



The Guidance Report from the EEF—*Improving Secondary Science*—is available online, and free to download.

## Why Science?

"Science education is one of the keys to social mobility... and scientific literacy is critically important to being an informed citizen. When asked why they chose to continue their study of science, most pupils mention an inspiring teacher."

Sir John Holman – report author

## Background

The guidance report draws on the best available evidence regarding science teaching at Key Stages 3 and 4. The primary source of evidence was a series of evidence reviews conducted by Southampton University.

## How was it put together?

The guidance report began with a consultation with teachers, academics, and other experts. The EEF team 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.

The evidence review team conducted searches for the best available international evidence about approaches to science teaching. Finally, the EEF worked with the support of the Advisory Panel to draft recommendations.

## Who was on the advisory panel?

Professor Judith Bennett (University of York)

Lia Comissar (Wellcome Trust)

Professor Harrie Eijkelhof (Universiteit Utrecht)

Dr Niki Kaiser (Notre Dame High School)

Lauren Stephenson (Blackpool Research School)

Recommendations	Research Base	Examples	Applications																		
<p><b>1 Preconceptions: Build on the ideas that pupils bring to lessons</b></p>	<p>Pupils construct their own explanations for phenomena, and these ideas may differ from scientific explanations. Cognitive conflict is an effective way of moving on pupils' thinking. Misconceptions can be difficult to shift, but doing so can lead to big gains in learning.</p>	<p>Teachers can sometimes inadvertently introduce misconceptions. For example, pupils can imagine 'molecular ionic compounds', prompted by the dot/cross models used to introduce them.</p>	<p>Johnstone's triangle refers to the three conceptual levels that must be linked, for pupils to understand Chemistry.</p>																		
<p><b>2 Self-regulation: Help pupils direct their own learning</b></p>	<p>Correlational studies show strong links between self-regulation and attainment in science. Low prior-attainers benefit most; skills need to be developed within the context of learning a subject; and specific strategies include modeling your own thinking to pupils and engaging pupils in metacognitive talk.</p>	<p>The planning-monitoring-evaluation cycle.</p>	<p>One of the reasons people find Chemistry tricky is because they have to explain phenomena they can see and experience (macroscopic level) using processes they can't see or even imagine (sub-microscopic level) and represent them using symbols (symbolic level). To fully understand Chemistry, students must link these conceptual levels, and move fluently between them.</p> <p>Explicitly modelling this type of thinking could help students to consciously monitor their understanding, and support them to connect apparently distinct ideas by recognising the underlying links. (1)</p>																		
<p><b>3 Modelling: Use models to support understanding</b></p>	<p>Modelling is widespread in science teaching. Ideas that models are based on should be familiar to pupils, and it is important that pupils understand how models differ from the idea being taught, and learn the underlying idea rather than the model.</p>	<p>Barrel analogy to explain the effect of limiting nutrients on plant growth.</p>	<p>Instructions for practical work, where written methods are displayed separately to diagrams, can add to extraneous cognitive load. Combining them could free up pupils' working memory. (2)</p>																		
<p><b>4 Memory: Support pupils to retain and retrieve knowledge</b></p>	<p>Cognitive science has led to breakthroughs in our understanding of brain functions and processes, but applying laboratory data to classroom practice is not straightforward. Research supports cognitive load theory, spaced review, retrieval practice and elaborative interrogation, which have a number of studies with positive effects.</p>	<p>A simplified model to show how working memory interacts with long-term memory.</p>	<p>Algebra is key to understanding many chemical ideas, but if you are struggling with the maths, you won't have enough working memory to understand the chemistry. They don't replace the algebra: it's a concrete representation of an otherwise abstract concept concrete. (3)</p>																		
<p><b>5 Practical Work: Use practical work purposefully and as part of a learning sequence</b></p>	<p>Practical science engages pupils, but it is important to be clear about your purpose for choosing a particular activity. Practical work has positive impacts on the development of specific practical skills, and there are benefits to developing scientific reasoning skills through practical work. Open-ended research projects can have positive impacts.</p>	<p>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'.</p> <table border="1"> <tr> <td>Assessing if a practical activity is 'hands on'</td> <td>Assessing if a practical activity is 'minds on'</td> </tr> <tr> <td>Do the pupils do what is intended?</td> <td>Pupils do what is intended with the objects and materials provided, and make the intended observations.</td> </tr> <tr> <td>Do the pupils learn what is intended?</td> <td>Pupils can later recall and describe what they did in the activity and what they observed.</td> </tr> </table>	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 is intended with the objects and materials provided, and make the intended observations.	Do the pupils learn what is intended?	Pupils can later recall and describe what they did in the activity and what they observed.	<p>Be clear about the skills or knowledge 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. Every time you do an experiment, model an aspect of scientific reasoning.</p>												
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<p><b>6 Language of Science: Develop scientific vocabulary and support pupils to read and write about science</b></p>	<p>There are consistent, strong correlations between pupils' literacy skills and their success in science. Pupils need to be explicitly taught new scientific vocabulary; showing the links between words is an efficient way of teaching vocabulary and aids understanding; extended reading and science writing can help develop pupils' understanding.</p>	<p>Teach pupils to segment and manipulate words according to their morphemes (unit parts) so that new words with similar morphemes are more easily recognised.</p> <p><b>photosynthesis</b></p> <p>'photo' light, 'syn' with or together, 'thesis' setting, putting or placing</p> <p>Putting together with light</p>	<p>Summarising examples and non-examples can help to manage intrinsic load when teaching new vocabulary. The Frayer model displays these alongside characteristics, to aid understanding. (6)</p> <table border="1"> <tr> <td><b>Definition</b></td> <td><b>Characteristics</b></td> </tr> <tr> <td><b>Examples</b></td> <td><b>Non-examples</b></td> </tr> </table> <p><b>Word</b></p> <table border="1"> <tr> <td><b>Definition</b></td> <td><b>Characteristics</b></td> </tr> <tr> <td><b>Examples</b></td> <td><b>Non-examples</b></td> </tr> </table> <p><b>Reptile</b></p> <table border="1"> <tr> <td><b>Definition</b></td> <td><b>Characteristics</b></td> </tr> <tr> <td><b>Examples</b></td> <td><b>Non-examples</b></td> </tr> </table>	<b>Definition</b>	<b>Characteristics</b>	<b>Examples</b>	<b>Non-examples</b>	<b>Definition</b>	<b>Characteristics</b>	<b>Examples</b>	<b>Non-examples</b>	<b>Definition</b>	<b>Characteristics</b>	<b>Examples</b>	<b>Non-examples</b>						
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<p><b>7 Feedback: Use structured feedback to move on pupils' thinking</b></p>	<p>Simply providing more feedback will not necessarily lead to better outcomes; it is the type of feedback that is critical. Teachers should use a range of strategies to find out what pupils understand; feedback should help pupils develop as learners; feedback is most effective when pupils know how to respond to it and are given time to do so.</p>	<p>Feedback at the task level is likely to be difficult for pupils to transfer, whilst feedback at the level of 'self-evaluation' may lead pupils to think that their abilities are fixed.</p> <table border="1"> <tr> <td>Level of feedback</td> <td>Type of feedback</td> <td>The questions it helps pupils to answer</td> <td>Examples in science</td> </tr> <tr> <td rowspan="2">Specific</td> <td>Task</td> <td>How can I get this done?</td> <td>Your understanding of photosynthesis is good, but I noticed you forgot the central axis.</td> </tr> <tr> <td>Self-regulation</td> <td>How can I manage myself to learn better?</td> <td>How many times did you check your work?</td> </tr> <tr> <td rowspan="2">General</td> <td>Self-regulation</td> <td>How can I manage myself to learn better?</td> <td>How many times did you check your work?</td> </tr> <tr> <td>Self-regulation</td> <td>How can I manage myself to learn better?</td> <td>How many times did you check your work?</td> </tr> </table>	Level of feedback	Type of feedback	The questions it helps pupils to answer	Examples in science	Specific	Task	How can I get this done?	Your understanding of photosynthesis is good, but I noticed you forgot the central axis.	Self-regulation	How can I manage myself to learn better?	How many times did you check your work?	General	Self-regulation	How can I manage myself to learn better?	How many times did you check your work?	Self-regulation	How can I manage myself to learn better?	How many times did you check your work?	<p>Feedback should help the pupil develop as a learner, not just improve on the specific task that you are providing feedback on. Teachers can provide feedback at different levels, and the most useful feedback is at the 'subject' and 'self-regulation' levels. Try to find common mistakes which lots of pupils make, then feed back on these to the whole class.</p>
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### References and acknowledgements

Adapted from a research poster by Niki Kaiser, Notre Dame High School, Norwich, UK

Improving Secondary Science Guidance Report (recommendations, research background, figures and examples) by Emily Yeomans (EEF) and Sir John Holman (University of York)  
<https://eef.li/science-ks3-ks4/>

Vocabulary example via Amanda Fleck

Feedback table from Harry Fletcher Wood – Responsive Teaching ISBN 1138298899

**Applications (figures and examples)**

(1) Niki Kaiser [chemdrk.wordpress.com/2018/12/29/ceeg-fellowship-notes-2-its-just-a-worksheet-right/](https://chemdrk.wordpress.com/2018/12/29/ceeg-fellowship-notes-2-its-just-a-worksheet-right/)

(2) David Paterson [dave2004b.wordpress.com/2018/07/09/integrated-instructions-for-aga-required-practicals/](https://dave2004b.wordpress.com/2018/07/09/integrated-instructions-for-aga-required-practicals/)

(3) Niki Kaiser [chemdrk.wordpress.com/2018/05/11/energy-bars-and-threshold-concepts/](https://chemdrk.wordpress.com/2018/05/11/energy-bars-and-threshold-concepts/) via Ben Rogers <https://eef.li/science-ks3-ks4/>

(4) Adam Boxer [achemicalorthodoxy.wordpress.com/2018/08/18/retrieval-rouettes/](https://achemicalorthodoxy.wordpress.com/2018/08/18/retrieval-rouettes/)

(5) Bernie Delahunty and Greensward Academy Science Team

(6) Alex Quigley [www.theconfidentteacher.com/2018/04/vocabulary-knowledge-and-the-frayer-model/](https://www.theconfidentteacher.com/2018/04/vocabulary-knowledge-and-the-frayer-model/) Many other examples taken and ideas taken from members of #CoqSciSci and colleagues from the Research Schools Network. Johnstone's triangle examples taken from a research project supported by the Royal Society of Chemistry's Chemical Education Research Group teacher-fellowship scheme. Mentors: Dr Suzanne Fergus and Dr Barry Ryan.

