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Research and analysis

Finding the optimum: the science subject report

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Applies to England

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Executive summary

Science helps us to answer our biggest questions and to meet our most basic needs: from explaining the deepest mysteries of the universe to the structure of elementary particles that form atoms. The findings of science have fundamentally shaped every aspect of our world. Science drives innovation, creating new knowledge to help us solve current and future problems. All young people are entitled to a high-quality science education, to the curiosity it engenders and the understanding and the opportunity it brings.

The report evaluates the common strengths and weaknesses of science in the schools inspected and considers the challenges that science faces. This evidence was gathered by His Majesty's Inspectors as part of routine inspections. The report builds on the 2021 Ofsted science research review.^{[\[footnote 1\]](#)} The report is split into findings in primary schools and those in secondary schools, and includes evidence

from Reception classes and sixth forms. Within each of these sections, we talk about:

- aspects of the curriculum
- pedagogy
- assessment
- the way schools are organised
- the impact of this on what pupils learn

Overall, this report identifies some significant strengths in school science education and recommends ways that school and subject leaders can ensure that all pupils leave school with an authentic understanding of science, as both a tradition of enquiry and a set of connected but distinct ideas that explain the world we live in.

It is important to note that we evaluate schools against the criteria in the school inspection handbooks. Findings from this report will not be used as a 'tick list' by inspectors when they are inspecting schools: we know that there are many different ways that schools can put together and teach a high-quality science curriculum.

Context

Science is a core subject of the national curriculum.^[footnote 2] It is an important part of what all pupils in England's schools should learn, whether they go to academies, free schools or maintained schools. Science subjects are a popular choice at A level, although female students are more likely to take A-level biology and male students are more likely to take A-level physics.^[footnote 3]

Schools in England perform well above global averages in international comparison tests in science.^[footnote 4] Data from the 2019 'Trends in international mathematics and science study' (TIMSS) shows that Year 5 pupils' performance was relatively good, and broadly similar to that of pupils in 2015. In 2019, 83% of Year 6 pupils reached the expected standard in science.^[footnote 5] However, we are concerned that the status of science in some primary schools has remained at a lower level since national tests in science were removed in 2009, and that this has affected key stage 3 performance. This is because the removal of national tests coincided with a relative decline in the performance in science of 10-year-old pupils in England.^[footnote 6] In TIMSS 2019, England recorded its lowest Year 9 science score. The proportion of Year 9 pupils performing below the lowest TIMSS science measure has doubled since 2015.

Our own research shows that science has been particularly affected by COVID-19.^[footnote 7] This is especially because restrictions deprived many pupils of the opportunity to take part in and learn from practical activities. Further, COVID-19 had a negative impact on the opportunities for many trainee teachers to teach a full science curriculum. Recruitment of enough specialist science teachers in secondary schools remains a challenge.^[footnote 8]

Because of the ways in which the COVID-19 pandemic affected schools, some of the evidence that we gathered for this report may not represent what happens normally. However, we hope that we have reduced this risk by focusing on the curriculum and the way it has been put into practice over time.

Key terms used in this report

Knowledge in science

Throughout this report, we use the same terminology to describe scientific knowledge as we did in our science research review. These are not terms that Ofsted necessarily expects pupils or teachers to use during inspections. Rather, we use them here to recognise these 2 important aspects of science in which pupils need to build their understanding throughout their time at school.

- **Substantive knowledge:** refers to the established knowledge produced by science, for example, the parts of a flower or the names of planets in our solar system. This is referred to as ‘scientific knowledge’ and ‘conceptual understanding’ in the national curriculum.
- **Disciplinary knowledge:** refers to what pupils learn about how to establish and refine scientific knowledge, for example by carrying out practical procedures. By identifying and sequencing this knowledge, it is possible to plan in the curriculum for how pupils will get better at working scientifically throughout their time at school.

Practical work

We are aware that primary and secondary school teachers talk about practical work in science using different terms. For clarity, this report defines practical work as: ‘any teaching and learning activity which at some point involves the students in observing or manipulating the objects and materials they are studying’.^[footnote 9] Practical work in this report can refer to a teacher demonstration or a hands-on practical activity for students.

Main findings

Most pupils, including those with special educational needs and/or disabilities (SEND), studied a science curriculum that was at least as ambitious as the national curriculum. These curriculums were mainly focused on developing, over time, pupils’ knowledge of substantive concepts such as ‘habitat’, ‘force’ and ‘material’.

Where science was strong, pupils had learned detailed and connected knowledge of the curriculum, and remembered what they had learned previously. In a significant minority of schools, pupils were not developing secure knowledge of science. Often, in these schools, the focus was on covering the content, rather than ensuring it was learned, or completing practical activities.

There were a small minority of primary schools where pupils went for entire half terms without learning science. This is a concern because science is a core subject of the national curriculum, and pupils benefit from regular opportunities to revisit and build on their knowledge so that it is not forgotten.

Some pupils came out of lockdown with significant gaps in their scientific knowledge, and COVID-19 prevented primary and secondary colleagues from working together to support pupils' transition.

Leaders' plans to develop pupils' disciplinary knowledge were usually much less developed than their plans to develop pupils' substantive knowledge. In general, not enough consideration was given to identifying the disciplinary knowledge, including concepts, that are needed to work scientifically. This limited how effectively leaders could plan a curriculum for pupils to get better at working scientifically over time. Too often, the focus was simply on identifying practical activities for pupils to complete.

There were large differences in the amount of practical work taking place in schools. For example, pupils in primary school were much more likely to take part in hands-on practical activities than pupils in secondary school. In all schools that we visited, teachers rarely used demonstrations.

Across primary and secondary schools, some pupils did not have sufficient opportunities to practise and consolidate what they learned before moving on to new content. This meant they did not remember key content taught previously. In some schools, there was an over-reliance on pupils catching up when the content was repeated later in the curriculum, rather than ensuring it was learned first time. Often this happened when teachers were expected to teach too much content in a short time. This was more common in secondary schools.

Overall, most leaders saw their school science curriculum as a description of what pupils needed to know and do. They had planned the curriculum carefully so that pupils studied content in a logical order. However, leaders generally did not see the curriculum as something that could make learning science easier. For example, very few leaders had planned their science curriculum to take account of what pupils learned in mathematics, and rarely did science curriculums help pupils to avoid misconceptions.

In some schools, leaders planned the science curriculum to build on what pupils had learned in the previous phase of education. However, in some secondary schools it was incorrectly assumed that pupils learned little science in primary school. This led to some content being unnecessarily repeated in Year 7 and beyond.

Children were generally introduced to a range of interesting phenomena in Reception. However, in some primary schools, the knowledge of the natural world that children were expected to learn in Reception was not clear enough. Often this was when curriculums simply identified general topic areas or activities for children to complete. This limited how effectively children were prepared for learning science in Year 1.

Teachers generally had secure subject knowledge. Clear explanations from teachers, alongside carefully selected teaching activities, supported the learning of specific content and played a key role in helping pupils to learn science. Teachers who had strong subject knowledge were able to bring into the lesson wider knowledge from across the science curriculum. This helped pupils to make connections between scientific concepts.

However, teachers rarely drew on evidence-based, subject-specific approaches when teaching science. Very few schools had a clear plan of how teachers' knowledge of science, and how to teach it, was developed over time through continuing professional development (CPD).

During the pandemic, many teachers were not able to take part in subject-specific CPD. However, not all schools have returned to their previous commitment of ensuring that CPD is closely aligned to the curriculum. When teachers had recently attended CPD courses, these were primarily around developing their knowledge of physics (if they were non-specialists in this discipline) or practical work.

In most schools, subject leaders played a crucial role in developing school science curriculums and supporting teachers to teach them. However, not all subject leaders had access to dedicated leadership time and subject leadership training. This is a concern, given their central role in ensuring good-quality teaching in their subject.

During the period when we were gathering evidence, schools were facing many challenges because of COVID-19. Despite these challenges, many subject leaders were improving and developing their school's science curriculum. Sometimes, this was because leaders wanted to address gaps in pupils' knowledge that were caused by science being taught remotely during the pandemic.

In some schools, assessment as learning was sometimes taking place at the expense of assessment for learning. Some pupils were asked to recall

knowledge that they had not successfully learned first time around.

Generally, assessment in science did not check whether pupils had remembered what they had learned in previous years. This was a particular concern in some primary schools, where generalised judgements at the end of a piece of learning were being made against age-related expectations, but what these grades represented in relation to the curriculum was not clear.

In some schools, there was not enough focus on checking whether pupils had learned the disciplinary knowledge that is needed to work scientifically. These schools only focused on checking that pupils had learned substantive knowledge. This was more common in primary schools.

Discussion of the main findings

Where science was strong in the primary and secondary schools that we visited, pupils had learned detailed and connected knowledge of the curriculum, and remembered what they had learned previously. In these schools, leaders and teachers were clear about the purpose of any teaching activity or specific content choice. They explained scientific ideas clearly and used assessment carefully to check what pupils had learned. This included disciplinary knowledge (knowledge of how to work scientifically) as well as substantive knowledge (established factual knowledge).

In schools where science was strong, leaders generally saw the purpose of a curriculum as more than just a description of what pupils needed to know and do. They saw the curriculum as a 'path' that can make learning science easier. For example, leaders planned the science curriculum to take account of what pupils learned in mathematics, or made sure that pupils had enough time to learn the most important content in a way that they could remember it. In the best cases, leaders saw this path as provisional, so that the curriculum could be refined and developed in ways that would improve it, year on year.

In a significant minority of schools visited, pupils were not developing secure knowledge of science. Often, in these schools, the focus was on covering content or completing practical activities. In both cases, the curriculum goal, that is what pupils needed to learn and remember, got lost. This led to pupils studying science, often for long periods of time, without developing sufficient substantive and disciplinary knowledge. Teaching was not planned to ensure that what pupils learned next was related to what they already knew, so that they could build connected knowledge. In these schools, we also found that teachers' assessment rarely checked knowledge that pupils had learned in previous years.

We found that primary and secondary schools had different priorities in science. In primary schools, for example, there was much more emphasis on pupils carrying out different types of scientific enquiry and encountering scientific phenomena and the objects they were learning about. In contrast, the focus in most secondary schools was on developing pupils' substantive knowledge. There is also evidence from the schools we visited that many pupils in secondary school spend too much time studying content that they have already learned in primary school.

Although there was a greater emphasis on practical work in primary schools, across both primary and secondary, plans to develop pupils' substantive knowledge were much more developed than the plans to develop pupils' disciplinary knowledge. Often, this was because leaders had not sufficiently considered the kind of knowledge that pupils need in order to be able to work scientifically or carry out practical work generally. Too often in primary and KS3 the focus was on simply selecting practical activities for pupils to complete. The apparent differences in practices between primary and secondary science may cause challenges for pupils moving from primary to secondary school.

Inspectors regularly found considerable differences in how well teachers taught the curriculum. Very few teachers used approaches that were based on evidence or that were specific to science. Other than for physics or practical work where leaders had identified a training need, few schools had developed a systematic plan of how to develop teachers' knowledge of science and how to teach it.

Overall, the evidence gathered as part of this report identifies some significant strengths in relation to science education in England's schools. This is particularly encouraging considering the significant impact that the pandemic has had, and continues to have, on pupils, teachers and leaders and the wider science education community. However, there is still more to do to make sure that curriculum, pedagogy, assessment and school systems all work together to create the most favourable, or 'optimum', conditions for learning science. Although many pupils leave school with a secure knowledge of science and working scientifically, there are still too many pupils who do not.

Recommendations

Curriculum

Schools should:

- Ensure that the curriculum is specific about the knowledge that children in Reception should learn about understanding the world. This knowledge should connect with what pupils go on to learn in Year 1 science.
- Plan the secondary science curriculum to build on what pupils learned in primary school, and not simply repeat it or assume that pupils learned little.
- Ensure that enough time is built into the curriculum for pupils to learn and remember key knowledge. It is important that pupils are helped to see how this knowledge connects with what they already know about science, so that they build connected knowledge.
- Ensure that the curriculum identifies and sequences the disciplinary knowledge that pupils need to work scientifically. This should not be limited to learning about scientific techniques, data analysis or fair tests. It should include developing their knowledge of all areas of working scientifically, including different types of scientific enquiry, such as pattern seeking, and concepts such as evidence and accuracy.
- Ensure that all pupils have enough opportunities to take part in high-quality practical work that has a clear purpose in relation to the curriculum. At secondary school, this should include laboratory work, fieldwork and teacher demonstrations.
- Ensure that the science curriculum is planned to take account of what pupils

learn, particularly in mathematics.

Pedagogy and assessment

Schools should:

- Ensure that, during explanations, teachers regularly connect new learning to what pupils have already learned. This includes showing pupils how knowledge from different areas of the curriculum connects.
- Ensure that pupils have a secure knowledge of what has been taught, before moving on to more content. This should include checking whether pupils have specific misconceptions
- Ensure that appropriate teaching and learning approaches are selected for specific content.
- Ensure that assessment checks whether pupils remember the substantive and disciplinary knowledge they have learned in previous years. This includes checking that they can use their substantive and disciplinary knowledge to select, plan and carry out different types of relevant scientific enquiry.

Systems at subject and school level

Schools should:

- Create a systematic and continuous approach to developing the science expertise of staff and leaders. This should align with the school's curriculum and take account of any specific needs and expertise.
- Support subject leaders to prioritise curriculum time for teaching key scientific knowledge. In some schools, the focus is on making sure that pupils learn and remember what has been taught, so that they develop increasingly sophisticated and connected scientific knowledge. However, too many subject leaders and teachers feel pressured to cover content and move on.

Other organisations

Subject associations and Ofsted should:

- Monitor the frequency and quality of practical work in schools, to make sure that all pupils have enough opportunities to take part in high-quality practical work.

Initial teacher education providers should:

- Support trainee teachers to develop their knowledge of what science is, the methods it uses and how to teach this.

Primary

Curriculum intent: identifying what pupils need to know and do

Summary of the research review relevant to curriculum

Expertise in science requires pupils to build, over time, their knowledge of key substantive concepts such as 'force', 'material' and 'habitat'. This is referred to as 'scientific knowledge' and 'conceptual understanding' in the national curriculum. Pupils also need to develop their knowledge of science as a tradition of enquiry. This understanding is broadly referred to as 'working scientifically' in the national curriculum.

In the research review, we refer to this curriculum content as 'disciplinary knowledge', to stress that pupils must build knowledge of these ways of working. The best curriculums, however, do not treat substantive and disciplinary knowledge as separate. They embed disciplinary knowledge within the most appropriate substantive content. For example, a curriculum might plan for pupils to know the structure of flowering plants (substantive knowledge) and learn how biologists classify plants (disciplinary knowledge). By doing so, pupils deepen their knowledge of plants and of classification.

Substantive knowledge – the knowledge produced by science

Summary of the research review relevant to substantive knowledge

A high-quality science curriculum is organised to ensure all pupils learn extensive and connected knowledge of substantive concepts. These concepts are developed over many years, during which pupils learn content that is sequenced in a logical order. Research suggests that pupils should not be expected to learn too much content in a short time. If they are, pupils may experience 'cognitive overload' (having too much information for the working memory to be able to process) and will not have time to practise and use what they have learned, to ensure that it is not forgotten.

Our findings are extrapolated from our sample of primary schools visited.

1. We found that science was taught weekly in most primary schools. However, in a few schools, pupils had less than one science lesson every week. Occasionally, pupils went for entire half terms without learning science. This is a concern because science is a core subject of the national curriculum, and pupils benefit from regular opportunities to revisit and build on their knowledge so that it is not forgotten.
2. In most schools visited, the primary science curriculum matched the scope of the national curriculum and the early years foundation stage framework. Generally, content was organised into topics such as 'plants' or 'everyday materials'. However, where curriculum thinking was strong, leaders ensured that pupils were developing, over time, their knowledge of substantive concepts such as 'habitat' or 'force'.
3. Leaders in approximately one quarter of schools had significantly developed their curriculum in recent years. Often, leaders had drawn on the support and curriculum

planning of organisations such as the Association for Science Education. This additional support gave subject leaders a strong starting point from which they could develop and refine their own science curriculum.

4. In most primary schools, leaders had considered how the curriculum in Reception supported pupils to learn science in Year 1. Often this involved leaders from different parts of a school all working together to make sure that Year 1 and Reception curriculums 'dovetailed'. This required leaders to have a clear understanding of the key vocabulary and concepts that they wanted children to learn, and the scientific phenomena that they wanted children to encounter and learn about.

5. However, in some schools visited, the precise knowledge that children were expected to learn in Reception was not clear enough. Often this was when leaders focused on activities or general topic areas such as 'changing seasons' or 'floating and sinking', without identifying what they wanted pupils to learn and why. Occasionally, leaders only referred to high-level descriptors from the early years foundation stage statutory framework when discussing the curriculum. This was a problem because they had not ensured that what pupils learned in Year 1 built on what they had learned in Reception.

6. Sometimes, leaders used commercial curriculum plans that began in Year 1. They used a different curriculum resource for Reception. However, they did not ensure that these 2 curriculums were coherent, and that the Year 1 science curriculum built on what children had learned in Reception.

7. In Years 1 to 6, pupils generally learned knowledge from all 3 sciences in each year. Most curriculums were planned to build pupils' knowledge of scientific concepts, such as 'force' and 'material'. For example, in one school, leaders took the concept of 'reflection', and revisited this at many stages of the curriculum, in different topics and in more depth, such as when the pupils were learning about the dangers of sunlight and again when they were looking at the phases of the moon.

8. Occasionally, leaders' curriculum thinking primarily focused on broader aims, for example 'making science relevant and fun', without having considered what concepts pupils should learn and why.

9. Where curriculum thinking was strong, leaders identified clearly what they wanted pupils to know and do, and then selected the best activity to teach it. Importantly, this did not simply involve selecting high-level statements from the national curriculum, but also identifying what pupils needed to know and do to reach these high-level goals.

10. Occasionally, inspectors found that the science curriculum was over-focused on aspects of literacy, such as punctuation and paragraphs, at the expense of learning scientific content.

11. In a few schools, pupils were being expected to learn content that was too technical. This was because they had not secured prerequisite knowledge first. For example, Year 6 pupils in one school were learning about genetics without having learned relevant prior knowledge. This was not surprising, given that in the national curriculum genetics is not introduced until the secondary phase.

12. Inspectors found that sometimes there was insufficient time in the curriculum for pupils to secure key knowledge before moving on to new content. This resulted in pupils 'covering content', but not remembering the key knowledge. This happened for a number of reasons:

- leaders did not allocate sufficient time to teach science
- pupils were expected to learn about too many different concepts in a short time
- subject leaders did not allocate enough curriculum time to teach a concept; for example, in one school, pupils had very little time to develop their knowledge of

the rock cycle before moving on to carrying out a scientific enquiry

- pupils spent too much of the time available collecting data during practical work

13. In some schools, leaders had explicitly designed the curriculum to take account of what pupils had learned in other subject areas. For example, pupils learned about the water cycle in geography after they had learned about states of matter and state changes in science. In this way, pupils could use their scientific knowledge of evaporation and condensation to better understand the water cycle in geography. This provided opportunities for pupils to consolidate their knowledge.

14. In a few schools, the science curriculum formed just one part of an interdisciplinary topic approach. Where this worked well, leaders prioritised pupils' development of science. In other words, the topic theme did not get in the way of the logical progression of scientific knowledge in the curriculum. However, at times, some curriculums were too focused on concerns such as careers or developing teamwork, at the expense of developing pupils' scientific knowledge.

15. In some schools, leaders considered the phenomena that pupils were learning about when sequencing knowledge. For example, they identified that the best time to learn about seed dispersal was when seeds were dispersed in the environment.

Disciplinary knowledge – the knowledge underpinning pupils' understanding of working scientifically

Summary of the research review relevant to disciplinary knowledge

A high-quality science curriculum plans for pupils' knowledge of working scientifically to develop over time. This involves identifying the underpinning disciplinary knowledge that pupils need to know. This knowledge can then be taught and revisited at the same time as the most relevant substantive knowledge is taught. Pupils should not be expected to learn this disciplinary knowledge simply as a by-product of taking part in practical activities.

A high-quality curriculum includes disciplinary knowledge that involves knowledge of concepts, such as measurement, as well as knowing how to perform various procedures. For example, pupils need to be able to draw line graphs and understand the concept of cause and effect.

In the research review, we considered disciplinary knowledge in relation to at least 4 content areas that pupils learn more about as they move from year to year:

1. knowledge of methods that scientists use to answer questions
2. knowledge of apparatus and techniques, including measurement
3. knowledge of data analysis
4. knowledge of how science uses evidence to develop explanations

The curriculum should distinguish carefully between learning about scientific enquiry and prescribing the use of enquiry-based teaching approaches, as a method of learning. Pupils can learn disciplinary knowledge through a variety of approaches including teacher explanation.

16. In most schools visited, leaders valued the importance of teaching pupils to work scientifically and giving pupils opportunities to develop their knowledge of a wide range of natural phenomena. However, leaders' plans to develop pupils' knowledge of working scientifically were typically much less developed than their plans to develop pupils' knowledge of substantive scientific concepts such as 'force', 'plant' or 'material'.

17. Where curriculum thinking was stronger, leaders identified the disciplinary knowledge needed to, for example, collect data. These curriculums did not make the mistake of organising the curriculum around practical activities or scientific enquiries. Instead, leaders first considered carefully what disciplinary knowledge they wanted pupils to learn, and then selected the best activity to teach it.

18. Sometimes the specific disciplinary purpose of practical activity choices was less clear. On occasion, disciplinary knowledge to be learned from practical work was identified, but was not part of a planned progression in gaining the specific knowledge needed to work scientifically.

19. In some primary schools, leaders only identified opportunities in the curriculum for pupils to work scientifically by specifying when pupils would grow plants or create simple models of the solar system, for example. They did not identify the specific knowledge that pupils were learning at this time. This made it difficult for teachers to know precisely what to teach and assess and, in some schools, resulted in completion of the activity becoming the goal, rather than development of pupils' scientific knowledge.

20. Leaders typically wanted pupils to learn about scientific enquiry, particularly knowledge of:

- observing over time
- pattern seeking
- identifying, classifying and grouping
- comparative and fair testing (controlled investigations)
- and researching using secondary sources

Where curriculums were strong, leaders clearly identified the disciplinary knowledge that pupils needed in order to develop their understanding of these practices. For example, in one school, leaders described how pupils' knowledge of fair testing developed over key stage 2 through increasingly sophisticated and detailed knowledge of variables.

21. Overall, in primary schools, inspectors found very few examples of pupils gaining knowledge of pattern seeking or learning about secondary sources.

22. Leaders considered a number of, sometimes competing, curriculum principles when making decisions about sequencing disciplinary knowledge. For example, they considered:

- the substantive content that pupils were learning
- the most logical order in which to develop pupils' disciplinary knowledge
- whether there were repeated opportunities for pupils to deepen and revisit their disciplinary knowledge

23. In some schools, pupils learned about the work of specific scientists. In the best cases, this was closely linked to the content that they were learning at that time. For example, in one school, pupils learned about the work of Mae Jemison when studying space. Leaders were generally keen that pupils learned about a range of scientists. This enabled pupils to develop an accurate and genuine understanding of science, for example knowing that scientific research is not just carried out by men in white coats working in laboratories.

How one school went about developing pupils' disciplinary knowledge of classification

In one school, leaders had considered carefully how pupils' knowledge of classification was developed throughout the curriculum. This involved pupils first

learning about how scientists classify animals. Leaders thought that animal classification was easier for pupils to learn. This knowledge was built on when plant classification was introduced, and pupils later learned how to use a classification key to identify different plant species. Pupils developed this knowledge further when they learned about variation within one species, by looking at differences in leaf structure. Finally, pupils used all this knowledge to carry out an assessment task that involved making their own classification key for a specific group of plants.

Planning the curriculum to make learning science easier

Summary of the research review relevant to how the curriculum can address specific barriers to learning science

A high-quality science curriculum focuses on what pupils need to learn in order to get better at science. Curriculum choices also influence how easy or difficult this journey is for pupils. This is because knowledge learned at a point in time influences future learning, and makes it easier or harder. For example, in the research review, we considered the importance of the curriculum building, step by step, on pupils' prior knowledge to reduce the likelihood of them forming misconceptions. We also considered the importance of planning the curriculum so that it takes account of what is taught in other subjects, such as mathematics.

24. In most of the schools visited, subject leaders and teachers were aware that pupils often have misconceptions that can make learning science more difficult. For example, pupils may incorrectly think that electricity flows to light bulbs, rather than through them or that trees are not plants. To address this, leaders generally identified the specific misconceptions and difficulties that pupils were likely to have. Teachers could then address these in lessons.

25. In a minority of schools, misconceptions were not explicitly flagged in curriculum planning. Teachers therefore had to rely on their own subject knowledge to identify these misunderstandings, which could lead to some being missed.

26. Some leaders recognised the importance of pupils having sufficient vocabulary to talk about the phenomena that they were learning about. They said that, without this knowledge, pupils would inevitably develop misconceptions and/or errors. They planned the curriculum carefully so that pupils had sufficient prior knowledge to discuss and explain any observations.

27. In only a small number of schools did leaders try to prevent misconceptions by changing what pupils learned. Most leaders did not consider fully enough ways in which the curriculum can be developed to avoid pupils forming misconceptions, such as thinking that there is no gravity in space.

28. Some leaders said that the most significant barrier to pupils learning science was the large number of words that they needed to know. Typically, leaders tried to address this by identifying the most important words such as 'classification', 'food chain' and 'data'. Leaders selected a few of the most important words and thought carefully about what they wanted pupils in each year group to know about each word, rather than simply identifying a long list of key words for each lesson.

29. Some leaders identified that pupils perform less well in science because of their limited background knowledge.^[footnote 10] These pupils can often think that science is not for them. Leaders typically tried to address this by helping pupils to see the relevance of what they were learning, for example by highlighting science in the

news, organising educational trips to museums and revealing real-world applications of scientific knowledge. Importantly, these approaches did not change the scientific concepts that pupils learned, but focused on specific approaches to teaching those concepts when they came up in the curriculum.

30. In some schools, leaders refined and adapted their curriculum after teaching it. In this way, the curriculum developed and improved from one year to the next. For example, one leader changed the curriculum so that pupils learned about the differences between a solution and a suspension. This was as a result of seeing pupils struggle to distinguish between these 2 mixtures when carrying out practical work.

Summary of the research review relevant to practical work and the curriculum

High-quality practical work, whether teachers' use of demonstrations or hands-on practical activities, forms a vital part of a science education. This is because it introduces pupils to the methods, objects and phenomena that scientists study. These, in turn, develop pupils' sense of wonder and curiosity about the material world. Practical work also teaches pupils about the often unpredictable and dynamic situations in which scientists work. However, research is clear that practical work is not always effective. Often this is because its purpose has not been established, or because pupils are expected to do and think about too much at once. Effective practical work has a clear purpose in relation to the curriculum. It forms part of a wider sequence of lessons and only takes place when pupils have enough prior knowledge to learn from the activity. When this is not the case, pupils experience too much complexity, which prevents them from learning what was intended.

31. Pupils took part in whole-class practical activities in a much larger proportion of lessons in primary schools than in secondary schools. Typically, whole-class practical activities in primary schools were of 3 types:

- **To help pupils learn substantive knowledge:** For example, pupils used torches and different materials to learn about opacity and transparency. This type of practical activity, aimed at teaching substantive knowledge, was the most common type that inspectors observed
- **To help pupils learn disciplinary knowledge:** For example, pupils explored the relationship between hand length and foot length. The focus of the activity was to develop their disciplinary knowledge of correlation
- **To help pupils learn substantive and disciplinary knowledge:** For example, pupils carried out a scientific enquiry to find out how waterproof different materials were. This involved carefully measuring the quantity of water that passes through a material in a specific length of time, recording their results in a table and drawing conclusions. By carrying out this enquiry, pupils developed their knowledge of materials and control variables in fair tests.

32. In a few cases, the reason that teachers had selected a specific practical activity was not clear. For example, in one school, pupils in Reception were mixing together different materials. This activity was not linked to specific curriculum intent. While children found the activity interesting, it was limited in terms of the science-related vocabulary and concepts that pupils were learning.

33. In a few cases, pupils were taking part in practical activities without having secured the necessary substantive knowledge to explain what they were observing. For example, in one school, pupils observed the bending of light by refraction before they had an understanding of how light travels. Therefore, they could not explain their

observations scientifically.

34. Sometimes, practical activities covered too many aspects, and pupils were expected to learn too much disciplinary and substantive knowledge at once. Often, this was because pupils had not remembered or understood previously taught content. For example, in one school, pupils were planning an investigation, but did not have sufficient knowledge of controlling variables to do this well.

35. Generally, pupils were not expected to discover scientific concepts through unguided teaching approaches. However, when this did happen, teachers were asking pupils to carry out practical work without having learned sufficient prior knowledge. For example, in one school, pupils were carrying out a flower dissection without having seen a demonstration of how to do this. This resulted in some pupils simply breaking the flowers apart and not learning what was intended.

36. Teachers often used well-structured enquiry questions to focus a particular activity on a particular aspect of the curriculum. For example, in one school, pupils were asked, 'How does the temperature of water affect the time taken for a substance to dissolve?' This question supported pupils to learn about dissolving by focusing on the outcome of the enquiry. However, sometimes the enquiry question was too complex and not helpful. In these cases, the enquiry question was a barrier to pupils learning the intended concepts.

37. Teachers used stand-alone demonstrations of practical science in very few of the science lessons visited by inspectors. If this finding is typical of non-inspection times, it is a concern, given that practical demonstrations have been shown to play an important role in helping pupils to learn science, involve minimal costs and can save valuable time.

38. In a very small number of schools, teachers and leaders assumed that pupils with SEND always learned best through carrying out hands-on practical activities. Perhaps this was due to the mistaken assumption that pupils have different 'learning styles'. As identified above, practical work can increase complexity and divert pupils' attention from the science to less relevant aspects of the activity. This can make learning key points harder for pupils. These teachers did not sufficiently consider this limitation.

39. In Reception classes, children usually had some choice of activities to develop their understanding of the natural world. For example, in one school, children could play with the water tray or record observations of a range of insects. Where this type of activity worked well:

- teachers were clear about the purpose of the activity in relation to the curriculum
- children had regular opportunities to talk with adults so that they could hear and use specific vocabulary
- teachers recognised that children's choices may not cumulatively add up to the full curriculum. When this happened, adults intervened so that all children learned all areas of the curriculum

Pedagogy: teaching the curriculum

Summary of the research review in relation to teaching

Science often involves pupils learning abstract concepts that might be contrary to what they expect. Teacher effectiveness, underpinned by strong subject knowledge, is therefore particularly important in science. Research highlights the importance of clear teacher explanations that carefully build on what pupils already know. Alongside this, pupils benefit from time to discuss ideas, answer questions and practise using the knowledge.

Teaching models and analogies can be particularly helpful tools in science classrooms. When these models are used alongside clear explanations, they can help pupils to learn connected knowledge. However, all models need to be used with caution because they can lead to misconceptions.

40. Across all schools, teachers typically selected interesting and appropriate activities for teaching science to pupils. Frequently, these activities introduced pupils to the scientific phenomena that they were learning about. Some teachers also drew on real-life examples so that pupils could connect the scientific principles they were learning about to their own experience. For example, when explaining friction, one teacher compared the outsoles of different types of footwear that pupils were familiar with.

41. In some classrooms, however, teaching activities were not well matched to the specific content that pupils were learning. Sometimes this was because pupils were taking part in activities that did not focus their thinking on what they were learning, or they did not have sufficient opportunities to practise using the specific knowledge that they had learned. This led to pupils moving to the next science lesson without having had sufficient time to consolidate what they had learned, or to get feedback.

42. In most classrooms, teachers introduced new words such as 'vibration' alongside clear explanations. These words were then usually emphasised throughout the lesson so that pupils had repeated opportunities to use and learn them. However, in a few cases, teachers selected resources that introduced pupils to overly technical vocabulary. For example, in one school, pupils were introduced to complex terms about plant cell structure before they had secured important foundational knowledge about plants.

43. In the best examples, teachers anticipated and clearly addressed content that pupils might find difficult or were likely to make mistakes with. For example, in one lesson, the teacher spent time discussing with pupils why clear and accurate presentation of circuit symbols was necessary when drawing electrical circuits. This drew pupils' attention to conventions in physics so that they could understand why inaccurate symbols might lead to ineffective communication between scientists.

44. Pupils with SEND were generally well supported in science lessons, and were expected to learn the same curriculum as their peers. This often involved adults building up explanations slowly, or giving pupils resources that provided additional scaffolding to meet their specific needs. In a few schools, pupils with SEND received additional support before a lesson, for example through pre-teaching of specific vocabulary. However, occasionally, strategies used to support pupils were not helpful. For example, in one school, some lesson outcomes were not expected to be achieved by all pupils. This was even though the planned lesson outcome was one that was possible for all pupils in the class. This, unintentionally, limited what some pupils with SEND were expected to learn.

45. Teachers used teaching models in some lessons that we visited. They provided a useful object that teachers and pupils could use to talk about the scientific concept. For example, in one school, pupils consolidated their knowledge of blood by building a physical model of human blood. Because they had secured key knowledge about the components of blood, the model provided a useful way for pupils to practise what they had learned and for the class teacher to check their understanding was correct.

46. Teachers' explanations played a key role in helping pupils to see the connections between what they were learning and prior knowledge. These explanations showed pupils how one concept connects to supposedly unrelated concepts. For example, the teacher in a Year 6 lesson deliberately drew attention to this kind of link, by showing pupils that carbon dioxide is both a product of respiration and a product of acid and carbonate reactions.

Assessment

Summary of the research review in relation to assessment

In the research review, we highlighted the importance of assessment having a clear purpose. Drawing on research, we distinguished between 3 different purposes:

- assessment **for** learning
- assessment **as** learning
- assessment **of** learning

Assessment should be designed so that it does not unintentionally narrow the curriculum or lead to unnecessary workload.

Assessment for learning – using assessment to provide feedback

Here, assessment for learning refers to formative assessment. This involves checking if pupils have learned the intended content of the curriculum lesson by lesson. These checks can be low-stakes and informal. They provide pupils and teachers with feedback that can be used to improve teaching. Evidence suggests that formative assessment in science should continue over extended periods and contexts in order to ensure learning has been understood as intended, and embedded in the pupils' memory. This is because pupils show variability in the concepts they recall and whether they are able to use them to understand more complex ideas or undertake activities. Multiple-choice questions can be helpful here to find out whether pupils have specific misconceptions. Teachers' content knowledge plays an important role in their ability to evaluate pupils' answers and provide subject-specific feedback.

47. Schools used a variety of formative assessment approaches, such as questions from teachers and low-stakes quizzes, to identify gaps in pupils' knowledge. Often this involved teachers identifying what pupils already knew about a topic at the start of a lesson or sequence of lessons. This information was then used to inform teaching.

48. However, we saw few examples of teachers proactively checking for specific misconceptions or misunderstandings. Some pupils therefore continued to hold unscientific ideas about the content they were learning. For example, in one school, a pupil had drawn a diagram with gravity pointing upwards and another pupil identified glass at room temperature as a gas. Neither of these errors were noticed or corrected.

49. When schools chose to give written feedback, there were often inconsistencies, both between and within schools, in how feedback was used to improve learning. Sometimes feedback was too general and not focused on specific content. In the best cases, teachers identified aspects of a pupil's answer that were particularly strong or needed further work in relation to specific curriculum content. For example, in one Year 6 class, a teacher provided clear feedback to address a pupil's misunderstanding that the heart carries blood.

Assessment as learning – using assessment to help pupils to remember what they have previously learned

Assessment as learning refers to the process, over extended periods, through which pupils embed knowledge in their memory. When pupils are asked to recall knowledge this is known as 'retrieval practice' or the 'testing effect'. Like assessment for learning, this type of assessment should be coupled with feedback so that pupils do not reinforce wrong answers. Assessment as learning should focus on reinforcing knowledge of the most important content without 'destroying the shaping of content that makes it memorable'. [\[footnote 11\]](#)

Research is clear that teachers and support staff need regular access to high-quality subject-specific CPD. Strong subject knowledge and the associated confidence it brings underpin many areas of high-quality science education, such as assessment and teacher explanations. Access to science-specific CPD is particularly important for primary teachers, given that they frequently teach outside their subject specialism, and that some reported a lack of confidence in teaching science. Evidence suggests that CPD should align with the curriculum and include teachers learning about the nature of science and its methods – which we broadly refer to as 'disciplinary knowledge' in the review. It is not enough to assume that teachers will get better at teaching science, simply by teaching science.

50. There was limited science-specific CPD taking place in most primary schools. The most common support came from sessions led by subject leaders. These sessions were often focused on developing teachers' knowledge of working scientifically. There were very few examples of CPD taking place that focused on other areas of the science curriculum, for example developing teachers' knowledge of substantive concepts and how to teach them.

51. In many schools, teachers found informal support from subject leaders to be a valuable source of subject-specific knowledge. They also identified that external resources from organisations such as STEM Learning and the Association for Science Education were helpful sources of information to refer to before teaching unfamiliar topics.

52. In a small number of schools visited, teachers had received no, or very limited, science-specific CPD. Overall, we found very few examples of teachers having attended training from external providers. Where teachers had received training, the most commonly reported benefit was that it developed their confidence.

53. Overall, in most primary schools, leaders were not sufficiently clear on how teachers would benefit from science-specific CPD. This suggests that, in many schools, leaders could work further with teachers to identify personalised, subject-specific areas for development.

Subject leadership

Summary of the research review in relation to leadership in science

Subject leadership plays a crucial role in the quality of school science. This is because, among other roles, subject leaders develop the school science curriculum and support teachers to teach it. However, research suggests that subject leaders do not always have sufficient leadership time to lead their subject. They may also lack the necessary subject expertise.

54. Most subject leaders felt well supported by their senior leadership team (SLT) and had dedicated time to lead science. However, the time available for subject

leaders varied considerably between schools, from 2 hours a week to an hour a term. In one school, time for subject leadership with an SLT coach was allocated on a rota basis. This enabled all subject leaders to have time to lead their subjects throughout the year.

55. Some subject leaders were well supported to lead science. For example, they were able to attend a range of external CPD courses, some of which developed their expertise in how to design science curriculums. However, other subject leaders felt that they wanted further training in order to lead science.

56. In a few schools, subject leaders received no additional support or time to lead their subject. This finding supports previous research carried out into subject leadership in primary schools.^[footnote 12] This is a concern, given that subject leaders provide a crucial role in developing the school science curriculum and in supporting the subject-knowledge development of staff.

57. Subject leaders typically valued being part of a wider group, for example the multi-academy trust's or local authority's science leaders' group. They thought that wider groups were valuable forums for sharing expertise.

58. Where leadership was strong, subject leaders focused on improving the quality of education, and not just on administration. For example, they visited lessons to discuss with pupils what pupils had learned, and checked that books matched the intended curriculum. They used this information to decide the focus of science training sessions.

What pupils know and remember

Summary of the research review in relation to impact

To gain expertise in science pupils need to assimilate content which is well-organised. Pupils need knowledge that builds around key scientific concepts and ideas. Pupils need to remember what they learned previously, so that new knowledge can be incorporated into this emerging schema (pattern of interconnected learning) and become flexible, meaningful and easy to use. However, research is clear that, for some pupils, science comprises an array of disconnected knowledge that lacks any organised structure. As a result, pupils do not appreciate the important relationships that can link and organise the knowledge learned and the logical structure of each scientific discipline remains a mystery.

59. In a minority of primary schools visited, most pupils were not able to remember what they had previously learned in science. In these schools, pupils had gained a limited knowledge of science. Some of these primary schools had recently developed their science curriculum. However, these changes had not had time to have a sufficient impact on what pupils knew and remembered.

60. In the remaining schools, what individual pupils remembered was too variable. For example, in a few schools, pupils demonstrated secure understanding of a range of different concepts from across the curriculum, representing both substantive and disciplinary knowledge. However, in most other schools, too many pupils only remembered what they had recently been taught. For example, in one school, some Year 5 pupils could not remember how long it took the Earth to orbit the Sun or what a variable was, despite this knowledge having been previously taught.

61. Sometimes, what some pupils knew was quite detailed and covered areas that are usually taught in secondary school. For example, in one school, Year 6 pupils were learning about the basic structure of the atom. This creates challenges for

secondary schools in making sure that content is not unnecessarily repeated. It is therefore important that, where possible, primary and secondary subject leaders communicate to ensure that they are knowledgeable about each other's curriculums.

62. Pupils generally carried out practical work well. In the best cases, pupils' knowledge went beyond how to carry out procedural aspects. It included developing the detailed disciplinary knowledge that underpins working scientifically, for example knowing why variables need to be kept the same during a fair test or whether samples are representative. However, sometimes, pupils struggled to recall what they had learned from practical work. They could only remember the activity. For example, pupils could remember that they grew plants, but could not remember what they learned.

63. In most schools, pupils could talk about why scientists do experiments. For example, one group of pupils could all say that scientists find explanations for things using experiments. It was less common for pupils to talk about specific types of scientific enquiry, such as making observations over time or the ways in which scientists classify and group organisms. Very few pupils referred to pattern seeking or the use of secondary sources. However, the responses given by primary pupils in this study typically showed a better awareness of the different types of scientific enquiry than was evident in the responses given by pupils in secondary school.

What a small sample of pupils, from different schools, knew about plants

Year 2 pupils:

- “ There is a sycamore plant like a tree”
- “ ... and oak trees”
- “ They have roots coming out of the bottom”
- “ ‘It sucks some water and food from the soil”
- “ They need sunlight – that is the food”

Year 6 pupils:

- “ ... how it goes from a seed to a normal plant and how to keep them alive”
- “ Plants need water, space, sunlight”
- “ ... petals, flower, pollen, stem”
- “ Not all plants need soil – some grow in sand”
- “ Seed dispersal – can happen by other animals, wind, water”

Year 6 pupils:

- “ ... pollination”
- “ I think we learned about the different cycles”
- “ ... parts of a flower”
- “ ... dissected a flower to see all the parts”
- “ ... the petals”
- “ ... the stamen”
- “ ... the stigma”
- “ ... the ovary”
- “ ... ovule”
- “ ... the style”

64. These extracts are typical of what primary pupils knew about plants. Most pupils typically referred to the basic structure of plants, plant reproduction and requirements for plant growth. However, there was a variety within and between schools as to how much knowledge, and what knowledge, individual pupils remembered. Sometimes, responses included misconceptions, for example that plants get their food from soil.

What a small sample of pupils in one school knew about how scientists find things out

Year 2 pupils:

- “ They find things and tell us what is healthy and [what] is not”
- “ We were doing jumping jacks to test if it will make our heart go faster”

Year 4 pupils:

- “ They research”
- “ They find evidence”
- “ They do experiments and try new stuff out”
- “ They might find things out that they have never found out before”

Year 6 pupils:

- “ Some are taxonomists”
- “ They separate animals into different groups”
- “ Carl Linnaeus was a famous taxonomist – he sorted the platypus into a group because it was a mammal that couldn’t walk – it could lay eggs”
- “ They find viruses”
- “ ... test things out to see if things work”
- “ They try different ways to see if things will work”
- “ Some antibiotics could be helpful”

65. These extracts are typical of what primary pupils knew about how scientists find things out. Most pupils referred to carrying out experiments. Some pupils went further and identified specific types of scientific enquiry, such as observing over time, or classification. Sometimes pupils referred to concepts such as ‘evidence’ or ‘variable’, but this was rare.

Secondary

Curriculum intent: identifying what pupils need to know and do

Summary of the research review relevant to curriculum

Expertise in science requires pupils to build, over time, knowledge of key substantive concepts such as 'force', 'material' and 'organ'. Pupils also need to develop their knowledge of science as a tradition of enquiry. This understanding is broadly referred to as 'working scientifically' in the national curriculum. In the research review, we refer to this curriculum content as 'disciplinary knowledge', to stress that pupils must build knowledge of these ways of working.

The best curriculums, however, do not treat substantive and disciplinary knowledge as separate. Instead, they embed disciplinary knowledge within the most appropriate substantive content. For example, a curriculum might plan for pupils to learn about the mechanism of evolution (substantive knowledge) and what a scientific theory is (disciplinary knowledge). By doing so, pupils deepen their knowledge of evolution and of scientific theories.

Substantive knowledge – the knowledge produced by science

Summary of the research review relevant to substantive knowledge

A high-quality science curriculum is organised to ensure all pupils learn extensive and connected knowledge of substantive concepts. These concepts are developed over many years, during which pupils learn content that is sequenced in a logical order. Research suggests that pupils should not be expected to learn too much content in a short time. If they are, pupils may experience 'cognitive overload' (having too much information for the working memory to be able to process) and will not have time to practise and use what they have learned, to ensure that it is not forgotten.

Our findings are extrapolated from our sample of secondary schools visited.

66. In nearly all schools visited, pupils studied a science curriculum that was at least as ambitious as the national curriculum. This included pupils with SEND who followed the same curriculum as their peers. Generally, content was organised into topics from biology, chemistry and physics. Topics, and the content within them, were sequenced in a logical order so that pupils learn knowledge of important concepts such as 'cells', 'forces' and 'chemical reactions' over time. Typically, within a topic, content was allocated to individual lessons.

67. Many schools started teaching pupils GCSE content at some point during Year 9. However, in most cases, this did not lead to narrowing of the curriculum. This was because leaders planned carefully how, over the 5 years, pupils would build and deepen their knowledge of the full breadth of the science national curriculum. These schools did not, for example, remove topics, such as space physics, because they are not assessed at GCSE.

68. In a few schools, however, pupils did not study the full breadth of the key stage 3 national curriculum. This was because GCSE content was introduced in Years 7 and 8 before pupils had secured understanding of necessary prior knowledge from key stage 3. On rare occasions, specific content areas of the national curriculum, for example 'rocks', were not taught.

69. At key stage 3, most schools taught science and rotated biology, chemistry and physics topics. Sometimes, this involved different classes studying different topics due to equipment constraints. This limited how effectively the curriculum could be planned in these schools, because classes covered content in a different order.

70. Most school science curriculums tended to follow the order of the GCSE awarding-body specifications at key stage 4. Often, this was because schools could then use full past examination papers as ‘mocks’ at the end of Year 10, once pupils had studied all the content. However, some leaders recognised the limitations of this approach. For example, it required key substantive concepts to be introduced in one year, and then not returned to. This is likely to pose challenges for pupils in remembering those concepts and in building connected knowledge over time.

71. Sometimes, curriculum planning was weaker because:

- **The knowledge that pupils needed to learn was not sufficiently clear.** For example, objectives were sometimes too broad and often set in relation to outcomes. For example, an objective in one school was to describe the function of certain organs and organ systems. Consequently, teachers were sometimes not clear what the essential learning was. This had implications for what pupils in different classes learned, which over time could limit the coherence of the curriculum
- **Pupils were expected to learn too much new content in a short time.** For example, in one school, we saw pupils being expected to learn, in a single lesson, how to:
 - use a new piece of scientific equipment correctly and safely
 - complete an experiment using this new equipment
 - record the findings of the experiment
 - explain how the equipment has led to advances in scientific knowledge

72. There was insufficient time for pupils to learn new knowledge and practise using it before moving on to new content. Often leaders attempted to compensate for overly short topics by returning to concepts in the curriculum many times. However, this approach was problematic because it simply repeated the same problem at a later stage.

73. In most schools, secondary subject leaders did not have a sufficiently clear understanding of what science pupils were expected to know from primary school. This had been made worse by COVID-19, because restrictions limited some leaders’ ability to visit and/or work with feeder primary schools to find out about their curriculums.

74. Typically, secondary subject leaders assumed that pupils in Year 7 had little or no knowledge of primary science. Where this was the case, most leaders did not demonstrate how they knew this, and could not explain how their science curriculum would address these assumed gaps in their pupils’ knowledge.

75. In a few schools, the science curriculum clearly identified the knowledge of primary science that pupils would be expected to know for each key stage 3 topic. This was clearly signposted, so that teachers knew they should activate and check this knowledge before teaching new content. This ensured that the curriculum built on, and did not simply repeat, what pupils had learned previously.

76. Some leaders attempted to address gaps in prior scientific knowledge by beginning Year 7 with a baseline assessment. However, it was unclear how information from this assessment was then used to inform the curriculum and teaching.

Examples of what pupils in some primary schools knew that is often repeated in secondary school

Year 5 pupils could confidently use terms such as ‘independent variable’, ‘dependent variable’ and ‘control variable’. They calculated the average time taken for sugar to dissolve in water of different temperatures.

Year 6 pupils could compare the physical properties of rocks, such as basalt, limestone, sandstone and granite. They had recently learned about states of matter, and that particles in solids are packed closely together, while particles in liquids slide over each other.

Disciplinary knowledge – the knowledge underpinning pupils’ understanding of working scientifically

Summary of the research review relevant to disciplinary knowledge

A high-quality science curriculum plans for pupils’ knowledge of working scientifically to develop over time. This involves identifying the underpinning disciplinary knowledge that pupils need to know. This knowledge can then be taught and revisited at the same time as the most relevant substantive knowledge is taught. Pupils should not be expected to learn this disciplinary knowledge simply as a by-product of taking part in practical activities. A high-quality curriculum includes disciplinary knowledge that involves knowledge of concepts, such as validity, as well as how to perform various procedures. In the research review, we considered disciplinary knowledge in relation to at least 4 content areas that pupils learn more about as they move from year to year:

1. knowledge of methods that scientists use to answer questions
2. knowledge of apparatus and techniques, including measurement
3. knowledge of data analysis
4. knowledge of how science uses evidence to develop explanations

77. Leaders’ plans to develop pupils’ disciplinary knowledge were generally much less comprehensive than their plans to develop pupils’ substantive knowledge. The focus in most schools was on developing pupils’ knowledge of apparatus and techniques, as well as data analysis. We found little evidence of other aspects of disciplinary knowledge being developed, for example knowledge of the full range of methods that scientists use, or how science uses evidence to develop explanations. However, this was a side of the curriculum that many leaders we spoke to were in the process of developing further.

78. In some school curriculums, disciplinary knowledge was not sufficiently well integrated with substantive content. It was treated as a stand-alone block or unit.

79. Overall, most curriculums planned for pupils to develop their disciplinary knowledge by providing ‘opportunities’ in the curriculum for them to carry out practical work, write up investigations or draw graphs. At key stages 4 and 5, this often involved pupils simply completing practical activities specified by awarding bodies. The focus was therefore on pupils carrying out activities, rather than on the knowledge that they were learning.

80. In some schools, the curriculum went further and identified aspects to focus on when pupils carried out practical work. For example, ‘drawing a results table’, ‘using equipment correctly’ or working in a ‘safe manner’. However, the precise knowledge that pupils were expected to learn to be successful in these aspects was not always clear. This was problematic because it limited how well the curriculum could be

planned to develop pupils' expertise in disciplinary knowledge over time, and often resulted in pupils simply 'doing' a skill without useful learning arising from the activity.

81. In a few schools, leaders had thought carefully about the specific knowledge that underpins complex skills such as graph drawing. They had identified and sequenced these components in the curriculum. It was therefore possible, for example, for leaders to describe how pupils' knowledge of graph drawing developed across Years 7 to 11. Further, these same curriculums often identified the key practical procedures that all pupils were required to be able to carry out. Importantly, in these cases, the curriculums also ensured that pupils had the necessary prior knowledge to carry out the practical activity skilfully.

82. In some schools, leaders began each year with a discrete scientific skills unit. These generally covered some areas of disciplinary knowledge, such as:

- using apparatus
- health and safety
- drawing graphs
- analysing data

However, there was often no clear plan for ways that pupils would then build on this disciplinary knowledge in subsequent topics. This was often left to chance.

The pitfalls when developing pupils' disciplinary knowledge

In one school, the subject leader wanted to develop pupils' ability to work scientifically and had chosen a commercially produced curriculum with a range of practical activities. However, the leader had not considered the underpinning knowledge necessary to complete and understand the practical tasks. Additionally, they had not considered the purpose of each activity carefully enough in relation to what pupils needed to learn through the activity. Although carrying out practical tasks may help some pupils to learn certain aspects of disciplinary knowledge, the limitation here was that the knowledge to be learned from the practical had not been identified and what pupils learned from the activity was a matter of chance. This approach also led to some pupils being expected to learn too much through one activity.

Planning the curriculum to make learning science easier

Summary of the research review for how the curriculum can address specific barriers to learning science

A high-quality science curriculum focuses on what pupils need to learn in order to get better at science. Curriculum choices also influence how easy or difficult this journey is for pupils. This is because knowledge learned at a point in time influences future learning, and makes it easier or harder. For example, in the research review, we considered the importance of the curriculum building, step by step, on pupils' prior knowledge, to reduce the likelihood of them forming misconceptions. We also considered the importance of planning the curriculum so that it takes account of what is taught in other subjects, such as mathematics.

83. Overall, most leaders saw their school curriculum as a description of what pupils need to know and do. However, leaders typically did not consider fully enough the function of a curriculum in making learning science easier. For example:

- in planning documentation, solutions to address or prevent misconceptions were nearly always in reference to pedagogy, assessment or signposting what the likely misconceptions were. There were very few examples of leaders having considered the knowledge taught, and when to address or anticipate pupils' difficulties
- pupils were being expected to learn too much content in a short time. There was insufficient time for pupils to practise and use what they had learned

84. Some leaders and teachers rightly recognised the provisional status of a curriculum. For example, in one school, leaders routinely asked teachers to reflect briefly on the science curriculum after teaching it, and suggest changes. This was not onerous in terms of teachers' time, and ensured that the curriculum continued to be refined and improved over subsequent years.

85. A minority of science curriculums took account of what pupils learn in mathematics. When this happened, schools adopted at least 3 different approaches to try to bring about coherence:

- **Re-ordering content:** For example, 'rates of reaction' was moved in the science curriculum so that it was taught after pupils had learned about gradients in mathematics
- **Flagging content:** The curriculum identified content that was used in science before it was taught in mathematics, for example 'standard form'. Teachers could then take this into account when planning the lesson
- **Applying content:** The science curriculum provided the opportunity for pupils to apply their mathematical knowledge in a scientific context. This involved mathematics teachers teaching pupils how to calculate density. Pupils then used this knowledge in science, and were able to consider additional disciplinary aspects such as the precision of an electronic balance

86. Some leaders identified that a barrier to learning science was the quantity of content that pupils were expected to know. Most schools prepared for this problem by starting lessons and new topics with activities that would encourage pupils to recall previously learned knowledge so that it was less likely to be forgotten. However, too often, inspectors found that pupils were asked to recall knowledge that they had not successfully learned when they first encountered it. A better approach might have been to allocate more curriculum time for teaching the content in the first instance, before asking pupils to recall this knowledge.

How one teacher supported pupils to develop connected knowledge of science

In this lesson, which was about sound, the teacher regularly reminded Year 8 pupils of how knowledge they were learning was connected to what they had previously learned in other areas of the curriculum. For example, the teacher began the lesson by reminding pupils what they should have learned about sound in primary school. The teacher then linked back to the lesson on electromagnets, in which pupils had learned how an electric bell works and how sound travels to the ear. This was then linked to what pupils had learned about particles vibrating. In this way, the teacher's explanations and questioning built incrementally from pupils' prior knowledge, drawing together related knowledge from different areas of the curriculum.

Summary of the research review relevant to practical work and the

curriculum

High-quality practical work, whether teachers' use of demonstrations or hands-on practical activities, forms a vital part of a science education. This is because it introduces pupils to the methods, objects and phenomena that scientists study. These, in turn, develop pupils' sense of wonder and curiosity about the material world. Practical work also teaches pupils about the often unpredictable and dynamic situations in which scientists work. However, research is clear that practical work is not always effective. Often this is because its purpose has not been established, or because pupils are expected to do and think about too much at once. Effective practical work has a clear purpose in relation to the curriculum. It forms part of a wider sequence of lessons and only takes place when pupils have enough prior knowledge to learn from the activity. When this is not the case, pupils experience too much complexity, which prevents them from learning what was intended.

87. Teachers' demonstrations were used in very few of the lessons visited by inspectors. The number of lessons visited in which pupils took part in whole-class practical activities was slightly higher, but still a small minority. Whole-class practical activities were seen much more frequently in lessons during visits to primary schools. In some secondary schools, inspectors did not see any practical work completed in lessons, either as a demonstration or activities carried out by pupils. Leaders typically said that this was linked to the behaviour of pupils or due to the lasting impact of the pandemic. However, it is a requirement of GCSEs and A levels and of the national curriculum that all pupils carry out laboratory work, fieldwork and scientific enquiries.

88. Although it is possible that inspections reduce the likelihood of teachers doing some kinds of practical work, this study raises some concerns about the frequency and type of practical work taking place across secondary schools in England.

89. Overall, across schools, the focus of practical work was generally on developing pupils' knowledge of practical techniques, such as microscopy and titration, and developing their substantive knowledge. Changes in the way practicals are assessed at GCSE and A level might explain some improvement in the focus of practical work. In 2015, before these changes, Ofqual reported that pupils focused too much on planning and analytical abilities rather than their technical skills.^[footnote 13] However, there was very little evidence of pupils developing their substantive and disciplinary knowledge at the same time, and then being given opportunities to undertake scientific enquiries. This is a concern, given that the national curriculum at key stage 3 requires that: 'Pupils should decide on the appropriate type of scientific enquiry to undertake to answer their own questions and develop a deeper understanding of factors to be taken into account when collecting, recording and processing data. They should evaluate their results and identify further questions arising from them.'^[footnote 14]

90. In some school curriculums, the purpose of practical activities was not considered carefully enough. It was not clear whether activities served a pedagogical role in helping pupils to learn a specific concept, or whether the goal was to learn disciplinary knowledge about practical work. For example, the technique to carry out an acid-base titration could fulfil either purpose, or both. This was problematic because it meant that some teachers were unclear about the teaching goal and so were also not clear about the knowledge they were teaching and assessing. It led to some departments not identifying which practical activities all pupils should be able to complete.

91. Across the small number of secondary schools where we observed teacher demonstrations, these tended to be quite simple, for example showing ice cubes

melting or using balloons to help pupils visualise the effects of static electricity. While simple demonstrations can be very effective in helping pupils to learn science, we found few examples of pupils being introduced to phenomena or objects of study that they had not encountered before, for example observing the effects of oscillating chemical reactions.

92. Where practical work was most effective, pupils were confident about using the apparatus. This enabled them to think about the scientific concepts rather than simply the procedures. For example, in one school, Year 7 pupils looked at onion cells under a microscope and, in another school, Year 11 pupils carried out a thiosulfate titration.

93. Occasionally, pupil groups for practical work were too large. For example, in one class, pupils were carrying out titrations in groups of 4. This meant that some pupils did not have a first-hand experience of the techniques they were learning.

94. In some lessons involving practical work, pupils lacked the necessary knowledge to analyse the data that they collected. Often, this was because certain knowledge was assumed and was not explicitly taught or checked beforehand. For example, pupils in one lesson needed to calculate an average, but did not know how to do this. In another example, pupils were completing calculations involving magnification before they knew the different parts of a microscope.

How one school considered practical work in the curriculum

In this school, the subject leader valued the role of practical work. Pupils had regular opportunities to carry out experiments in each topic. For example, when learning about plants in Year 7, pupils carried out a test on leaves to confirm whether starch was present. However, the leader had not considered the purpose of this activity carefully enough in relation to the curriculum. For example, they had not considered whether it was to illustrate the substantive concept of photosynthesis or a technique that pupils needed to know how to carry out, or both. Fundamentally, it was not clear what the essential learning was.

Pedagogy: teaching the curriculum

Summary of the research review in relation to teaching

Science often involves pupils learning abstract concepts that might be contrary to what they expect. Teacher effectiveness, underpinned by strong subject knowledge, is therefore particularly important in science. Research highlights how important it is that teachers' explanations are clear, and carefully build on what pupils already know. Alongside this, pupils benefit from time to discuss ideas, answer questions and practise using the knowledge. Teaching models and analogies can be particularly helpful tools in science classrooms because they provide tangible examples that pupils can use to think about abstract concepts. Teaching models and clear explanations can also help pupils to learn connected knowledge, for example knowing how changes at the macroscopic and tangible levels (for example, a balloon expanding) link to what is happening at the sub-microscopic and cellular levels (for example, gas particles moving further apart). However, all models need to be used with caution because they can lead to misconceptions.

95. Science teachers generally had secure subject knowledge. Inspectors rarely saw examples of misconceptions or errors introduced by teachers. Where subject knowledge was strong, teachers were able to bring into the lesson wider knowledge from across the science curriculum. For example, in one lesson, the teacher explicitly linked previous learning on atomic structure and electrons to new learning on electric circuits. By doing so, this teacher supported pupils to connect their knowledge from different content areas.

96. In some lessons, teachers carefully modelled what they wanted pupils to learn. However, sometimes there were insufficient opportunities for pupils to practise what they had been taught. For example, in one lesson, pupils did not have enough opportunities to develop confidence in writing chemical formulae.

97. Across schools, pupils with SEND were generally well supported to learn the same curriculum as their peers. This involved teachers using a range of approaches, from adapting resources for visually impaired students to providing further scaffolding and chunking of information. Teaching assistants played an important role in supporting some pupils. However, occasionally some pupils with SEND were not given the support they needed, because support was not provided consistently.

98. Generally, teachers were clear about the knowledge that pupils would be learning. They selected appropriate activities to teach that knowledge. For example, sorting activities were used in one A-level classroom to help pupils order the different stages of cell division. In this way, the task of ordering stages was well matched to the curriculum intent, which was to know the stages of cell division. In another classroom, a well-selected video was used to help pupils understand the abstract idea of a chemical equilibrium.

99. At times, the focus of a lesson was on completing a task that was not well matched to the curriculum intent. For example, in some classrooms, pupils were asked to watch videos that were not sufficiently focused on the content they were learning. These videos often introduced too many new terms at once, making it difficult for pupils to know what to think about. In another example, pupils were learning about the relationship between force and the extension of a spring. However, they were spending most of their time simply writing out a method.

100. In a minority of lessons visited, teachers used teaching models to help pupils build knowledge of abstract concepts. For example, in one school, pupils learned about electrical resistance by comparing electrical wires to school corridors. These teaching models were often helpful because they provided a tangible reference point for pupils and teachers to discuss. However, sometimes teachers did not spend enough time explaining the model to make sure that it helped pupils to learn the target concept.

101. In some lessons, teachers were expected to teach too much content at once. This resulted in the teaching moving on before there had been time for all pupils to consolidate their knowledge, get feedback and act on it. This often occurred when a teacher's focus was on keeping pace with curriculum plans or making sure that all content had been covered before an assessment. This issue was identified by inspectors during lesson visits and by looking at pupils' work, and it made the curriculum less effective.

102. In some schools, staff used shared PowerPoint presentations to teach the curriculum. Teachers said that this was beneficial because it helped to reduce their workload. It also enabled helpful resources and whole-departmental approaches to be easily shared. However, a drawback of using PowerPoint was that, unless guarded against, it could encourage teachers to focus on how the activities would be carried out, rather than the knowledge that pupils needed to know.

Assessment

Summary of the research review in relation to assessment

In the research review, we highlighted the importance of assessment having a clear purpose. Drawing on research, we distinguished between 3 different purposes:

- assessment **for** learning
- assessment **as** learning
- assessment **of** learning

Assessment should be designed so that it does not unintentionally narrow the curriculum or lead to unnecessary workload.

Assessment for learning – using assessment to provide feedback

Here, assessment for learning refers to formative assessment. This involves checking if pupils have learned the intended content of the curriculum lesson by lesson. These checks can be low-stakes and informal. They provide pupils and teachers with feedback that can be used to improve teaching. Evidence suggests that formative assessment in science should continue over extended periods and contexts in order to ensure learning has been understood as intended, and embedded in the pupils' memory. This is because pupils show variability in the concepts they recall and whether they are able to use them to understand more complex ideas or undertake activities. Multiple-choice questions can be helpful here to find out whether pupils have specific misconceptions. Teachers' content knowledge plays an important role in their ability to evaluate pupils' answers and provide subject-specific feedback.

103. Where formative assessment worked well, teachers identified the specific knowledge or misconception/error that pupils had. Often these inaccurate answers were only subtly different from the scientific answer, which sometimes made them difficult for teachers to identify. For example, in one school, pupils confused the number of different types of amino acids with the number of proteins in the body.

104. Questioning was the most common way in which teachers tried to ascertain what their pupils knew. Sometimes these questions focused on checking whether pupils had specific misconceptions. However, this was rarely done. Some schools used mini-whiteboards effectively to reveal what everyone in the class was thinking. By doing this, these teachers were not always reliant on questioning only some of the pupils.

105. In some lessons, there was insufficient checking of understanding, and teachers wrongly assumed that what had been taught had been learned. This led them to move on to teaching new content before pupils were ready.

106. Some schools used mid-topic assessments, to identify specific gaps in pupils' knowledge before they reached the end of the topic. In this way, teachers and pupils obtained important feedback before all the content had been taught.

107. Where formative assessment worked well, teachers with strong subject knowledge used questions and tasks throughout the lesson to check the specific

knowledge that pupils had learned. Often these tasks gave pupils the opportunity to practise and consolidate their knowledge, while allowing the teacher time to move around the classroom and check what pupils had learned. This assessment was not just checking what pupils knew at the start of the lesson, nor did it involve overly performative strategies to 'show progress'. Rather, teachers' checks of what pupils had learned formed an integral part of every activity.

108. Teachers' feedback was effective when it helped pupils to learn specific content. This took place through whole-class or one-to-one feedback. Feedback was sometimes less helpful, and involved stand-alone questions for pupils to answer that did not directly relate to the mistakes in their answers.

Assessment as learning – using assessment to help pupils to remember what they have previously learned

Assessment as learning refers to the process, over extended periods, through which pupils embed knowledge in their memory. When pupils are asked to recall knowledge this is known as 'retrieval practice' or the 'testing effect'. Like assessment for learning, this type of assessment should be coupled with feedback so that pupils do not reinforce wrong answers. Assessment as learning should focus on reinforcing knowledge of the most important content without 'destroying the shaping of content that makes it memorable'. [\[footnote 15\]](#)

109. In most schools visited, teachers used frequent low-stakes quizzing to encourage pupils to revisit and embed knowledge more deeply in memory. This was usually done at the start of the lesson, and was often a whole-school or departmental approach that drew on the principle of interleaving recall of crucial knowledge through the curriculum. This was most effective when the recall was mostly successful and coupled with feedback. For example, a teacher circulated around the classroom to check what pupils could remember so that, if there were gaps or errors, they were aware and could give feedback or additional work to the whole class, either immediately or at a later stage.

110. In some schools, assessment **as** learning was sometimes taking place at the expense of assessment **for** learning. For example, some pupils were asked to retrieve knowledge that they had not successfully learned in the first place. These gaps had not been identified before. As a result, teachers were having to spend too much lesson time on teaching pupils the answers to the retrieval questions. This led to some pupils becoming confused and disengaged.

111. In many schools, retrieval practice only went as far as asking pupils to remember facts in isolation, usually through short quizzes. It was rarely used to support pupils to develop interconnected knowledge, for example by asking them to compare their knowledge of related but different concepts using Venn diagrams or tables.

112. Assessment as learning was much less effective when pupils were asked to recall overly large composites like definitions, without first having secured knowledge of the underpinning components. This is because, although successful in the retrieval task, pupils did not have the prior knowledge to understand what they had retrieved. For example, in one class, pupils were asked to learn the definition of 'isotopes', but did not know what elements or atoms were. The definition, therefore, did not make sense.

113. Some leaders told inspectors that they use retrieval practice at the start of lessons, to address misconceptions. However, as outlined in the science research review, there are a number of significant challenges in addressing misconceptions

through quick quizzes. It is likely that quizzing may consolidate misconceptions. Also, there is often a lack of time and opportunity at the start of a lesson for pupils to receive the specific feedback that they need. It is therefore important that quizzes carefully distinguish between errors that are easy to correct, and misconceptions.

Assessment of learning – have curricular goals been achieved?

Assessment of learning refers to summative forms of assessment used to help teachers identify whether broader curricular goals have been achieved. It therefore plays an important role in evaluating the impact of any science curriculum. This assessment should check that pupils have secured the intended substantive and disciplinary knowledge. This includes pupils' ability to carry out specific practical procedures and scientific enquiries, which are important outcomes of a science education. Over-frequent use of summative assessment can lead to unnecessary burdens on staff and pupils. Improper use of summative assessment content can also lead to narrowing of the curriculum, until teaching is little more than an exercise in teaching 'to the test'.

114. Schools used different types of summative assessment to ascertain what pupils knew and remembered. Typically, this included end-of-topic assessments and longer termly examinations. Schools typically carried out 2 or 3 of these longer assessments each year.

115. Most schools assessed both substantive and disciplinary knowledge in key stage 3 assessments. However, some of the schools visited only checked substantive knowledge. This is a concern, given that the national curriculum requires pupils to develop their knowledge of the 'nature, processes and methods of science'. [\[footnote 16\]](#)

116. Approximately half the schools we visited carried out cumulative key stage 3 summative assessments. These tests checked that pupils had remembered knowledge taught in previous years. In the other schools visited, summative assessment at key stage 3 only checked what pupils had learned in recently taught topics.

117. In only a few cases did schools directly assess pupils' ability to carry out specific practical procedures or types of scientific enquiry. Given that competence in these areas is an important requirement of the national curriculum and preparation for practical work in key stages 4 and 5, this is a concern.

118. A few schools focused too much on preparing pupils to answer examination questions without them having first secured an understanding of the components.

119. In rare cases, assessment took up too much time and narrowed the curriculum. For example, in one school, pupils spent too many science lessons completing summative assessments and revising for them. This limited the time available for pupils to learn science.

Systems at subject and school level

Making sure that pupils gain the right science qualifications

Summary of the research review in relation to science qualifications

Science differs from many other subjects at GCSE because pupils can complete different qualifications. In England, science is assessed as either combined science, which is worth 2 GCSEs, or as 3 separate science GCSEs, often referred to as triple science. A small number of pupils complete entry-level or vocational qualifications. Research shows that having a range of qualifications creates some challenges for schools in designing a science curriculum. Schools need to make sure certain pupils are not prematurely excluded from studying specific qualifications. This is especially problematic if the decision to study a specific qualification, for example triple science, comes too early.

120. The majority of the schools we visited offered both combined science and triple science. The proportion of Year 11 pupils entering triple science in these schools ranged from 7% to 50% in 2021. The average was 28%. This figure is similar to the proportion of pupils entered nationally for triple science in 2022, which was 25%. [\[footnote 17\]](#) In 2 schools visited, all pupils were entered for triple science. These were both grammar schools.

121. In a small number of schools, triple science was not offered as a qualification. Instead, all pupils completed combined science. Leaders said that this was for a number of reasons. For example, in one school, leaders were developing capacity for triple science to be taught effectively in the future. In another school, leaders made the decision in consideration of the impact of the pandemic. This has implications for pupils who want to study science at A level. For example, some aspects of quantitative chemistry are not assessed in combined science, but form an important part of A-level chemistry. Leaders therefore need to take this into account when constructing the key stage 5 curriculum.

122. In a few schools visited, a minority of pupils completed an entry-level qualification. This was because leaders believed that these pupils might not manage GCSE content. However, where this worked, leaders designed the curriculum so that, where possible, these pupils could also enter for combined science. In doing so, leaders did not narrow the curriculum for these pupils, and they did not unnecessarily limit what qualification these pupils could achieve.

123. In the best cases, leaders recognised the importance of ‘fluidity’ when it came to curriculum design and key stage 4 qualifications. These leaders planned the curriculum so that pupils were not restricted to specific qualifications too early. For example, in one school, the curriculum was designed so that pupils could move between combined and triple science until the start of Year 11. This gave those pupils who needed it the time to catch up, so that they could complete the qualification if they wanted to.

124. On rare occasions, inspectors found that some pupils sat qualifications in only 1 or 2 of the 3 separate sciences. In some cases, this meant pupils had not had the opportunity to study all 3 sciences and in other cases entry choice was despite pupils studying all 3 science subjects at key stages 3 and 4. This was unlikely to be in the best interests of these pupils. It is a requirement that all schools, including academies, offer a broad and balanced science curriculum. This includes all pupils learning content from across all 3 sciences. [\[footnote 18\]](#)

Teachers’ knowledge and expertise

Summary of the research review in relation to developing teachers’ knowledge and expertise

Research is clear that teachers and support staff need regular access to

high-quality subject-specific CPD. Strong subject knowledge, and the associated confidence it brings, underpins many areas of high-quality science education, such as assessment and teacher explanations. Access to subject-specific CPD is particularly important for science teachers, given that they frequently teach outside their subject specialism. Evidence suggests that CPD should align with the curriculum and include teachers learning about the nature of science and its methods – which we broadly refer to as ‘disciplinary knowledge’ in the review. It is not enough to assume that teachers will get better at teaching science, simply by teaching science.

125. Inspectors found that, even within the same school, the quality of teaching can vary considerably between teachers. Reducing this variability by improving teachers’ effectiveness should be a key priority for all subject leaders.

126. An important source of CPD in nearly all science departments was informal discussions with colleagues. Given the high frequency and low cost of this type of collaboration, it could be a fruitful way for leaders to develop their team’s expertise. For example, leaders could make their team members aware of the staff who have specific knowledge, or restructure areas of a department, so that teachers and technicians meet more regularly.

127. Science technicians played a key role in supporting teachers to deliver high-quality practical work across schools. This support was particularly valued by teachers new to teaching science and those teaching outside their area of specialism. In schools where technicians were valued staff, supported with appropriate training and CPD, practical work was more likely to be high quality, well resourced and meaningful.

128. In the majority of schools we visited, at least one teacher had taken part in some form of external subject-specific CPD, for example through the Institute of Physics or STEM Learning. Typically, the content of these sessions focused on developing teachers’ knowledge of physics. We saw fewer instances of teachers undertaking external CPD in either chemistry or biology, for example how to teach quantitative chemistry or carry out biology fieldwork. Other external sessions involved awarding-body training or focused on developing teachers’ confidence in practical work.

129. Subject associations such as the Association for Science Education, and professional bodies such as the Royal Society of Chemistry, Institute of Physics and Royal Society of Biology, were valuable sources of subject knowledge for teachers. This support was provided through the courses they offered, or publications and online resources. Many teachers identified the important role these organisations played in providing online CPD throughout the pandemic.

130. In about half of the schools, leaders used some form of departmental time to develop teachers’ subject expertise. However, sessions tended to be restricted to pedagogy and often had quite high-level outcomes, for example focusing on how to carry out practical activities or how to use tablets in science classrooms. Where departmental time worked well, there was a clear focus on specific content. In one school, for example, teachers learned how to use a teaching model effectively, to teach pupils about circuits.

131. Despite teachers valuing the CPD that they received, in many schools teachers did not have access to a high-quality ongoing programme of professional development to improve their subject and pedagogical content knowledge. This was because there was no clear plan for how teachers would develop their expertise over time. Instead, there was an over-reliance on stand-alone training sessions, which often restricted CPD in science to learning about practical work. Our findings suggest that there needs to be a much greater focus on developing teachers’ expertise in relation to specific areas of the science curriculum and engaging with science-

specific research.

Subject leadership

Summary of the research review in relation to leadership in science

Science departments often face considerable challenges in recruiting and retaining teachers. Science teachers are more likely to leave teaching than non-science teachers, and recruitment targets in initial teacher education for chemistry and physics are regularly missed. Research suggests that careful school timetabling can play an important role in retaining and developing science teachers. For example, early-stage teachers can benefit from timetables that enable them to teach fewer subjects and year groups.

132. Where science leaders were well supported by senior leaders, they had dedicated time to attend local authority or trust meetings as well as external CPD. This allowed them to look beyond their own school. In some schools, leaders were supported to undertake leadership qualifications, such as the national professional qualification for middle leadership, and experience dedicated coaching and mentoring. However, very few science leaders received dedicated subject-specific support to lead a science department.

133. Some leaders considered the timetable to be a way of reducing teachers' workload. For example, they tried to ensure that teachers taught mostly their specialism and more than one class from the same year group. This was because they thought it reduced teachers' planning time and helped them to develop their expertise because they had less subject matter to focus on.

134. Occasionally, senior leaders were too focused on evaluating the quality of science education in relation to generic features, such as 'extended writing' or 'literacy'. They did not focus on considering whether pupils learned more science.

What pupils know and remember

Summary of the research review in relation to impact

To gain expertise in science pupils need to assimilate content which is well-organised. Pupils need knowledge that builds around key scientific concepts and ideas. Pupils need to remember what they learned previously, so that new knowledge can be incorporated into this emerging schema (pattern of interconnected learning) and become flexible, meaningful and easy to use. However, research is clear that, for some pupils, science comprises an array of disconnected knowledge that lacks any organised structure. As a result, pupils do not appreciate the important relationships that can link and organise the knowledge learned and the logical structure of each scientific discipline remains a mystery.

What inspectors learned from their visits to classrooms and speaking to pupils

135. In most schools, pupils' work followed the intended curriculum sequence. However, in some of the secondary schools, most pupils were not able to remember what they had previously learned in science.

136. In a few schools, pupils demonstrated particularly secure knowledge of science because they knew how different concepts, often from different content areas, connected. For example, pupils in one school made valid comparisons between the transportation systems of plants and the transportation systems of animals, and recognised how sophisticated plants are.

137. In each class, what pupils knew was often quite variable, and some pupils' foundational knowledge was not secure. For example, in one Year 10 class, pupils were drawing diagrams of ions, and some pupils thought the diagram showed an electron. In another class, pupils learned about electric plugs, but did not know that metals conduct electricity.

138. At times, what pupils were learning did not make sense to them. For example, although most pupils could recall that plants carry out photosynthesis, some pupils did not know what the function of this was. As expected from the research literature on misconceptions, some pupils' responses suggested that they held misconceptions. For example, some said that plants 'create energy'. Pupils also demonstrated difficulties in using terms precisely, for example confusing the word 'cell' with 'organelle'.

139. Where pupils' knowledge was particularly fragile, this was often attributed by teachers and school leaders to the effects of the pandemic or classes having experienced changes in teachers and/or supply teachers.

What one group of Year 9 pupils knew about plants

What have you learned about plants?

" ... last time was Year 7"

" ... plants can spread out their pollen so they can reproduce, and wind takes it"

" ... looked at bees and stuff"

" ... there is nucleus in the centre of a plant"

" ... there is photosynthesis process"

What is photosynthesis?

" ... when a plant takes the food from the sun"

These extracts are typical of pupils' scientific knowledge. This identifies that pupils have learned about key processes such as pollination and photosynthesis. However, they have not secured an appropriate depth of knowledge. For example, they hold incorrect ideas about photosynthesis. Simply teaching these pupils new knowledge about plants would likely lead to further confusion. This is why formative assessment is so important.

140. In some schools, inspectors found that pupils had excellent practical skills. These pupils were confident about setting up equipment such as microscopes and oscilloscopes, and weighing out and measuring the volume and masses of chemicals. In addition to their knowledge of practical procedures, pupils were also able to explain, using detailed scientific knowledge, the reasons for the equipment they had selected. They also knew some of the common 'pitfalls' in setting up the apparatus. At key stage 5, a few schools went beyond the required practical activities to ensure that students had sufficient opportunities to practise specific aspects of practical work.

141. In some schools, pupils explained the work of scientists as in some way related to a fair test approach. For example, they identified that scientists 'control variables'

and ‘repeat experiments’. Some pupils went further and explained why repetitions were necessary, and described how anomalous results could be identified and dealt with. In contrast, some pupils had very limited knowledge of how scientists find things out. Their answers were limited to ‘doing research’ or ‘doing tests’.

142. Overall, few pupils talked about types of scientific enquiry beyond fair testing. For example, pattern seeking, classification or observing over time were rarely mentioned. Peer review and scientific models were referred to by students in only a very small number of schools. Fieldwork was not mentioned by any pupil from any school. This provides further evidence, alongside other areas described in this report, that schools should focus further on developing pupils’ disciplinary knowledge so that they have a more genuine understanding of how scientists and science work to establish and refine scientific knowledge.

What a small sample of pupils in one school knew about how scientists find things out

Year 9 pupils:

“ They do research”

“ They do experiments”

“ ... learned about Charles Darwin who discovered some bird on an island”

Year 11 pupils:

“ ... not sure”

“ ... analyse data”

“ ... use a hypothesis to see if their experiment matches it”

“ They try to keep things the same to see what happens when they change stuff”

“ ... not sure”

“ ... don’t know”

Sixth-form pupils:

“ ... important to get the hypothesis right”

“ They have different perspectives depending on the evidence”

These extracts are typical of what inspectors found when they asked pupils about how scientists find things out. Most pupils typically referred to carrying out fair tests and could name some famous scientists. However, often pupils’ knowledge was superficial and did not demonstrate that they had a secure understanding of science as a discipline of enquiry, involving a number of different methods.

Appendix

Methodological note

This thematic report draws on findings from 50 research visits to schools in England. These visits were carried out between September 2021 and July 2022.

Deep dives into science took place as part of scheduled school inspections under the Education Inspection Framework. They were carried out by inspectors with

relevant expertise in science education who had received training for this work. This inspector carried out a deep dive as part of our methodology for evaluating the quality of education. Inspectors gathered rich range of data from speaking to senior leaders, subject leaders and teachers, visiting science lessons and speaking to pupils. They also reviewed pupils' work in science.

Various criteria were monitored consistently to identify characteristics for the sample that risked being underrepresented. These criteria were: region, inspection outcome, disadvantage quintile, size of school, and a rural or urban location. We made sure that the sample was broadly representative of the national picture and there was some representation from schools with different characteristics. The deep dive evidence collected was split evenly between primary and secondary schools.

Inspectors gathered qualitative evidence about science education in schools they visited. The range of evidence gathered across these visits enabled us to identify common themes in science education which are likely to be relevant in a wide range of schools.

Inspectors focused on gathering evidence which related to the following areas:

- curriculum
- pedagogy
- assessment
- school-level systems and their impact on science education

When analysing this evidence, we drew on the conception of quality in science education which we outlined in our science research review. This enabled us to consider how science education in English schools relates to our best evidence-based understanding of how schools can ensure a high-quality science education for all pupils.

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1. [‘Research review series: science’](#), Ofsted, April 2021; [‘Inspecting the curriculum’](#), Ofsted, May 2019.↵
 2. The requirement for maintained schools and academies to offer a broad and balanced curriculum is set out in the Education Act 2002 (for maintained schools) and the Academies Act 2010. This expectation is reflected in the national curriculum and is at the heart of the education inspection framework.↵
 3. [‘Analysing 2021’s A-Level and GCSE entries’](#), Campaign for Science and Engineering, August 2021.↵
 4. M Richardson, T Isaacs, I Barnes, C Swensson, D Wilkinson and J Golding, [‘Trends in international mathematics and science study 2019: national report for England’](#), Department for Education, December 2020.↵
 5. [‘National curriculum assessments at key stage 2 in England, 2019 \(interim\)’](#), Department for Education, September 2019.↵
 6. M Martin, I Mullis, P Foy and G Stanco, [‘TIMSS 2011 international results in science’](#), TIMSS & PIRLS International Study Center, 2012.↵
 7. [‘Ofsted COVID-19 series’](#), Ofsted, October 2020.↵
 8. [‘Initial teacher training: trainee number census 2021 to 2022’](#), Department for Education, December 2021.↵
 9. R Millar, ‘The role of practical work in the teaching and learning of science’, paper prepared for the Committee on High School Science Laboratories: Role and Vision, National Academy of Sciences, October 2004, quote on page 2.↵
 10. This relates to the concept of ‘science capital’. ‘The concept of science capital... includes what science you know, how you think about science (your attitudes and dispositions), who you know (for example, if your parents are very interested in

science) and what sort of everyday engagement you have with science.’ See [‘Science capital made clear’](#), King’s College London, 2016.↵

11. C Counsell, ‘Better conversations with subject leaders: how secondary senior leaders can see a curriculum more clearly’, in ‘The researchED guide to the curriculum’, edited by C Sealy and T Bennett, John Catt, 2020, pages 95 to 121, quote on page 98.↵
12. [‘The deployment of science and maths leaders in primary schools’](#), Wellcome Trust, October 2013.↵
13. [Assessment of Practical Work in New Science GCSEs – Summary](#) Ofqual, March 2015.↵
14. ‘National curriculum in England: science programmes of study’, Department for Education, September 2013.↵
15. C Counsell, ‘Better conversations with subject leaders: how secondary senior leaders can see a curriculum more clearly’, in ‘The researchED guide to the curriculum’, edited by C Sealy and T Bennett, John Catt, 2020, pages 95 to 121, quote on page 98.↵
16. [‘National curriculum in England: science programmes of study’](#), Department for Education, September 2013.↵
17. [‘Find school and college performance data in England’](#), GOV.UK.

EBacc science includes combined science GCSE, and single GCSEs in biology, chemistry, physics and computer science. Triple science includes 3 of: biology, chemistry, physics or computer science.↵

18. The requirement for maintained schools and academies to offer a broad and balanced curriculum is set out in the Education Act 2002 (for maintained schools) and the Academies Act 2010. This expectation is reflected in the national curriculum and is at the heart of the education inspection framework.↵

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