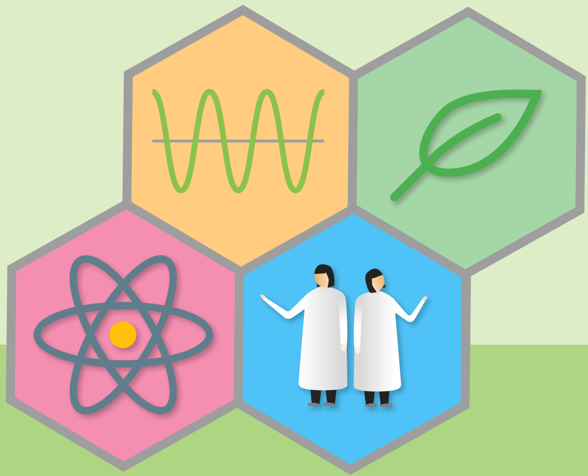
IMPROVING SECONDARY SCIENCE

Guidance Report



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The authors would like to thank the many researchers and practitioners who provided support and feedback on drafts of this guidance. In particular we would like to thank the Advisory Panel and Evidence Review Group:

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FOREWORD

The attainment gap in science may not be as well-documented as the gap in English and maths, but it is just as pervasive. Our research has shown that disadvantaged pupils start to fall behind in science in Key Stage 1; the gap only gets wider throughout primary and secondary school and on to A-level.

Helping schools to use evidence and to understand better the most effective ways to improve results is the best way to tackle this country's stark science attainment gap.

This is why we've produced this guidance report. It offers seven practical evidence-based recommendations—that are relevant to all pupils, but particularly to those struggling with science. To develop the recommendations we reviewed the best available international research and consulted experts to arrive at key principles for effective secondary science teaching.

As with all our guidance reports, the publication is just the start. We will now be working with the sector, including through our colleagues in the Research Schools Network, to build on the recommendations with further training and resources. And, as ever, we will be looking to support and test the most promising programmes that put the lessons from the research into practice.

Our hope is that this report – and our whole series of guidance reports - will help to support a consistently excellent, evidence-informed education system in England that creates great opportunities for all children, regardless of their family background.

Sir Kevan Collins

Chief Executive
Education Endowment Foundation

Science education is one of the keys to social mobility. Science qualifications open the doors to many rewarding and interesting careers, and scientific literacy is critically important to being an informed citizen. Science is the most powerful method humans have for understanding the world, and science teachers in secondary schools lay the foundations of that understanding. When asked why they chose to continue their study of science, most pupils mention an inspiring teacher.

If anyone understands the importance of evidence, it is science teachers. There is no shortage of research evidence about good science teaching, but few teachers have time to read it and sometimes it is difficult to unpick the implications for classroom practice.

This report gives accessible guidance for science teachers that is based on robust evidence. We have looked at seven areas which our expert advisers told us are particularly important for successful science teaching, and we set out to find what the research evidence tells us about each. We commissioned evidence reviews to see what the research literature says, and our expert advisers helped us to identify the parts of these reviews that could make most difference to teaching. We then consulted teacher panels to see if our suggestions made sense in today's classrooms.

Much of what we have to say—about literacy, memory and feedback, for example—is applicable to teaching in many subjects. But in this report we have set the guidance in the context of secondary science, and drawn all our examples from it.

We are very grateful to the many researchers and practitioners who provided support and feedback on drafts of this guidance. In particular we would like to thank our expert advisers and evidence reviewers, whose names are on page 2.

Sir John Holman
University of York

INTRODUCTION

Who is this guidance for?

This guidance is for secondary science teachers, heads of science departments, and senior leaders. The recommendations are designed to be actionable by classroom teachers, but there is benefit in teachers coming together as a department to think about how it applies in their context.

What does this guidance cover?

This guidance report is relevant to the teaching of science at Key Stages 3 and 4. We have focused on the seven areas where the evidence provides the strongest steer about how to enhance the teaching of science to pupils in this age group and have provided examples of how to apply the recommendations in practice. Each recommendation provides a 'First stop for further reading' for teachers who want to find out more about the evidence underpinning the recommendations. In addition to the seven areas, we provide guidance on the overarching theme of teaching for engagement, something which is particularly important for science education.

Research in science education has a strong history in areas such as teaching difficult ideas in science, language in science lessons, and ways of engaging pupils with what they are learning in their lessons. However, there are also important messages from research about learning more generally, such as in the area of memory and strategies for improving self-regulated learning.

"Science is exceptional among school subjects in the number of organisations that provide support for teachers, often free of charge"

Evidence-informed science teaching is not about fitting more into a tight timetable: it's about using limited time and resources as smartly as possible, by focusing on what is most likely to have a positive impact. Many of the suggestions in this guidance report will be familiar to you from your own experience and practice. We have used the research evidence to show how some of the things you already do can be as effective as possible, as well as some ideas which may be new to your practice. Take practical work, for example. Many of your lessons will involve practicals: in this report we summarise what the research says about how to get the most out of your lab time by being clear about its purpose and sequencing it with other learning activities.

INTRODUCTION

Acting on the guidance

Science teaching involves supporting both the language and mathematical development of pupils and there is a lot to be gained by working with your colleagues from maths and English departments. More information on best practice teaching of maths and literacy can be found in the EEF's published report *Improving Mathematics in Key Stages 2 and 3* and the EEF's upcoming report on literacy in secondary schools.

The more general EEF guidance, such as *Putting Evidence to Work—A School's Guide to Implementation*, can also support you and senior staff in your school to apply the recommendations. You may also want to seek support from our national network of Research Schools, a collaboration between the EEF and the Institute for Effective Education.* A CPD course based on the recommendations from this report will be available from the Research School's Network.

There is also a wealth of support in addition to that provided by the EEF, and science is exceptional among school subjects in the number of organisations that provide support for teachers, often free of charge. Support may be in the form of CPD for teachers, resources for pupils, or outreach activities. The range of organisations supporting science teaching can be bewildering, but a good place to start finding out what is available is the National STEM Learning Centre, https://www.stem.org.uk.

The broad categories of STEM-supporting organisations are summarised in Table 1. CPD does not have to be provided by external organisations and you can keep your own knowledge of research evidence up to date by using sources which are quickly and easily read, such as *Best Evidence in Brief* from the Institute for Effective Education and *Impact*, the journal of the Chartered College of Teaching.

Table 1: Types of organisation supporting science education with examples

Type of organisation	Example organisations	Examples of support
Charitable foundations	Wellcome Trust Gatsby Foundation The Chartered College of Teaching	Research reports Support for teachers' CPD
Industry and business	BP GSK BAe Systems Rolls Royce	Resources for pupils Support for teachers' CPD Outreach, especially STEM Ambassadors
Professional bodies and subject associations	Association for Science Education Royal Society of Biology Institute of Physics Royal Society of Chemistry Royal Society	Journals Teachers' CPD Advice for teachers Resources for pupils
Further and higher education	Universities Colleges of FE	Outreach by staff and student ambassadors

* https://educationendowmentfoundation.org.uk/scaling-up-evidence/research-schools/

TEACHING FOR ENGAGEMENT

Good teaching begins with gaining pupils' engagement and winning their commitment to learn. Science teaching is not just about getting good results at GCSE, important though that is; every secondary teacher knows the deep satisfaction that comes from lighting the fires of interest in young people and stimulating them to take a particular subject further. A considerable body of evidence now identifies the quality of teaching as a major determinant of pupil engagement and success.[1] Good science teaching improves both attainment *and* engagement, and all of the recommendations in this report should therefore support positive attitudes to science.

But there is an engagement problem in science. Many pupils feel that science is 'important, but not for me'.[2] They know science is powerful, but they do not see its relevance to their lives and they don't believe that 'people like them' go on to study science. This is an issue that starts young and worsens through compulsory schooling, with attitudes declining from the age of five onwards;[3] interest in pursuing further study in science is largely formed by the age of 14.[4]

A major study of attitudes towards science (ASPIRES) has shown that pupils who aspire to study science subjects are more likely to have high levels of 'science capital'.[5] There are eight key dimensions of science capital—these include a pupil's science-related attitudes, their knowledge about the transferability of science, their participation in out-of-school science contexts, and the science skills and qualifications of their family.[6] Knowledge about the features that lead to high engagement with science has led to the development of a 'Science Capital Teaching Approach'.[7] This has promising evidence suggesting it leads to more pupils being interested in studying science at A-level.[8]

So an important part of science teaching is to make pupils feel that science is something they can achieve in, whatever their background. As a science teacher, you have two big advantages. The first is that science is a practical subject. When the Wellcome Trust asked pupils what made school science enjoyable, the leading reasons turned out to be having a good teacher and enjoying practical work.[9]

The second advantage is the ease with which you can make links to issues that matter, and are of interest, to pupils. A major international review of research evidence showed that school science courses that emphasise links between science and everyday life foster more positive attitudes to the subject and to school science.[10] Personalising and localising science learning is also a key pillar of the 'Science Capital Teaching Approach' and examples of how to do this can be found in the teachers' pack.[11]

> *"Science qualifications open the door to many rewarding careers and this can be motivating for pupils"*

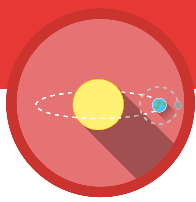
Science is often perceived to be harder than other subjects and this perception has been found to be a determinant of subject choice,[12] but science qualifications open the door to many rewarding careers and this can be motivating for pupils. As a science teacher, you see far more of your pupils than a career guidance specialist ever can. 'Careers in the curriculum' is one of the eight Gatsby benchmarks for good career guidance that form the basis of DfE's careers guidance strategy.[13,14] Science lessons are the starting point for making links between what is being taught and future careers—the examples are numerous: radiography technician (physics), food analyst (chemistry), conservationist (biology), and so on. There is evidence from the US that this approach can impact on academic outcomes.[15]

Science teachers can be powerful role models too, attracting pupils towards their subject and the careers that flow from it. Providing role models of people studying science[16] or working in science[17] enables pupils to develop a 'science identity' and to see themselves as possibly studying STEM subjects at university or following a different technical route to a career. Opportunities can be accessed through the STEM Ambassador scheme.

SUMMARY OF RECOMMENDATIONS

Sections are colour coded for ease of reference

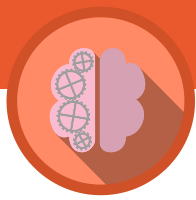
1
Preconceptions: Build on the ideas that pupils bring to lessons



- 1a: Understand the preconceptions that pupils bring to science lessons
- 1b: Develop pupils' thinking through cognitive conflict and discussion
- 1c: Allow enough time to challenge misconceptions and change thinking

Find this info on: **Page 10**

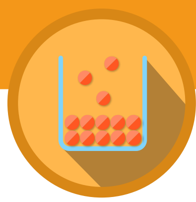
2
Self-regulation: Help pupils direct their own learning



- 2a: Explicitly teach pupils how to plan, monitor, and evaluate their learning
- 2b: Model your own thinking to help pupils develop their metacognitive and cognitive knowledge
- 2c: Promote metacognitive talk and dialogue in the classroom

Find this info on: **Page 14**

3
Modelling: Use models to support understanding



- 3a: Use models to help pupils develop a deeper understanding of scientific concepts
- 3b: Select the models you use with care
- 3c: Explicitly teach pupils about models and encourage pupils to critique them

Find this info on: **Page 18**

See also: **Teaching for engagement: Page 7**

4

Memory: Support pupils to retain and retrieve knowledge

- 4a: Pay attention to cognitive load—structure tasks to limit the amount of new information pupils need to process
- 4b: Revisit knowledge after a gap to help pupils retain it in their long-term memory
- 4c: Provide opportunities for pupils to retrieve the knowledge that they have previously learnt
- 4d: Encourage pupils to elaborate on what they have learnt

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5

Practical Work: Use practical work purposefully and as part of a learning sequence

- 5a: Know the purpose of each practical activity
- 5b: Sequence practical activities with other learning
- 5c: Use practical work to develop scientific reasoning
- 5d: Use a variety of approaches to practical science

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6

Language of Science: Develop scientific vocabulary and support pupils to read and write about science

- 6a: Carefully select the vocabulary to teach and focus on the most tricky words
- 6b: Show the links between words and their composite parts
- 6c: Use activities to engage pupils with reading scientific text and help them to comprehend it
- 6d: Support pupils to develop their scientific writing skills

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7

Feedback: Use structured feedback to move on pupils' thinking

- 7a: Find out what your pupils understand
- 7b: Think about what you're providing feedback on
- 7c: Provide feedback as comments rather than marks
- 7d: Make sure pupils can respond to your feedback

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Teaching for engagement: Page 7

1 Preconceptions: Build on the ideas that pupils bring to lessons

Science is about how the world works and long before children start a formal education in science they build their own understanding about the phenomena that they meet on a daily basis. These **preconceptions** are built through sensory experiences and social interaction.[18] These self-constructed ideas may or may not align with scientific understanding and, if they do not, are called **misconceptions**. Pupils usually need to go through a process of adjusting their ideas, or even replacing them with more scientifically correct ones.

"Pupils usually need to go through a process of adjusting their ideas, or even replacing them with more scientifically correct ones"

The process of pupils adapting and refining their theories is akin to the process of scientific discovery itself. Think of how the theory of relativity built on and refined Newton's classical mechanics. There is much that we can learn from the process of scientific discovery when dealing with pupils' preconceptions:

- Preconceptions are part of the history of science and we all have them. The key things is to be aware of the ones that your pupils are likely to hold and to know how to build on them;
- To adjust their misconceptions, pupils need to see compelling evidence that helps them to change their thinking and accept the new conception;
- Changing thinking takes time and pupils need to revisit ideas and be shown different examples to develop their thinking.

It is common for adults to hold misconceptions, as well as children. Pupils need to feel comfortable to share their ideas so you can build on their thinking.

Where's the evidence?

This is a well-researched field and there is strong evidence that learning is more effective when pupils' prior knowledge is taken into account. In particular, evidence suggests that:

- pupils construct their own explanations for phenomena and these ideas may differ from scientific explanations—there are common misconceptions in science and there is research to suggest what these are;
- cognitive conflict is an effective way of moving on pupils' thinking, helping them to reconstruct their existing ideas; and
- misconceptions can be difficult to shift, but doing so can lead to big gains in learning, particularly for threshold concepts.

Box 1: Online sources of information on common misconceptions

- STEM Learning *Understanding misconceptions* https://www.stem.org.uk/resources/elibrary/resource/31725/understanding-misconceptions
- The Royal Society of Chemistry's *Learn Chemistry* site http://www.rsc.org/learn-chemistry
- The Institute of Physics *Supporting Physics Teaching* site http://www.iop.org/education/teacher/support/spt/page_41531.html
- AAAS Project 2061 http://assessment.aaas.org/topics

1a: Understand the preconceptions that pupils bring to science lessons

First, find out what your pupils' preconceptions are. Well known misconceptions are a useful place to start; Box 1 contains some places that you can find information on common misconceptions. However, they may not be the preconceptions held by *your* class and it is important to get pupils' ideas into the open quickly at the start of a topic. You can then use the information to judge how best to approach the topic. It is useful for your pupils themselves to be aware of the ideas they hold so they can compare them with the scientific explanations you are teaching.

There are different ways to make pupils' thinking explicit and two routes are explored in Box 2.

Box 2: Helping pupils to make their thinking explicit

Diagnostic questions

These are multiple choice questions with the incorrect options (the distractors) carefully designed to uncover common misconceptions. Below is an example question from the U.S. AAAS Assessment bank http://assessment.aaas.org/topics:

Which of the following parts of an animal's body are made of cells?

A. The muscles, but not the brain
B. The brain, but not the muscles
C. Both the muscles and brain
D. Neither the brain nor the muscles

The correct answer to this question is C: the other answers demonstrate the misconception that some living parts of organisms are not made of cells.

Such questions can be usefully employed at 'hinge points' in your teaching, helping to inform where teaching should go next.[19]
A good source of diagnostic questions is Best Evidence Science Teaching (BEST)
https://www.stem.org.uk/best-evidence-science-teaching.

Class and small group discussions

Misconceptions can be uncovered through dialogue and it is often useful to use concept cartoons as a basis for discussion, (more information on these can be found in the self-regulation section of this report). Another approach is to get pupils in groups to write down or discuss what they know about a topic. At the start of the topic study, all answers are acceptable. A list of their ideas can be kept throughout the topic and revisited to show pupils how their thinking has changed over the course of several lessons.

1b: Develop pupils' thinking through cognitive conflict and discussion

Once you have identified their preconceptions, you can begin to help pupils develop their thinking. A useful way to develop thinking is to provide evidence that may conflict with pupils' currently held ideas.[20]

One way of achieving this is to introduce cognitive conflict into lessons.[21,22] This has been widely tested as part of the Cognitive Acceleration through Science Education (CASE) programme. As part of CASE lessons, pupils make unexpected observations which challenge their misconceptions and require them to restructure their way of thinking to accommodate this new evidence. They are then supported, by the teacher and their peers, to work through the problem and resolve the cognitive conflict. By doing this pupils develop new learning strategies and knowledge that they can then apply to other contexts.

An example of cognitive conflict may be found in Box 3.

Box 3: Example of cognitive conflict

Teaching about the particle model of gases

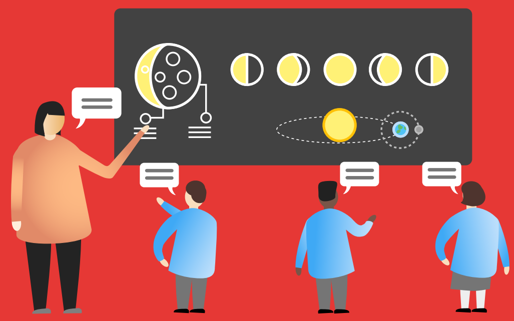
Adapted from Burrows et al., (2017 p. 47)[23]

One of the key things that pupils need to know about gases is that there is empty space (a vacuum) between the particles.

These ideas can, however, conflict with pupils' preconceptions. Even if pupils know that the particles in a gas have gaps between them, they often think that the space between them is full of other things such as bacteria, pollutants, or oxygen.

One way to create cognitive conflict in this case is to show that air in a blocked syringe can be compressed into a smaller volume (for example using a $100cm^3$ syringe and showing that the air can be compressed to $50cm^3$), but that a liquid and a solid cannot. This provides pupils with a situation that cannot be explained without a vacuum between particles and means that they will need to adjust their ideas to accommodate this new situation.

Pupils can work in groups to come up with models of how the particles in air are arranged to allow this compression to happen. This could be done through drawing, allowing a class discussion about the different models proposed by pupils. The understanding can be extended by asking if they think a gas could ever be compressed to zero volume.



1c: Allow enough time to challenge misconceptions and change thinking

Throughout teaching sequences it is useful to revisit misconceptions and remind pupils of what they thought at the beginning, getting them to revisit these early ideas and acknowledge any changes in their thinking. Some misconceptions can take time to shift, so it is important to use formative assessment to check that thinking has changed in the long-term.

Many misconceptions link to **threshold concepts**. These are transformative to the way pupils think and, although they are difficult to master,[24] once you have them you are unlikely to go back. Evolution is an example of a threshold concept, as is the particle theory of matter, which opens the door to all of chemistry. It is worth persevering with threshold concepts because they are so fundamental to other understanding.

Meyer and Land offer a number of characteristics of threshold concepts. They are likely to be:

- *transformative* – they result in a change in perception of a subject and may involve a shift in values or attitudes;
- *irreversible* – the resulting change is unlikely to be forgotten;
- *integrative* – they 'expose a previously hidden interrelatedness' between other concepts within the discipline, as evolution does for biology; and
- *potentially troublesome* – pupils may have difficulty coping with the new perspective that is offered.

First stop for further reading

Driver, R., Squires, A., Rushworth, P. and Wood-Robinson, V. (1994) *Making sense of Secondary Science: Research Into Children's Ideas*, London: Routledge.[18]

Although an older reference, this book provides a useful and accessible overview of misconceptions and how to deal with them in science.

2 Self-regulation: Help pupils direct their own learning

The ability of pupils to direct their own learning is often called 'self-regulation' and includes three parts:

- **cognition**–pupils' understanding about strategies they can use to learn, for example, strategies for solving equations or planning controlled experiments;
- **metacognition**–pupils being able to monitor and purposefully direct their learning, for example, checking that the cognitive strategies they have chosen for solving an equation are helping; and
- **motivation**–pupils' motivation to learn, including their self-beliefs and interest in topics; for example, pupils motivating themselves to undertake a tricky task for homework.

Although skills such as monitoring learning may seem like generic skills, it is important to develop them within the context of learning a specific subject. It is often supposed that these skills will be naturally developed by pupils, but the reality is that explicit instruction is needed and that this may be particularly beneficial for low-attaining pupils. This section contains specific pedagogies that will help to develop metacognitive skills within science lessons.

Where's the evidence?

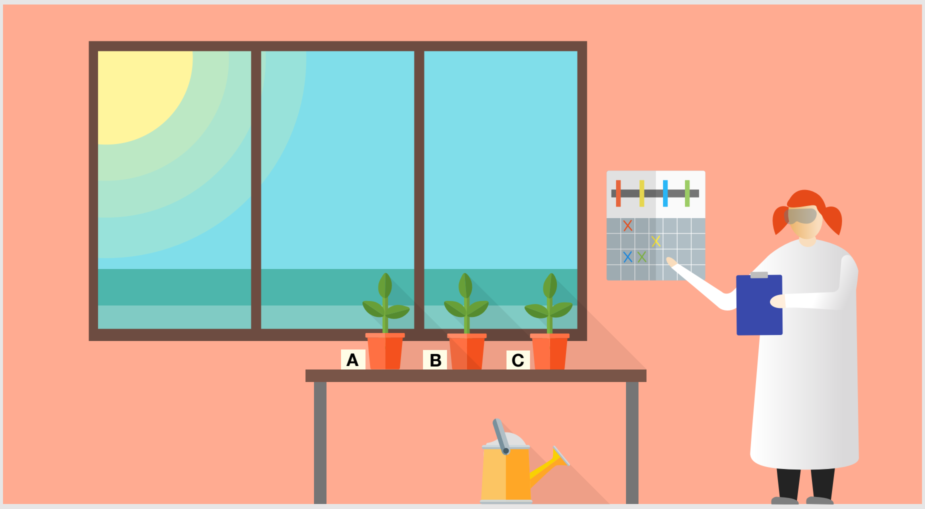
Several large correlational studies show strong links between self-regulation and attainment in science. In addition there are intervention studies, testing the impact of programmes aimed at improving self-regulation, which show improvements in science outcomes. Evidence also suggests that:

- low prior attainers benefit more than high prior attainers, so explicitly teaching these strategies may help to close the attainment gap;
- self-regulation skills need to be developed within the context of learning a subject; and
- specific strategies to develop these skills in science lessons include modelling your own thinking to pupils and engaging pupils in metacognitive talk.

Box 4: Using a task to develop metacognition

Design an experiment to find out the effect of an abiotic factor on plant growth

You will be given some seedlings. Choose a factor to test on the growth of the seedlings (for example, amount of sunlight, amount of water, or different mineral solutions added to the soil). Design an experiment to find out the effect that the factor has on plant growth.



2a: Explicitly teach pupils how to plan, monitor, and evaluate their learning

Metacognition is not just 'thinking about one's thinking', but also monitoring one's learning and, importantly, making changes to one's approach to a task as a result of the monitoring. Encourage pupils to engage in the Planning-Monitoring-Evaluation cycle (Figure 1) as part of science lessons.

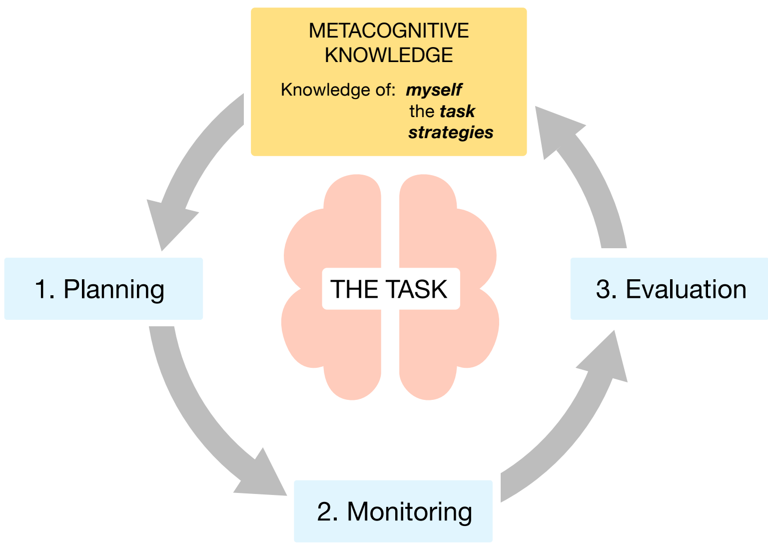
This is a cycle rather than a one-off process. As pupils progress through a task they may need to go through the cycle more than once to complete the task fully. In expert learners, these processes become unconscious and automatic. In novice learners, however, it is valuable to make them explicit.

Metacognition needs to be embedded within a specific task rather than addressed in abstract. The task starts with pupils accessing their existing metacognitive knowledge, including about their own abilities, the strategies they could use, and their knowledge about this type of task. During the task itself they engage in the planning, monitoring, and evaluation cycle, which then updates their metacognitive knowledge for tackling similar tasks in the future.

Take as an example the task in Box 4. The teacher has set a clear learning goal. Pupils then begin the planning phase to decide how they will achieve the goal. At this stage it is helpful for teachers to encourage pupils to ask questions that activate their prior knowledge of plant growth as well as the process of designing a successful experiment such as, *'Are there any strategies that I have used before that might be useful?'*, or, *'How will I ensure I only change one factor at a time?'*. Depending on the ability of pupils to work in this way, these questions may have to be approached as a class or in groups, with teachers suggesting suitable strategies that may be helpful.

During the monitoring phase of the cycle, pupils will be following their plans: *'Are the strategies I've chosen working?'*; *'Am I really only changing one thing at a time?'*. They will also monitor and update their prior knowledge of plant growth. If pupils are not practised in this approach you may have to prompt them to monitor and provide dedicated breaks in activity to ensure monitoring happens.

Figure 1: The Metacognition Cycle



"Metacognition is not just 'thinking about one's thinking', but also monitoring one's learning and, importantly, making changes"

During the evaluation phase, pupils determine how successful the strategy they used was in helping them to achieve the learning goal. *'What went well?'*, *'What didn't go well?'*, *'What could I do differently next time I have to plan an experiment?'*, *'What have I learnt about plant growth?'*. Again, pupils less practised in the approach may need your guidance.

2b: Model your thinking to help pupils develop metacognitive and cognitive knowledge

Show your pupils how you think. You can provide a useful example for pupils by making your thinking processes explicit.[22] You can do this by working through problems in front of a class, talking through how you are approaching the problem, the kinds of strategies you are trying and why you've chosen them, and how you are monitoring if they are successful. You can do this with problems that you have seen before, but it is often useful to do it with problems you haven't seen, to provide pupils with a live example of how to approach a new problem.

This approach is particularly useful when pupils first approach a new problem or way of thinking, but encourage pupils to become increasingly independent over time. Introduce some 'deliberate difficulty'[25] so that pupils have to think for themselves at points and reflect on their learning.

2c: Promote metacognitive talk and dialogue in the classroom

Discussion requires careful structuring and pupils need explicit instruction on how to have effective group discussions.[26] One way of doing this is to set out ground rules for the group. The example in Box 5 has rules that have been found to impact positively on reasoned argument.

Argumentation is a specific form of dialogue that can help pupils make reasoned claims that are backed by evidence.[28] This helps them to understand the power and limitation of scientific knowledge, showing not only *what* we know but *how* we know.

One way to promote argumentation is to help pupils to move from weaker arguments—which use minimal data and warrants (statements that link data to claims)—to stronger arguments that include greater use of data and rebuttals of counter arguments (see Box 6 for examples of weak and strong arguments).

It is helpful to discuss wrong ideas and why they're wrong, as well as why the right idea is right and this helps pupils to examine their preconceptions – see also recommendation 1.

Evidence also suggests that group discussions work better when a stimulus is used to present a diversity of views.[26] One way of stimulating pupils to explore different ideas is to use 'talking heads' items (see Figure 2). The groups can use the 'talking heads' to answer a variety of questions, including:

- who has the right idea, who has the wrong idea?
- who gives the best scientific explanation?
- who is talking about data, who is giving an explanation?
- who is using evidence, who is expressing an opinion?

Box 5: Group rules

Adapted from Mercer et al., 2004.[27]

- All group members must contribute; no one member should say too much or too little. Team members should encourage those who are saying less;
- Every contribution should be treated with respect, listened to thoughtfully, and allowed to finish;
- Each group much achieve consensus by the end of the activity, and you may need to resolve differences; and
- Every suggestion a member makes has to be justified—say what you think and why you think it.

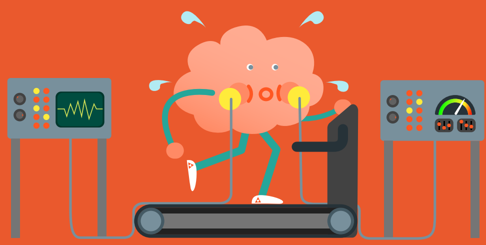
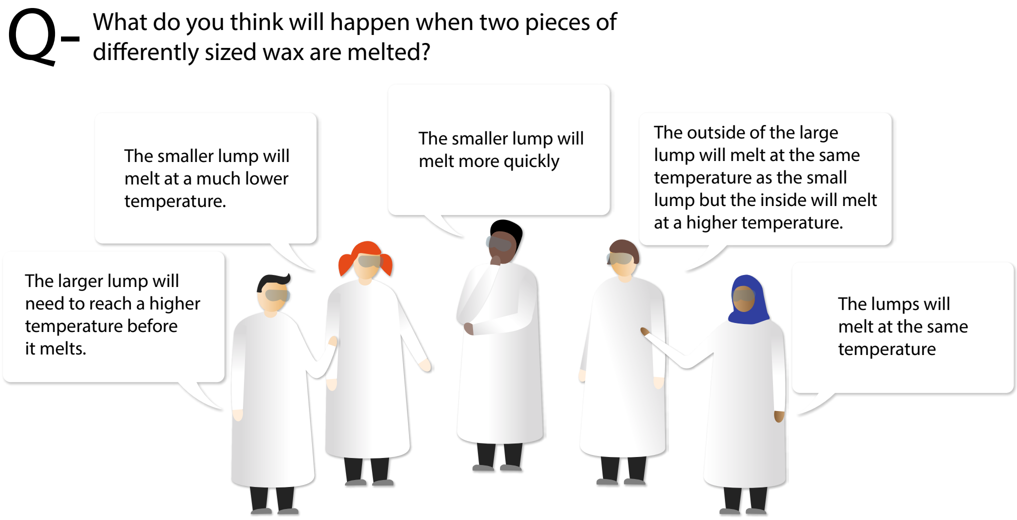


Figure 2: 'Talking heads' to encourage exploratory talk
Adapted from BEST science project[29]



Box 6: Weak and strong arguments

Adapted from Osborne et al., 2004.[28]

Weak argument

We must see because light enters the eye [claim]. You need light to see by [data]. After all, otherwise we would be able to see in the dark [warrant].

Stronger argument

Seeing because light enters the eye makes more sense [claim]. We can't see when there is no light at all [data]. If something was coming out of our eyes, we should always be able to see even in the pitch dark [rebuttal]. Sunglasses stop something coming in, not something going out [data]. The only reason you have to look towards something to see it is because you need to catch the light coming from that direction [rebuttal]. The eye is rather like a camera with a light-sensitive coating at the back, which picks up light coming in, not something going out [warrant].

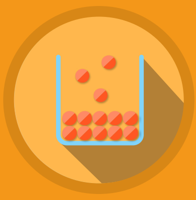
First stop for further reading

Metacognition and Self-Regulated Learning Guidance Report
https://eef.li/metacognition

Cambridge Assessment – Getting started with Meta-cognition
https://cambridge-community.org.uk/professional-development/gswmeta/index.html

Both of these reports provide accessible summaries of the evidence about self-regulation and practical suggestions for implementing ideas in the classroom.

3 Modelling: Use models to support understanding



Models are an essential part of developing and sharing scientific knowledge and they have been around for as long as scientists have been explaining their ideas to one another (Figure 3). Models are critical as science often involves working with phenomena and concepts that are inaccessible to our everyday senses. Reality is complicated and models can help to simplify things and make them easier to manage and understand.

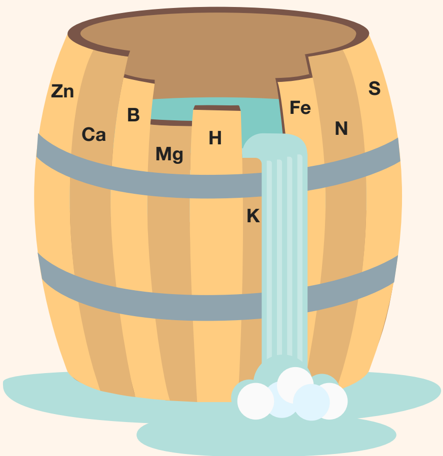
Good teachers use models all the time to provide a bridge between pupils' current ideas and new understanding. Models are ways of thinking about the 'real thing', and there are many kinds (see Box 7). By being explicit about models, you can help your pupils understand their own thinking. By inviting them to comment on and improve models you can give them extra insights.

Where's the evidence?

Research shows that modelling is widespread in science teaching. The focus of studies tends to be on how to optimise the use of models rather than on the value of models themselves. Evidence suggests that:

- the ideas that models are based on should be familiar to pupils, as otherwise this can confuse them further; and
- it is important that pupils understand how models differs from the idea being taught and learn the underlying idea rather than the model.

Figure 3: The barrel analogy for limiting factors



Justus von Leibig (1803–1873) used the barrel analogy (Figure 3) to explain the effect of limiting nutrients on plant growth. The height of the water represents plant growth and each of the wooden staves represents one of the nutrients that the plant needs to grow. In this example, the growth rate is being limited by potassium, K.

Box 7: Models that teachers often use

Models that teachers often use include:

- *three dimensional models* – for example, a plastic ball-and-stick model of an organic molecule, or a coloured plastic model of the human circulatory system;
- *verbal and written models* – for example, analogies such as the water flow analogy for electric current;
- *mathematical models* – for example, equations of motion and chemical formulae;
- *visuals* – such as graphs, diagrams, and animations; and
- *computer models* – such as simulations of population growth.

3a: Use models to help pupils develop a deeper understanding of scientific concepts

Scientific knowledge is difficult to learn because we are constantly moving between observations we can make with our senses, the explanations for observations, and the symbolic representation of these explanations. You can use models to link observations to explanations and representations.

The idea of three levels of scientific knowledge was first developed by Alex Johnstone,[30] who initially used it to explain the three levels of chemical knowledge. Figure 4 shows Johnstone's Triangle.

Johnstone's Triangle can be expanded to include all science learning. In physics, the three levels might be 'the macro' (for example, physical objects), 'the invisible' (such as forces, reactions, and electrons), and 'the symbolic' (formulae). In biology the three levels might be 'the macro' (for example, plants or animals), 'the micro' (such as cells), and 'the biochemical' (for example, DNA).

Each of these levels helps create an individual's understanding of a phenomenon, and expert scientists will build understanding that blends the three levels. Pupils, however, often operate at the macroscopic level and find it hard to relate their experiences of the phenomenon to the sub-microscopic and symbolic levels – particularly as they can't observe these two levels. Models help pupils to link observations to the sub-microscopic and symbolic levels and to build a richer understanding.

Figure 4: Johnstone's Triangle – for the three levels of chemistry knowledge

The three levels of description are:

- the **macroscopic** – including descriptive knowledge as acquired through experience, either directly (through our senses) or indirectly (through measurement), for example:

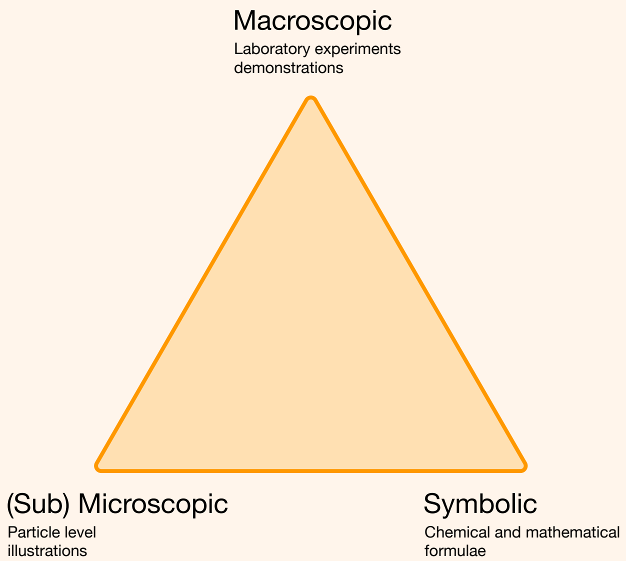
  Natural gas burns in the presence of air and can be used to warm things up;

- the **sub-microscopic** – including the explanatory models that scientists have developed to make sense of observations at the macroscopic level; we can't directly observe things at this level. For example:

  Natural gas is mainly composed of methane, a chemical compound that undergoes a combustion reaction with oxygen in the air, producing two new substances, carbon dioxide and water, and releasing energy as heat and light; and

- the **symbolic** – including chemical symbols, formulas, and mathematical equations:

  $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + energy.$



3b: Select the models you use with care

As a science teacher you have many models in your repertoire. Models should only be used if they aid understanding—and there are plenty of concepts that can be taught without the use of models.

Think about the models that you are going to use before, during, and following lessons. A useful way of doing this is the Focus, Action and Reflection (FAR) approach (Box 8).

Make sure pupils are familiar with the underlying idea that the intended model is based on. If the model is just as unfamiliar as the new concept being taught, the model may hinder rather than help teaching.

Box 8: The FAR approach to using models

Focus (before lesson)	
Concept that will be taught during the lesson	Is it a difficult, unfamiliar, or abstract concept or process?
Pupils	What ideas do pupils already know about the concept or process that the model will be describing?
Model	Is the model itself something that pupils are familiar with? (For example, if using water flow to model electric current, do pupils know about turbines and water pumps?).

Action (during lesson)	
Discuss	Discuss the features of the science concept and the model.
Likes	Draw similarities between the concept and the model.
Unlikes	Discuss where the model is different from the concept.

Reflection (after lesson)	
Conclusions	Was the model clear and useful, or confusing?
Improvements	How could the model be improved for future use? Do the class need to revisit the idea?

Adapted from Treagust et al., 1998[31]

3c: Explicitly teach pupils about models and encourage pupils to critique them

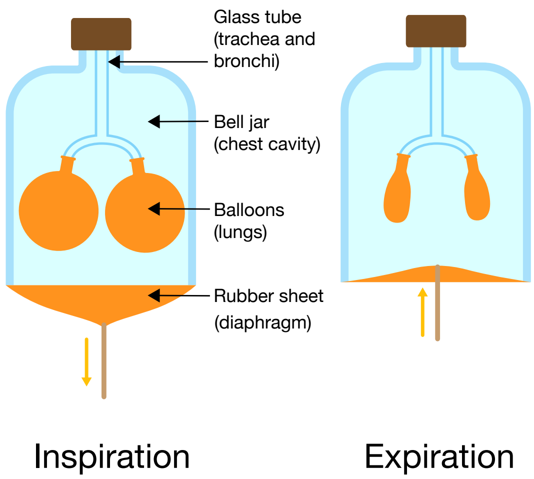
For pupils to get the most out of models they need to understand how models relate to reality and why they are used. This is an important step in developing their ability to 'reason like a scientist'. Three levels for understanding the 'nature of models'[32] are:

- **beginner** – 'I think that models are a direct copy of reality and don't see how they differ from reality';
- **intermediate** – 'I understand that models are not direct copies of reality and I understand that models are used to help me develop my scientific understanding'; and
- **expert** – 'I know that several different models can be used to explain different aspects of an idea; I understand that models have strengths and weaknesses and that existing models can be changed and improved; I know that models can be used to test ideas and are created for specific purposes'.

Most models are limited. For example, a physical model of the lungs showing balloons inflating inside an evacuated glass bell-jar is useful (Figure 5)—but it is limited because the chest wall is not rigid like a glass jar and the role of the ribs and intercostal muscles are not explained by that model. Be careful that models do not lead to pupils being confused or developing misconceptions.

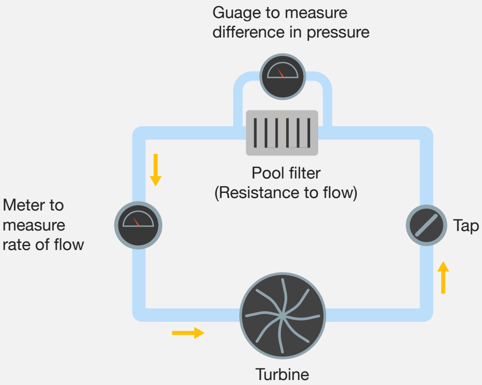
Avoid pupils learning the model rather than the concept it is meant to explain. You can do this by explicitly directing pupils to the similarities and differences between the model and the concept. One way to do this is to give them first-hand experience with a wide range of model types, then challenge them to compare existing models. For example, they could compare the three different models to represent electric current (Box 9, overleaf).

Figure 5: The bell jar model of the lungs

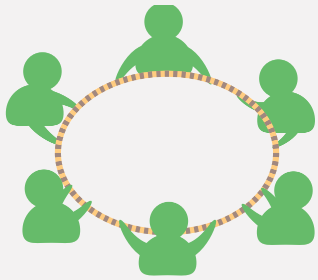


Box 9: Different models for electric current and the limitations of each

The water circuit model



The rope model

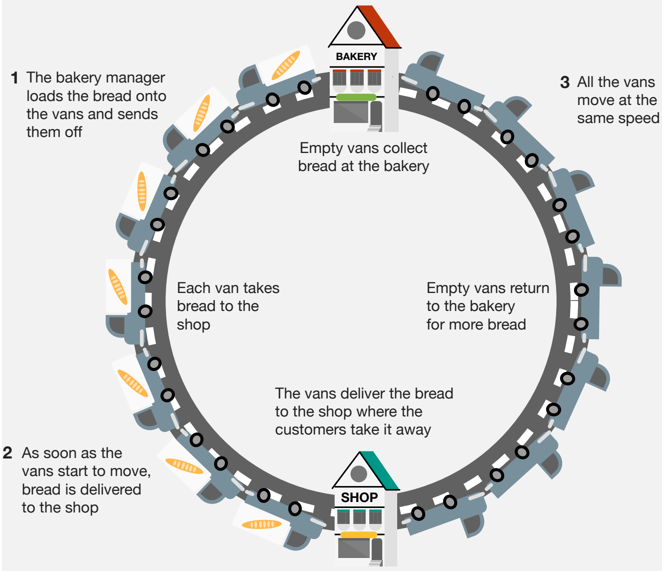


There are three commonly used models for electric current—the water circuit model, the rope model, and the delivery van model.

The water circuit model is one that pupils can easily relate to. However, they need to be aware of the differences from their everyday experiences with water in pipes. For example, unlike water leaving the plumbing through taps, electricity cannot leave the circuit.

The rope model is useful for developing the idea of energy flow and for showing the constancy of current in a circuit. However, this model does have limited use as there is not a component in the circuit that is performing energy transfer. It is tangible: pupils can stand in a circle and hold and feel the rope and it can demonstrate heating in an electric circuit.

The delivery van model



The delivery van model is useful for showing that the movement of electrons in a circuit is accompanied by a transfer of energy. The limitation here is that energy is seen as a substance rather than a concept. It is also important that the delivery vans are seen as being in a continuous line rather than with gaps between them as otherwise the model does not depict how electrons move around the circuit.

The point here is not to pick one model but to use the comparison between models to help pupils develop an understanding of both the concept and the nature of models.

When discussing the three models, typical discussion questions might be:

- In each model, how would you represent:
  - — increasing the current?
  - — increasing the voltage?
- Which model do you find most helpful? Why?
- How could you improve the models?
- How would you develop each model to deal with alternating current?

First stop for further reading

Gilbert, J. K. and Justi, R. (2016) *Modelling-based Teaching in Science Education*, Switzerland: Springer International.[33]

This book provides detail on the research in this area and how to best use models as part of science teaching.

4 Memory: Support pupils to retain and retrieve knowledge

You cannot do science without knowledge. Pupils have to learn new concepts and vocabulary and apply this learning in new contexts. So being able to remember information is important for success in school science.

"Long-term memory should not be thought of as a static store of knowledge; it is constantly updating and evolving."

This is not about rote learning: knowledge is an important step in progressing to more complex understanding.

There are two important components of memory—long-term memory and working memory. **Long-term memory** can be considered as a 'store of knowledge'. **Working memory** is where information that is being actively processed is held—it is where 'thinking' happens. Long-term memory, however, should not be thought of as a static store of knowledge; it is constantly updating and evolving.

The important thing to appreciate is that working memory is limited in how much information it can hold at any one time. On average, your working memory can hold around seven 'bits' of information and only keeps them for about 20 seconds unless they are refreshed by rehearsal.

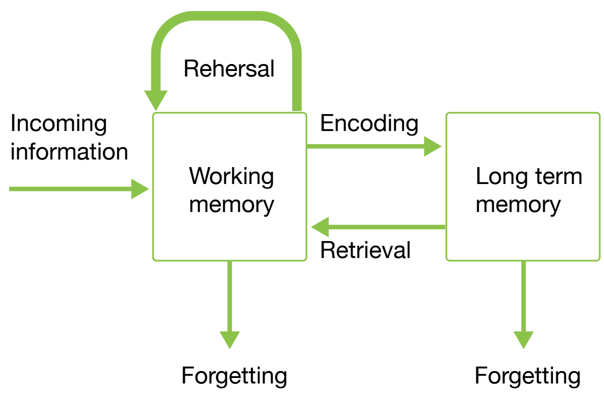
These capacity limits apply to new information, but working memory does not have this limitation when dealing with information retrieved from your long-term memory. Information in your long-term memory is stored in schemas: a **schema** is a pattern of thought that organises categories of information, and the links between them. The working memory deals with each schema as a single element of information so the load on the working memory is reduced because even complex schema can be dealt with as a single element.

Where's the evidence?

Cognitive science has recently led to significant breakthroughs in understanding the different functions and processes of the brain, but applying laboratory data to classroom practice is not straightforward. Research does support:

- cognitive load theory, although it is less clear how much information pupils can hold in their working memory;
- spaced review, which has the most evidence from classroom studies of the strategies discussed in this section, with effects noted across different contexts; and
- retrieval practice and elaborative interrogation, which have a number of studies with positive effects.

Figure 6: Working memory and long term memory



4a: Pay attention to cognitive load

The limit of the working memory means that it can quickly become overloaded when dealing with a new task. Any task that exceeds the limit of the working memory will result in cognitive overload and this increases the possibility that the content may be misunderstood and not effectively encoded in the long-term memory.

Here is an example from chemistry of a task that may require lots of information to be held in the short term memory. When pupils learn about titrations, there are many new concepts and practical skills to learn, as well as new equipment to get to grips with. If all of this is introduced simultaneously, learners are likely to find it difficult to process.

You can structure complex tasks, so that working memories are not overloaded, by limiting the amount of new information pupils need to process. Here are some approaches:

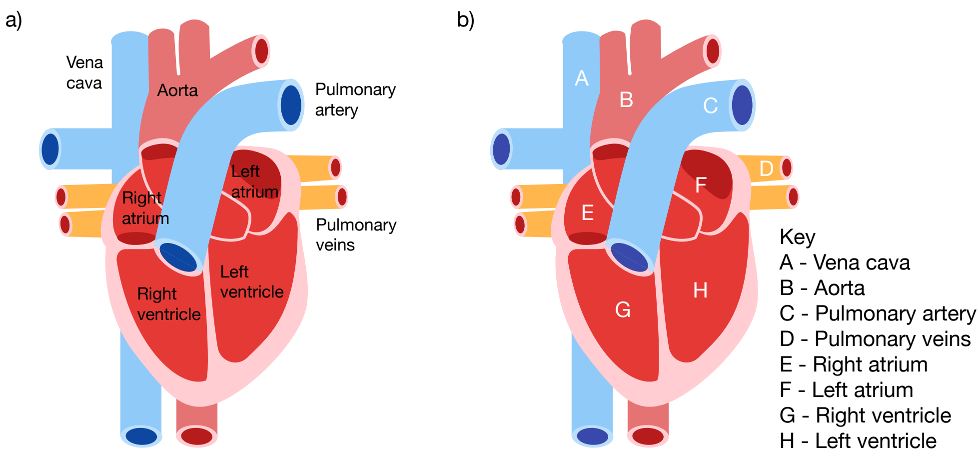
- Plan lesson sequences so that any necessary background knowledge is covered in advance, including revisiting previously taught ideas that a complex task relies on;
- Avoid **split attention** by ensuring pupils do not need to refer to multiple sources to complete a task. For example, split attention occurs when pupils have to move between a diagram and a written explanation (see Figure 7);
- Use worked examples or partially solved examples that take pupils through each step of a process—this is particularly useful when first learning a problem-solving strategy—but reduce the use of examples as pupils' expertise increases; and
- Break down a task so that pupils tackle it step-by-step, writing down what they know at each step, before tackling the next step.

"Any task that exceeds the limit of the working memory will result in cognitive overload and this increases the possibility that the content may be misunderstood"

A key way of preventing cognitive overload is to help pupils commit important and frequently used pieces of information to their long-term memory.

Figure 7: Avoiding split attention

Diagram (a) prevents split attention and reduces cognitive load by integrating the labels with the visual; (b) requires pupils' attention to move between the visual and the list of labels, splitting their attention and increasing cognitive load.[34]



4b: Revisit knowledge after a gap to help pupils retain it in their long-term memory

Learning everything to do with a topic during a single time period is not as effective as distributed learning.[35,36] **Spaced review** involves revisiting a topic after a 'forgetting gap' and strengthens long-term memory. A simple way to manage this is to build in review time, including reviewing learning from the previous lesson at the start of the next one or over longer periods (at the end of each week, month, or topic). This also links with retrieval practice: combining spaced review and retrieval practice can lead to great benefits in retention in the long-term.

4c: Provide opportunities for pupils to retrieve knowledge they previously learnt

Repeatedly re-reading a text is not an effective way of learning. It is much more effective for pupils to try to retrieve what they already know about a topic,[37] or what they have recently read about it, from memory. **Retrieval practice** involves retrieving something you have learnt in the past and bringing it back to mind. You can use retrieval to review past learning before introducing new related learning. For example, you might ask pupils to recall group one of the periodic table before introducing group seven, showing its similarities and differences.

"Ask pupils to recall group one of the periodic table before introducing group seven, showing its similarities and differences"

Pupils are using retrieval practice every time you administer a test. Using frequent (for example, weekly instead of termly), short, and, importantly, low-stakes tests causes pupils to retrieve knowledge on a regular basis. *Any* activity that requires pupils to draw on past knowledge can have the same effect, including activities such as the use of flashcards, completing practice questions, or writing a concept map. The key is that pupils are drawing on their long-term memory as much as possible, although they can look at sources afterwards to help them fill in any gaps and to give themselves feedback.

Retrieval practice needs to occur a reasonable time after the topic has been initially taught. Research shows that longer (at least a week) intervals are more effective. What makes retrieval practice really interesting for education is the durability of the effect, with impacts being seen sometimes years after the approach has been used.[38]

4d: Encourage pupils to elaborate on what they have learnt

Elaboration involves describing and explaining in detail something you have learnt. This approach supports learning by integrating new information with existing prior knowledge, helping to embed it in the long-term memory. This is useful as pupils progress in their understanding of a concept.

A well-studied form of elaboration is **elaborative interrogation**, which involves prompting pupils to generate an explanation for an idea that they have learnt. Prompt them to ask and answer 'Why?' and 'How?' questions about the topics that they are learning (for example, 'Tell me how an electric motor works'; 'Why does it turn faster when the current is higher?'; 'How does the electric current get into the coil?'). Studies show that learning effects are larger when pupils generate answers to these questions themselves rather than being provided with the explanations.[26]

First stop for further reading

Learning Scientists website http://www.learningscientists.org/

This is a good place to look for more information on all of the areas covered in this section and provides examples of how to apply these techniques in the classroom.

5 Practical Work: Use practical work purposefully and as part of a learning sequence

Seeing is believing. As well as being intrinsic to science, experiments help pupils to root scientific theory and knowledge in reality.

Our definition of 'Practical science' includes a wide variety of activities in which pupils manipulate and observe real objects and materials in laboratories and field studies.

Gatsby's international study[39] found science educators are broadly agreed on five purposes for practical science, shown in Box 10.

Where's the evidence?

Different studies on practical work tend to focus on different purposes which makes reaching a consensus view about the impact of practical work difficult and there are few studies that compare the effectiveness of different types of practical activity. However, evidence suggests that:

- practical science engages pupils;
- due to the wide variety of aims and purposes of practical work, it is important to be clear about your purpose for choosing a particular activity as different types of practical work are needed to achieve different aims;
- practical work has positive impacts on the development of specific practical skills;
- there are benefits of developing scientific reasoning skills through practical work and this can impact on pupil attainment; and
- open ended research projects can have impacts on skill development, pupil attitudes, and attainment.

5a: Know the purpose of each practical activity

It is important that you are clear about the skills or knowledge that you are trying to develop in your pupils with a particular practical activity. Think through the best approach to developing these things and plan how to sequence it with other learning.

'Are we doing an experiment today?' You know the cry. Practical work engages pupils.[40] But keeping pupils happy is not enough of a reason on its own for using your valuable time. Look at the purposes in Box 10. Are you doing the experiment to introduce a new phenomenon such as electromagnetism, engaging pupils' interest so they will be more receptive to learning? Are you teaching them a new skill, such as using a microscope, so that when you want them to look at plant cells they can do so without the distraction of working out how to focus? Be clear in your own mind about the purpose and the outcomes you are looking for from the experiment—and make sure your pupils know them too. Pupils should know why they are doing an experiment, but young people often report 'just following the instructions' without understanding the purpose of practical work.[40]

Box 10: Purposes of practical science

(Not in any order of priority.)

- to teach the principles of scientific enquiry;
- to improve understanding of theory through practical experience;
- to teach specific practical skills, such as measurement and observation, that may be useful in future study or employment;
- to develop higher level skills and attributes such as communication, teamwork and perseverance; and
- to motivate and engage pupils.

5b: Sequence practical activities with other learning

It is unreasonable to expect lasting learning of a scientific concept from a single, relatively brief practical activity. Practical work is an important string to your bow, but as a successful science teacher you will use it alongside a range of other activities. An experiment may be the centre-piece of a lesson, but don't forget the activities that go with it.

Think about how the practical activity sequences with other work on the topic, before and after. What knowledge and skills will pupils need before they can get the most out of the practical? Will the practical introduce a new idea, or will it reinforce ideas pupils have already met? You need to plan how their practical skills develop in the same way as you plan the development of their knowledge.

For practical activities that aim to improve understanding of scientific theory, you may have to help pupils to make links between the practical activity and the underlying scientific ideas. Pupils need to be 'minds on' as well as 'hands on'.[41] Table 1 shows how to assess whether a practical activity is effective in being both.

Table 1: Assessing effectiveness of a practical in terms of whether it is 'hands on' or 'minds on'

Adapted from Millar and Abrahams, 2009.[41]

	Assessing if a practical activity is 'hands on'	Assessing if a practical activity is 'minds on'
Do the pupils do what is intended?	Pupils do what was intended with the objects and materials provided, and make the intended observations.	During the activity, pupils think about what they are doing and observing, using the ideas intended in the activity.
Do the pupils learn what is intended?	Pupils can later recall and describe what they did in the activity and what they observed.	Pupils can later discuss the activity using the ideas it was aiming to develop.

5c: Use practical work to develop scientific reasoning

Science, for humans, is the most powerful way of discovering truth about the world. A scientific attitude is an attribute that will serve pupils well in life.

"Experiments sometimes go wrong; think of this as an opportunity as well as a problem"

Every time you do an experiment, you can model some aspect of scientific reasoning. Even if the main purpose of the experiment is to develop a particular scientific theory or a scientific skill, you can point out how you are using scientific methodology.

One of the fundamentals of scientific reasoning is the control of variables. Indeed, performance on 'control of variables' tasks predicts pupils' attainment on tests of scientific knowledge.[42] Discuss the control of variables explicitly when you introduce an experiment such as the factors affecting reaction rates, or the limiting factors for photosynthesis. It is also beneficial for pupils to practice controlling variables when designing their own experiments.[43] An example of the type of thinking it is helpful to take pupils through can be found in the Self-regulation section of this report.

Experiments sometimes go wrong; think of this as an opportunity as well as a problem. Use scientific reasoning to explain the unexpected.

5d: Use a variety of approaches to practical science

There are different ways to expose pupils to the processes of practical science, from virtual experiments to open-ended projects. Virtual experiments, such as the PhET simulations from the University of Colorado[44] at Boulder, allow pupils to quickly change variables, see patterns in data, and understand relationships. Virtual experiments should not replace the real thing, but they can support it. A computer simulation of an experiment can allow pupils to go through the process of a particular practical activity so that when they do it in the classroom they are already familiar with the steps they need to take and can concentrate on the learning that it is aimed at developing.

An approach to practical work that requires more time involves open-ended projects, with pupils pursuing a project of their own choosing over an extended period of time. Providing project opportunities within the constrained curriculum, especially at GCSE, is challenging. But there are opportunities for project work outside the timetable and in STEM clubs (see STEM Projects Toolkit).[45] A synthesis of the international evidence of the impact of open-ended projects in science showed several benefits for these types of projects, including learning science ideas, attitudes towards pursuing science careers, and skill development. There were also interesting attitudinal outcomes for groups typically under-represented in science.

First stop for further reading

Holman, J. (2017) *Good Practical Science*, London: Gatsby Foundation.[39]

This report is the result of an international study. It includes a useful literature review of available evidence and examples of good international practice.

Abrahams, I. and Reiss, M. J. (2016) *Enhancing learning with effective practical science 11–16*, London: Bloomsbury.[47]

This book provides a summary of research as well as example lesson plans for how to make practical work effective.

6 Language of Science: Develop scientific vocabulary and support pupils to read and write about science

Learning science involves learning a whole new language and it is important that you develop pupils' fluency in that language.

To become competent in the language of science pupils need to be able to comprehend, analyse, and interpret texts and use the language of science to explain ideas and construct evidence-based explanations.This may seem like something that needs extra time and work, but it is really the core of learning and teaching science.

Science requires a breadth of literacy skills, but this section deals specifically with teaching scientific vocabulary and supporting pupils to read and write about science. More information on the types of talk that are helpful in developing thinking can be found in the self-regulation section of this report.

Where's the evidence?

The research literature shows consistent and strong correlations between pupils' literacy skills and their success in learning science, and literacy interventions have shown impacts on science outcomes. Evidence suggest that:

- pupils need to be explicitly taught new scientific vocabulary and this can be challenging; however, it is familiar words used in unfamiliar contexts that cause most difficulty;
- showing the links between words is an efficient way of teaching vocabulary and aids understanding;
- extended reading rarely happens in science lessons but reading authentic texts is a good way of exposing pupils to scientific writing; and
- science writing can help develop pupils' understanding and writing frames can provide helpful scaffolds.

6a: Carefully select the vocabulary to teach and focus on the most tricky words

Be aware of the vocabulary demands of a topic and make a conscious choice about the words that you are going to teach and when to introduce them. Focus on the words that pupils really need to understand and make sure they understand them well. Less is more: a deep understanding of fewer words is better than understanding lots of words at a surface level.[48]

Remember that some familiar words, such as 'field', have a different meaning in science from everyday life, and several studies have shown that these words often cause more problems for pupils than words we might normally consider to be technical language.[49,50]

Discussing how the meaning of such words differs in science should be a key part of teaching the word. Even though they are not 'new' words they should be a focus of vocabulary teaching. Box 11 shows examples of these 'tricky' words.

Box 11: Example words in science with alternative everyday meanings

- Incident
- Complex
- Spontaneous
- Relevant
- Valid
- Composition
- Emit
- Random

6b: Show the links between words and their composite parts

Teach new scientific vocabulary explicitly. Direct instruction is a good way of doing this.[51] You also need to show pupils how words are linked and how to use them in a range of contexts.

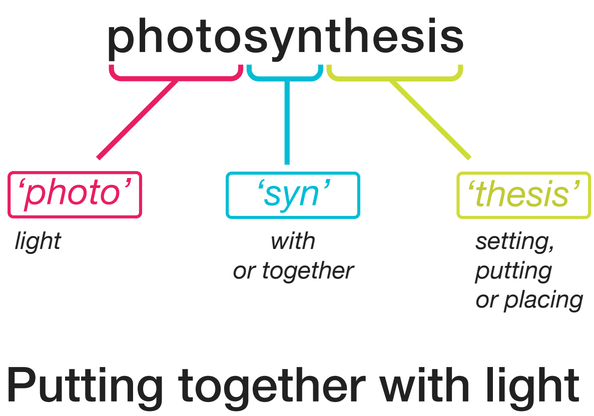
Support pupils to understand the meaning of root words and how to use prefixes and suffixes to change the meaning of root words. This helps them to learn new words and make connections between different words.[52] This approach also helps pupils to see the differences between words with the same root but with different meanings such as 'compress', 'compression', and 'compressional', which can often be challenging.

Teach pupils to segment and manipulate words according to their morphemes (unit parts) so that new words with similar morphemes are more easily recognised and understood; this is also an efficient way of expanding pupils' vocabulary. Figure 8 shows how the word 'photosynthesis' breaks down, so pupils will more easily recognise words with these morphemes in the future.

Another way of demonstrating links between words is through the use of knowledge organisers. These act as a taxonomy of words and display how words are linked together across topics. You can give them to pupils as reference material, or get pupils to generate them as they meet new words and ideas. You can display a class knowledge organiser during lessons and add to it as new terminology is learnt across a topic.[53]

Once you have introduced a new scientific word, it is important to reinforce it by encouraging pupils to use it as much as possible in your lessons. For example, get pupils using the word in different contexts ('give me a sentence that has both "photosynthesis" and "night" in it').

Figure 8: Teaching the morphemes that make up the word 'photosynthesis'



6c: Use activities to engage pupils with reading scientific text & help them to comprehend it

It is important that the texts pupils are reading are at an appropriate level, but challenging and interesting; pupils should have the opportunity to engage with authentic scientific books and texts.[54]

The use of authentic texts does not mean that all pupils need to be reading journal articles but they should have access to quality texts from a range of sources, including news articles and parts of popular science books.

Support pupils to read science. Teach them the necessary vocabulary, and use structured activities to help them comprehend text. DARTS (Directed Activities Related to Text) can help with this. See Box 12 for a summary of types of DARTs and the types of learning they can support.

Box 12: Summary of types of DART

Adapted from Osborne and Dillon, 2010.[55]

Reconstruction DARTs	Analysis DARTs
Completing text, diagrams, or tables Completing phrases or sentences Labelling diagrams using text Using text to complete a table	**Marking and labelling** Underlining (pupils search for specified parts of a text) Labelling (pupils label text according to labels given to them) Segmenting (pupils break the text down and label the different parts)
Ordering or classifying text Pupils put segments of text into a logical order Pupils classify segments of text according to set categories (e.g., 'instruction', 'explanation', 'evidence')	**Recording and constructing** Constructing diagrams to show the content and flow of text Pupils make up their own tables from information in the text Pupils use the text to answer questions or to create their own questions Pupils list the key points made in a text
Predicting Pupils write the next part of the text	

6d: Support pupils to develop their scientific writing skills

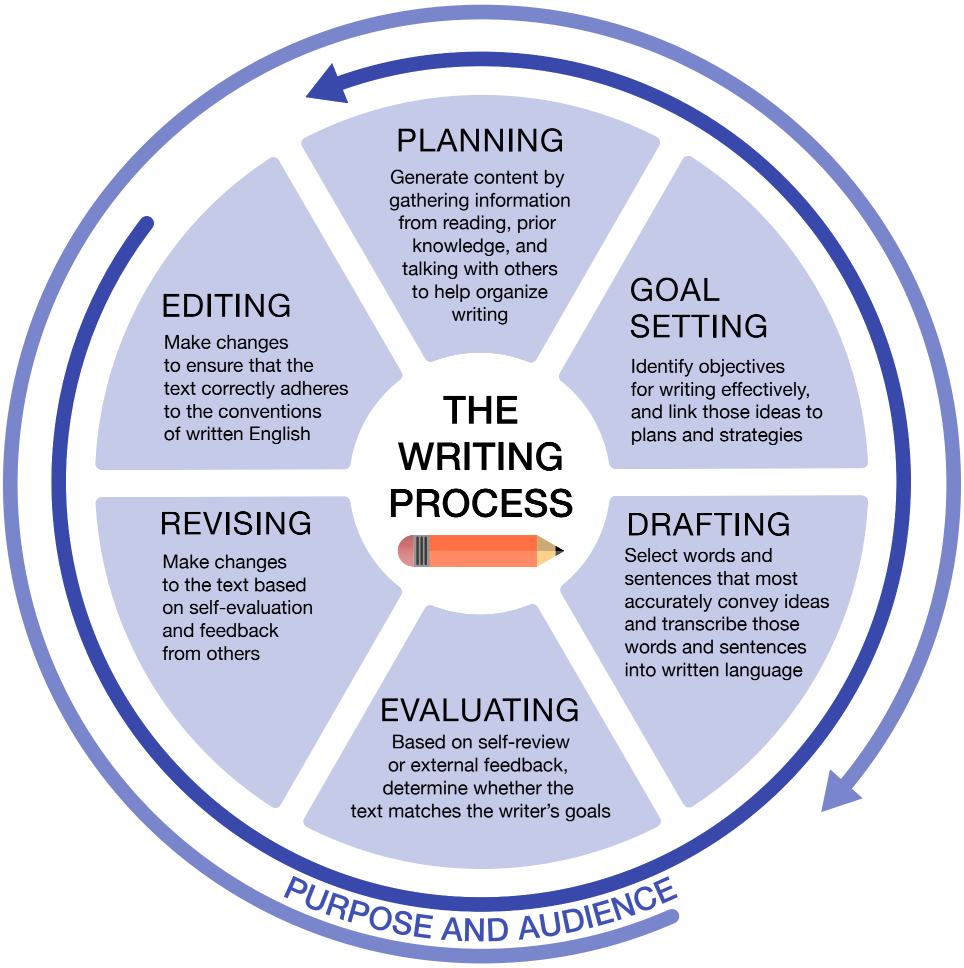
Writing about science is more than communication alone; it supports pupils in their learning because when they write about science they reflect on their understanding, formulate their own ideas, and combine ideas in new ways.

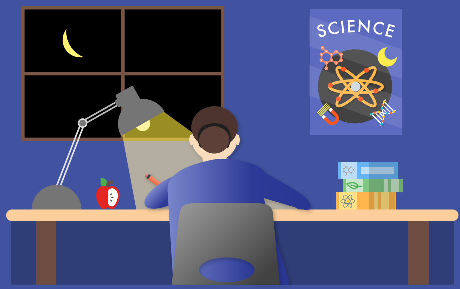
The Process Approach to Writing (Figure 9—see the What Works Clearinghouse - *Teaching secondary students to write effectively*, 2016,[56] for more information on this) is an effective way of developing pupils' writing skills. Good writing needs a strong sense of purpose and audience: 'Why am I writing this, and who is it for?' Thinking about purpose and audience helps pupils to evaluate their own writing and increases pupils' motivation and interest.[57]

Figure 9: The writing process

Adapted from What Works Clearinghouse *Teaching secondary students to write effectively* 2016

The writing process involves several components and is iterative. Pupils may implement these components in a different order (as illustrated by the arrows going in both directions in the figure) or implement some of the components simultaneously.

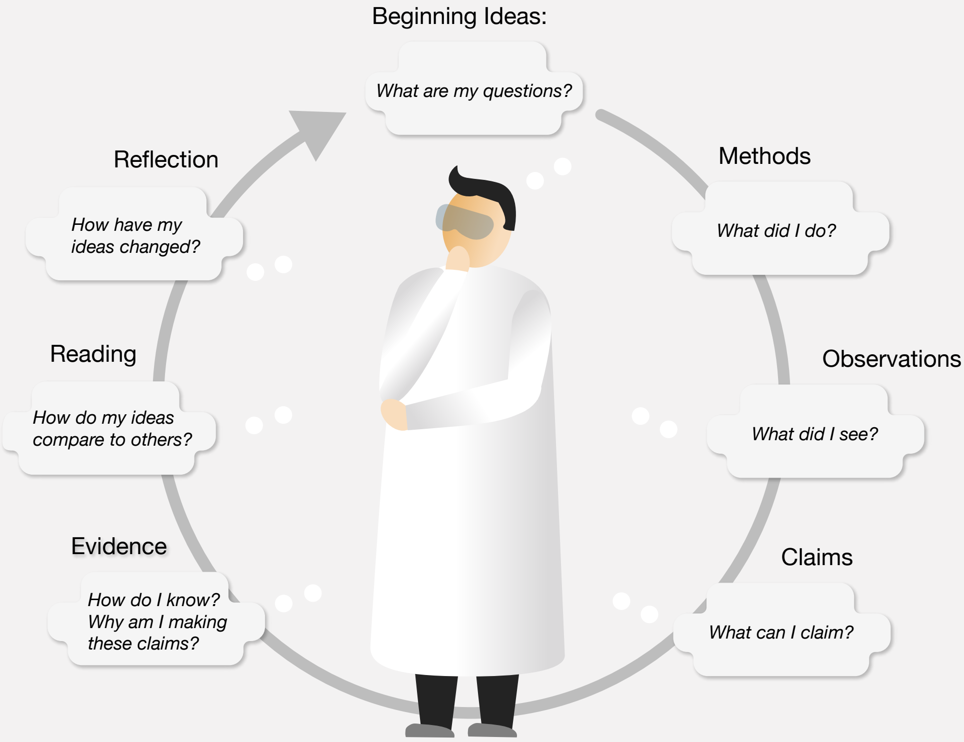




Frameworks can be helpful to support early writing and to teach pupils strategies they can use over time: the frameworks can be withdrawn as pupils become more confident writers. A useful frame is the Science Writing Heuristic[58] which aims to support pupils in developing scientific arguments and planning how to present these. The framework has both a template for pupils (Box 13) and a template for teachers with activities to promote understanding.

Box 13 - Science writing heuristic - template for pupils

Adapted from Hand et al., 2016.[58]



First stop for further reading

Wellington, J. and Osborne, J. (2001) *Language and literacy in science education* (2011 ed.), Buckingham, Philadelphia: Open University Press.[57]

A useful overview of language in science with examples for applying in the classroom.

7 Feedback:
Use structured feedback to move on pupils' thinking

Where's the evidence?

There are many meta-analyses pointing to feedback having a very high effect on pupil outcomes. However, simply providing more feedback will not necessarily lead to better outcomes as it is the type of feedback that is critical. The evidence shows:

- teachers should use a range of strategies to find out what pupils understand, not just formal assessments;
- feedback should help pupils develop as learners, not just improve performance on a specific task;
- pupil performance improves when feedback is in the form of constructive comments, and there are ways of doing this that minimise workload; and
- feedback is most effective when pupils know how to respond to it and are given time to do so.

7a: Find out what your pupils understand

Pupils can have strengths in one area and weaknesses in another. So it is important that you build up an accurate picture of the current understanding of all your pupils. One way to get this is through the use of formal tests. Less formally, you can use frequent low-stakes class assessments, informal observations of pupils, whole-class or group discussions, and peer- and self-assessment.

Peer assessment is useful as pupils often accept criticism of their work from their peers which they would not accept from their teacher.[59] A useful way to structure peer assessment is to get a group to look at the responses of each member and assess the strength and weaknesses of each. By doing this they can start to objectively understand how their work compares to the work of their peers.[60] Pupils can do this with a marking scheme, or can develop their own criteria for quality which may help them to self-assess their own work in the future.

More guidance on how to conduct useful and accurate assessment is available in the EEF's *Assessing and Monitoring Pupil Progress* resource.

7b: Think about what you're providing feedback on

Feedback should help the pupil develop as a learner, not just improve on the specific task that you are providing feedback on—and teachers can provide feedback at different levels (see Figure 10). Feedback at the task level is likely to be difficult for pupils to transfer, although it is useful for correcting errors, whilst feedback at the level of 'self-evaluation' may lead pupils to think that their abilities are fixed, which could limit their willingness to try difficult things in the future. The most useful feedback is therefore at the 'subject' and 'self-regulation' levels, although it may sometimes be appropriate to give feedback at the other two levels.

Figure 10: The four types of feedback that teachers can give

Adapted from Fletcher-Wood, 2018.[61]

Level of feedback		Type of feedback	The questions it helps pupils to answer	Examples in science
Specific ↑	*Concrete*	This task	How can I get this done? How can I make this better?	'Your understanding of Ohm's Law is good, but be careful to use the correct units.'
	Reflective	The subject	How can I do better in tasks like this? What does it mean to be good in this subject?	'Next time you do a calculation like this, try to set it out the way I showed you.'
		Self-regulation	How can I manage myself to learn better? How can I motivate myself?	'Are you happy that you understand photosynthesis now? What could you do to extend your understanding further?'
General ↓	*Existential*	Self-evaluation	How good am I?	'Well done, you've worked really hard this week.'

7c: Provide feedback as comments rather than marks

Black and Harrison[62] found that feedback from science teachers was mainly through marks rather than comments. However, marks can demotivate low attainers and can make high attainers complacent; in contrast, comments show both how they can do better: 'You understand about homeostasis, but try to find some examples from plants as well as animals.'

Remember that comments do not necessarily need to be written: effective feedback can be given orally to individuals or groups of pupils during lesson time. While you are looking at pupils' work, try to find common mistakes which lots of pupils make, then feed back on these to the whole class. This approach can reassure pupils when they realise they have the same misunderstandings as many of their peers. Try to make quality, not quantity, the watchword when it comes to looking at pupils' work: a smaller quantity of rich feedback is likely to do more good than a larger quantity of superficial marking.

A summary of the evidence regarding different marking approaches and their impact on workload can be found in the Education Endowment Foundation's report *A Marked Improvement?*.

7d: Make sure pupils can respond to your feedback

Several studies report that pupils do not always understand feedback, or they misunderstand it. Try to make the feedback clear and easy to act on, as well as appropriate for the pupil concerned. Feedback can vary in quality (Box 14 outlines some features of quality feedback) and in the ease it can be acted on.

It is helpful to frame feedback as a question. Black and Harrison[62] compare 'Add notes on seed dispersal' with 'Can you suggest how the plant might disperse its seeds? Could this be an advantage?'. Feedback can also usefully direct pupils where to go for help: 'Go back to your notes from last week and check where chlorophyll is in the leaf and the reasons why leaves are good photosynthetic structures.'

It is important to ensure that pupils have enough time to respond to feedback, in lesson or homework time.

Box 14: Features of quality feedback

Quality feedback:

- is specific, accurate, and clear;
- makes connections with prior performance, or to pupils' success or failure on another part of the task;
- is encouraging, helping pupils to identify things that are hard and require extra attention;
- provides guidance to pupils on how to respond to their teacher's comments; and
- provides concrete suggestions for improvement.

First stop for further reading

Black, P. and Harrison, C. (2004) *Science Inside the Black Box: Assessment for Learning in the Science Classroom*, London: NfER Nelson.[62]

This provides a good overview of how to apply formative assessment in science.

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HOW WAS THIS GUIDANCE COMPILED?

This guidance report draws on the best available evidence regarding the teaching of science at Key Stages 3 and 4. The primary source of evidence for the recommendations was a series of evidence reviews conducted by Professor Marcus Grace and his team at Southampton University. We also often drew on an earlier review commissioned by the EEF and the Royal Society and led by Professor Terezinha Nunes and Professor Peter Bryant at Oxford University.

The guidance report was created over three stages.

1. **Scoping.** The process began with a consultation with teachers, academics, and other experts. The EEF team selected the area of interest (science at Key Stages 3 and 4), appointed an Advisory Panel and evidence review team, and agreed research questions for the evidence review. The Advisory Panel consisted of both expert teachers and academics.

2. **Evidence review.** The evidence review team conducted searches for the best available international evidence about approaches to science teaching.

3. **Writing recommendations.** The EEF worked with the support of the Advisory Panel to draft the recommendations. Academic and teaching experts were consulted on drafts of the report.

We would like to thank the many researchers and practitioners who provided support and feedback on drafts of this guidance.

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