained at the end of a topic was not analysed and passed on in a way that might inform subsequent learning of that topic; although the data might have triggered some form of intervention, normally an extra class for some Key Stage 4 students, either at lunchtime or after school. Students who attended these appreciated the extra support. It was rare, however, to find such provision at Key Stage 3. Generally, managers logged the Key Stage 3 data but then did not use it, unless they noticed major underachievement.

Monitoring and evaluation

122. Monitoring of science provision and outcomes for students was common. Subject leaders observed teaching, conducted scrutinies of students' work and monitored summative assessment data. But fewer than half of the science departments visited made a succinct evaluation of these sources of information. Twelve of these departments were failing to identify weaknesses. Most of the subject review documents seen avoided judgements and, instead, emphasised descriptions of what was happening.

123. Almost all of the monitoring of outcomes seen referred only to attainment and progress and did not include post-16 or post-18 progression; the behaviour of students in science; measures of students' commitment such as completion of homework and attendance at extra science activities; the views of parents and carers; views of primary, further education or employer partners; or attitudinal survey data on pupils.

124. The majority of the departments visited did not evaluate the impact of their work on the attitudes of their students, because they did not place the purpose of science education at the centre of their evaluation. However, several schools had seized on that purpose and this ensured that their teaching resulted in motivated students who went on to achieve very well. The result was the need to build more science accommodation for a growing number of sixth formers studying science.

125. Some science departments visited held destination data for their Key Stage 4 students and Level 3 students, but they did not use these data as performance indicators. Many department managers did not collect such data and, unless the students were in their own science sixth form, they had no idea whether or not students had continued with study, training or employment in science. Further, since managers were not asking why students were choosing different pathways, they were not in a position to review the impact of the provision.

126. Leaders in the schools visited accepted the stereotypical choices that students made without asking questions. When numbers were small – for example, girls choosing physics – individual faculties disregarded their own small figures for some groups because the statistical significance was low. At the very least, faculty managers should record the numbers of students continuing with science at 16 and, if appropriate, at 18 and compare these with the figures nationally. Given the high cost of teaching science, and the fact that most students spend more time studying science than any other subject, the drop-out at 16+ should be of as much concern to science teachers as it is to the government.

127. Most science leaders in the schools visited had attended some generic middle management training or been paired with a senior manager as a mentor. Of the 89 school science leaders, 26 had not received any subject-specific management training. The overall effectiveness of science was outstanding in only one of these schools compared with six of the 15 schools where the science leaders had been trained to lead science. Similarly, schools are more likely to be outstanding if their leaders have been given subject-specific leadership training.

Part C: Factors promoting achievement

128. Parts A and B of this report refer to factors that were effective in promoting high achievement in the schools visited, namely:

- accurate evaluation of science outcomes leading to effective improvement strategies
- making science interesting
- assessment for learning
- effective differentiation
- support for learning beyond lessons
- time for learners to develop science practical skills.

These are explored in more detail here. Examples from the primary and secondary schools visited provide details of implementation and impact.

Accurate evaluation

129. In the best primary schools visited, senior leaders, including the subject coordinator, kept a close watch on pupils' progress in science as frequently as they did for English and mathematics. The best coordinators and senior managers of science 'levelled' classwork accurately, internally moderated individual teachers' judgements and also collaborated with neighbouring schools, including secondary partners, to affirm the reliability of their assessments. This allowed clear diagnoses of strengths and weaknesses at pupil level. It facilitated the tracking of pupils' progress and informed any catch-up activity.

130. Effective tracking in both phases included good records of pupils' developing practical skills as well as their knowledge of the actual subject content they had covered. This allowed changes to the pre-planned schemes of work during the year to ensure that pupils covered the National Curriculum programmes of study requirements and had opportunities to reinforce the particular elements of 'How science works' (Sc1). Additionally, gaps in teachers' expertise were quickly identified, with effective steps taken to deal with them, in the first instance usually through sharing good practice between teachers in the school. The good quality of evaluation allowed subject leaders to identify good practice and, with the help of senior leaders, they could arrange in-school mentoring and shared teaching activities. The overall effectiveness of schools that provided subject-based continuing professional development was more likely to be outstanding. These schools were accurately identifying their strengths and any areas for improvement and then making sure those improvements took place.

131. In the best secondary schools visited, the monitoring and evaluation of students' outcomes in science were closely connected to teachers' professional development through each school's performance management system. Good secondary schools used several sources of evidence to determine the quality of science provision, but primarily looked at students' achievement in science. They analysed the progress of different groups and used their analysis to consider strategies that might help close any gaps. These included additional revision classes and close mentoring of students by a subject expert. The best science faculties also analysed the data from their surveys of students', staff's and parents' perceptions, and monitored the progression of students to their post-16 and post-18 destinations.

Making science interesting

132. The schools visited that made science interesting for their pupils, both primary and secondary schools, raised achievement in science. In both phases the most effective approach seen was through practically based investigations. Pupils experienced the scientific phenomena for themselves and then used that experience to raise their own further questions, thereby maintaining curiosity. In the best practice in all schools, pupils could answer the question, 'What is it

for?' when asked by teachers and inspectors. At lesson level, pupils contributed to the questions that were going to be investigated. For example, a Year 5 teacher asked pupils, 'What would you like to find out about sound?' The responses included some very challenging questions, such as 'What does a sound wave look like?' and 'How do you know a bat can hear higher [frequencies] than a dog?' Lessons that teachers set into a bigger 'learning journey' allowed pupils to see how the element of learning in the lesson connected to the bigger scheme of things. That led to learning intentions that lasted for several lessons, for example work on dissolving solids in liquids was a step towards evidence for the particulate nature of matter. At the highest level the most effective teachers constructed lessons that connected explicitly with other subject areas, notably English and mathematics. This allowed pupils to relate learning across subjects, and to use science as the context for others.

133. Interest in science was stimulated by teachers' regular references to science in the media. It meant going off topic for some of the lesson, but helped pupils to connect abstract science ideas to concrete news events; the recent meteorite entry over Russia was one such example, with Felix Baumgartner's free-fall parachute jump from high altitude another. In one good school, for example, pupils were challenged to bring in their own interests and refer to their own experiences. Another school invited pupils to try and 'stump the teacher' and had a display board of questions from pupils awaiting answers, which often then came from other pupils.

134. The key indicator of successfully engaging students' interest in secondary science was the proportion of students continuing within science at 16+. The best school managers monitored these numbers, not just in total but by gender, ethnic heritage, and eligibility for the Pupil Premium. They knew the reasons why students chose different career pathways and fed back that information to their teachers to ensure that future generations had the best guidance.

Assessment for learning

135. The most effective practice took place where pupils had extended opportunities to explain, either orally or in writing, their understanding of the science behind the activities they were doing. A common format for this was a circus of different practical investigations that illustrated one aspect of a big idea in science, as illustrated here.

> A Year 10 class was learning about infra-red radiation through a mix of practical experiments and multi-media resources. As the students carried out each task, they used their growing understanding of the concept to explain the phenomena they were witnessing. The teacher circulated around the class, listening to students' explanations and then suggesting further activities in the light of the student's responses. This feedback very

quickly took pupils beyond the limits of the GCSE syllabus, stimulated their interest and allowed them to see why the concept was so important.

136. The questions used by teachers to elicit a response from pupils formed a critical feature of the best formative assessment. Whether orally or in writing, the best questions demanded extended responses from pupils that gave teachers information about a pupil's grasp of the science ideas, and allowed the teacher to affirm or correct a pupil's developing understanding. This was more often done well in small group discussions with a teacher or support assistant, or by longer written answers to open-ended questions.

137. The best marking of written work in science occurred where teachers used their school's marking policy consistently, particularly in relation to identifying and correcting errors in pupils' literacy and numeracy. They also noted any factual errors in terms of science content and either corrected them or gave pupils a supplementary task that led pupils to learn from their own errors. Importantly, pupils then had time in subsequent lessons to respond to those personal requests from their teachers.

Effective differentiation

138. Effective differentiation was the best way of raising achievement in science, across all phases. However, a majority of the schools visited used only a limited model of differentiation that did not personalise learning activities well enough to ensure that pupils of all abilities were sufficiently challenged from the start of lessons.

139. In primary schools, most teachers of science were the pupils' main class teacher and had good knowledge of their pupils' talents. In the best schools they used this knowledge to plan science lessons for different ability groups in their class in the same way as they did for English and mathematics. Irrespective of the overall setting of a class, normally the most effective grouping of pupils seen in primary science classes was by ability. This allowed resources and practical activities to be pitched at a level that challenged each member of that group.

140. The best secondary schools trusted the incoming 'levels' achieved by pupils in primary school as a starting point in planning differentiated lessons. They reminded their students of those levels by setting similarly demanding tasks in the early part of Year 7. Once a school had its own topic test data, the best ones used it to build progression in learning, and kept records that allowed students to build on their prior learning when the topic was revisited later.

141. The best schools made sure that pupils finished the work set, especially if it was a practical investigation. This led to some pupils continuing with the activity in the next lesson, with different starting points for different pupils depending on the progress they had made previously. The more common alternative in science, however, was for all pupils to start something new in the

next lesson. That undermined the importance of the original task and cemented a gap in pupils' learning.

Support for learning beyond lessons

142. Support for pupils' independent learning beyond lessons improved achievement in both the primary and secondary schools visited.

143. The key feature that enhanced pupils' independence was activities and supporting structures that gave each pupil, individually, the time and responsibility to think about the question or task, and design their own plan to solve it. Teachers needed to limit the scope of the options, actively supervised to ensure safety, and then steer pupils away from over-elaborate plans and spurious variables. It was much better for pupils' learning of the skills of scientific enquiry when they conducted an investigation for themselves, and then evaluated whether it had answered the question 'fairly', 'reliably' and 'accurately'. They discovered by experience the importance of these basic scientific enquiry skills. The results of scientific investigations are what have driven our knowledge and understanding in science: the best schools ensure pupils understand that results matter as much as the process of carrying out an experiment.

144. Inspectors observed several examples in primary schools, and a couple in secondary schools, where pupils were finding out about cross-curricular topics that included science. More often than not, partner subjects included design and technology, information and communication technology, geography, history and mathematics. This project approach motivated pupils exceptionally well, and had a marked impact on their understanding of the relevance and application of science to other fields. The projects often required substantial input from pupils' families, which helped develop good school–home relationships. The best schools took this approach seriously, providing reward and recognition to pupils as well as formative feedback to help them improve the project. This caused pupils to take a real pride in their work and they devoted considerable out-of-hours time to it.

145. A few outstanding secondary schools had started to use the EPQ award as a school-wide framework to teach independent study skills, usually for their sixth-form students but at least one was also using the Key Stage 4 version. Science subject matter appeared to feature in about a third of the examples seen by inspectors. Students who followed that course reported considerable benefits to their study skills.

146. Evidence of barriers to independent learning included:

- exercise books containing identical text and diagrams among pupils
- worksheets that limited the opportunity for pupils to explain ideas for themselves

- whole-class ‘discussions’ leading to a ‘whole-class’ experimental plan
- following a set of pre-prepared practical instructions (a recipe)
- results tables, prepared in advance by the teacher, that denied pupils the chance to choose for themselves their system of recording
- internet-based research without pupil-centred analysis of the evidence they had retrieved
- over-use of small groups or ‘working in pairs’ in practical activities to the exclusion of individual activities
- lack of good prior information that pupils could use when they tried making predictions.

More time for scientific enquiry

147. The best schools ensured that pupils had sufficient time to be taught and subsequently develop the skills of scientific enquiry.

148. In the primary schools where pupils were taught science in a discrete lesson once a week, they had sufficient and regular opportunities to carry out practical investigations. As a result, they could revisit and relearn manipulative skills regularly enough for these to develop over time. Some schools had incorporated the science ‘lesson’ as part of a wider cross-curricular topic, but the best schools still made sure science practical work happened weekly, for all its pupils, regardless of the title of the topic. Some of the better schools supplemented the weekly session with occasional special focus days that featured science from time to time. The longer sessions allowed for more complex investigations and also provided the time to connect the science work with design and technology products.

149. In secondary schools, the best providers made sure that students following the three separate science GCSE courses had enough timetabled lessons to learn the subject content through the best approach: namely practical work based on scientific enquiry. They had resisted the temptation, to which some other schools had succumbed, to squeeze three GCSE subjects into the teaching time for two. The latter approach usually resulted in students doing only the minimum practical work necessary to meet the assessment criteria of the course. By itself, that resulted in dull practise of some of the necessary skills in isolation, without the students having the experience of connecting the practical activity with a big idea in science.

150. There were two equally effective secondary school strategies that ensured students did have sufficient teaching time to learn science through experiencing the phenomena for themselves. The more common model led to students starting the GCSE programmes of study in science partway through Year 9. In effect, this added extra time to all the science examination courses, but risked some students struggling with difficult concepts during Year 9 if they had not yet reached a level of cognitive development appropriate to those ideas. By

Year 10, both the separate science and dual award students used up to two GCSE slots. The simpler strategy was to assign three GCSE-sized timetable slots, one to each of the separate sciences, and continue with two slots for those students following the core plus additional science route. This kept the total number of GCSEs per student to a reasonable and common limit for every student in the school.

Notes

Inspectors visited 91 primary and 89 secondary schools, including six special schools, between summer 2010 and spring 2013. The schools were chosen to ensure that the sample fully represented the various types and sizes of school; the full range of socio-economic contexts; the range of overall effectiveness; and pupils' ethnic heritage, gender and admission criteria.[19]

The inspectors used specialist science criteria to supplement the section 5 school inspection schedule. Although that schedule changed in detail during the period of the visits, the science-specific elements remained largely the same. The section 5 judgement of 'satisfactory' was replaced by 'requires improvement' in September 2012.

Ofsted gave schools five days' notice of a science visit. During the visits, inspectors observed a total of 1,004 science lessons. In each school, they held discussions with senior staff, heads of department and heads of science faculties, and also held discussions with groups of pupils from all key stages, as well as examining written work in science. Inspectors also held discussions with governors (where they were available during the visit).

Inspectors wrote to each school afterwards to summarise the judgements made about the quality of the science provision. Ofsted has published the letters on its website; they can be accessed via the 'expert knowledge' web pages.

Further information

Publications by Ofsted

Girls' career aspirations (090239), Ofsted, 2011; www.ofsted.gov.uk/resources/090239.

Improving science in colleges (110081), Ofsted, 2011; www.ofsted.gov.uk/resources/110081.

Successful science (100034), Ofsted, 2011; www.ofsted.gov.uk/resources/100034.

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[19] However, inspectors did not visit schools that Ofsted had already placed in a category of concern, since such schools are subject to monitoring by Ofsted.

The most able pupils: are they doing as well as they should in our non-selective secondary schools? (130118), Ofsted, 2013; www.ofsted.gov.uk/resources/130118.

Other publications

W Harlen (ed) *Principles and big ideas of science education*, Association for Science Education, 2010; www.ase.org.uk/bookshop/books-for-subject-leaders/.

M O Martin, I V S Mullis, P Foy, and G M Stanco, *TIMMS 2011 international results in science*, Chestnut Hill, MA: TIMSS & PIRLS International Study Center, Boston College, 2012; http://timssandpirls.bc.edu/timss2011/international-results-science.html

It's different for girls: the influence of schools – an exploration of data from the National Pupil Database looking at progression to A-level physics in 2011 from different types of school at Key Stage 4, Institute of Physics, 2012. www.iop.org/publications/iop/2012/page_58292.html.

Annex: Providers visited

Primary schools	Local authority
Beis Yaakov Primary School	Barnet
Beulah Junior School	Croydon
Biggin Hill Primary School*	Bromley
Birdlip Primary School ⓘ	Gloucestershire
Birley Spa Community Primary School	Sheffield
Biscovey Junior School*	Cornwall
Blackthorn Primary School*	Northamptonshire
Bonsall CofE (A) Primary School	Derbyshire
Booker Park Community School	Buckinghamshire
Brightlingsea Junior School	Essex
Brimscombe Church of England VA Primary School	Gloucestershire
Brook Acre Community Primary School	Warrington
Burghclere Primary School	Hampshire
Burrough Green CofE Primary School	Cambridgeshire
Camblesforth Community Primary School	North Yorkshire
Cherry Trees School	Staffordshire
Copnor Junior School ⓘ	Portsmouth
Corpus Christi Catholic Primary School ⓘ	Portsmouth
East Hoathly CofE Primary School	East Sussex
Eastry Church of England Primary School ⓘ	Kent
Elsley Primary School	Brent
Fenstanton and Hilton Primary School	Cambridgeshire
Four Oaks Primary School ⓘ	Birmingham
Gedney Drove End Primary School	Lincolnshire
Granby Primary School	Leicester
Great Glen St Cuthbert’s Church of England Primary School	Leicestershire
Hatch Beauchamp Church of England Primary School	Somerset
Helpringham School	Lincolnshire
Hipswell Church of England Primary School	North Yorkshire
Holy Family Catholic Primary School	Wigan
Horncastle Community Primary School	Lincolnshire
Hunwick Primary School	Durham

Killisick Junior School	Nottinghamshire
King Charles Primary School	Walsall
Kirkby Thore School	Cumbria
Ladygrove Primary School	Telford and Wrekin
Lindfield Primary School ⓘ	West Sussex
Lockerley Church of England Endowed Primary School	Hampshire
Loudwater Combined School	Buckinghamshire
Loxdale Primary School	Wolverhampton
Ludham Primary School and Nursery ⓘ	Norfolk
Lytchett Matravers Primary School	Dorset
Manor Primary School	Reading
Melbourne Community Primary School	East Riding of Yorkshire
Mellers Primary and Nursery School	Nottingham
Middlestone Moor Primary School ⓘ	Durham
Moorpark Junior School	Stoke-on-Trent
Muschamp Primary School and Language Opportunity Base	Sutton
Ormskirk Church of England Primary School	Lancashire
Otley The Whartons Primary School	Leeds
Oughtrington Community Primary School	Warrington
Parkfield Primary School	Rochdale
Parrett and Axe Church of England Voluntary Aided Primary School	Dorset
Richard Cobden Primary School ⓘ	Camden
Rufford CofE School	Lancashire
Salcombe CofE Primary School	Devon
Saltfleetby CofE Primary School	Lincolnshire
Sellincourt Primary School	Wandsworth
Shipley CofE Primary School	Bradford
Sir Frank Whittle Primary School	Coventry
South Ferriby Primary School	North Lincolnshire
Southroyd Primary and Nursery School	Leeds
Springwell School	Hartlepool
St Bega's RC Primary School	Hartlepool
St George's Junior School	Shropshire
St Giles Church of England Primary School	Walsall
St John and St Francis CofE VA Primary School*	Somerset

St Marie's Catholic Primary School*	Sheffield
St Mary's CofE Primary, Moston	Manchester
St Matthew's Church of England Primary School	Stockport
St Michael and St Martin RC Primary School	Hounslow
St Paul of the Cross Catholic Primary School	Warrington
St Peter and Paul Catholic Primary School	Staffordshire
St Thomas of Canterbury Catholic Primary School	Hammersmith and Fulham
St Werburgh's CofE (A) Primary School	Staffordshire
Swinford Church of England Primary School	Leicestershire
Tarleton Community Primary School	Lancashire
The Gerrards Cross Church of England School* ⓘ	Buckinghamshire
The Grange School	Oxfordshire
The Highway Primary School	Bromley
Thomlinson Junior school	Cumbria
Tower Bridge Primary School	Southwark
Wakefield Pathways School	Wakefield
Walgrave Primary School	Northamptonshire
Walton Church of England Voluntary Controlled Primary School	Somerset
Western Road Community Primary School	East Sussex
Whitburn Village Primary School	South Tyneside
Whitehouse Primary School	Stockton-on-Tees
Whitgreave Junior School ⓘ	Wolverhampton
Worthen CofE Primary School	Shropshire
Wrington Church of England Primary School ⓘ	North Somerset

Secondary schools	**Local authority**
Alfreton Grange Arts College	Derbyshire
Al-Hijrah Secondary School	Birmingham
Ashcroft High School	Luton
Ashlyns School	Hertfordshire
Avonbourne School*	Bournemouth
Bacon's College	Southwark
Barnfield South Academy	Luton
Bedford High School	Wigan

Beechen Cliff School	Bath and NE Somerset
Beths Grammar School ⓘ	Bexley
Bournville School and Sixth Form Centre	Birmingham
Brumby Engineering College*	North Lincolnshire
Bruntcliffe School	Leeds
Cardinal Heenan Catholic High School	Liverpool
Clevedon Community School*	North Somerset
Devonport High School for Girls	Plymouth
Eastlea Community School	Newham
Emmanuel College ⓘ	Gateshead
English Martyrs Catholic School	Leicester
Ercall Wood Technology College	Telford and Wrekin
Hagley Catholic High School ⓘ	Worcestershire
Halifax High At Wellesley Park	Calderdale
Highbury Grove School ⓘ	Islington
Highdown School and Sixth Form Centre*	Reading
Holloway School	Islington
Hurlingham and Chelsea Secondary School	Hammersmith and Fulham
John O'Gaunt Community Technology College	West Berkshire
Keswick School ⓘ	Cumbria
Kettlethorpe High School, A Specialist Maths and Computing College	Wakefield
King Edward VII School	Sheffield
Lady Manners School	Derbyshire
Lathom High School : A Technology College ⓘ	Lancashire
Leytonstone Business and Enterprise Specialist School	Waltham Forest
Little Heath School ⓘ	West Berkshire
Lytham St Annes Technology and Performing Arts College ⓘ	Lancashire
Manchester Mesivta School	Bury
Manor School and Sports College*	Northamptonshire
Moor Park Business and Enterprise School	Lancashire
Moorside High School	Staffordshire
NCHS The Science College	Staffordshire
Neston High School*	Cheshire West and Chester
Nicholas Breakspear Catholic School*	Hertfordshire
North Bromsgrove High School	Worcestershire

Northfleet Technology College	Kent
Nunnery Wood High School* ⓘ	Worcestershire
Oak Wood Secondary School* ⓘ	Warwickshire
Orleans Park School	Richmond upon Thames
Ormskirk School	Lancashire
Parklands High School* ⓘ	Lancashire
Plymouth High School for Girls	Plymouth
Prince Henry's High School* ⓘ	Worcestershire
Queen's Park High School	Cheshire West and Chester
Raine's Foundation School	Tower Hamlets
Redhill School* ⓘ	Nottinghamshire
Rye Hills School	Redcar and Cleveland
Sandringham School* ⓘ	Hertfordshire
Sir William Ramsay School*	Buckinghamshire
Southmoor Community School, Mathematics and Computing College*	Sunderland
Springfield School ⓘ	Portsmouth
Springwood High School	Norfolk
St Andrew's CofE Voluntary Aided High School	Croydon
St Edward's Roman Catholic/Church of England School	Poole
St Ives School, A Technology College	Cornwall
St Julie's Catholic High School	Liverpool
St Matthew's RC High School	Manchester
St Paul's Catholic High School*	Manchester
Stepney Green Mathematics and Computing College ⓘ	Tower Hamlets
Sydenham School	Lewisham
Teddington School* ⓘ	Richmond upon Thames
The Albany, A Business and Enterprise College	Havering
The Archbishop Lanfranc School	Croydon
The Community College Whitstable	Kent
The Grange School and Sports College	South Gloucestershire
The Kimberley School*	Nottinghamshire
The Knights Templar School	Hertfordshire
The Observatory School	Wirral
The Park Community School	Devon

The Radclyffe School	Oldham
Virgo Fidelis Convent Senior School	Croydon
Wadebridge School*	Cornwall
Welling School	Bexley
Westfield Community School	Somerset
Wetherby High School	Leeds
Whitecross School (Foundation)*	Gloucestershire
Wilmslow High School ⓘ	Cheshire East
Windsor Girls' School	Windsor and Maidenhead
Wishmore Cross Academy	Surrey
Woldgate College	East Riding of Yorkshire
Wymondham High School	Norfolk

* The provider has closed or become an academy since the time of the visit.

ⓘ The overall effectiveness of science in this provider was outstanding.