Education Endowment Foundation

USING RESEARCH TO IMPROVE SCIENCE TEACHING: THE EDUCATION ENDOWMENT FOUNDATION'S GUIDANCE REPORT

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 Commissar (Wellcome Trust),

Professor Harrie Eijkelhof (Universiteit Utrecht)

Dr Niki Kaiser (Notre Dame High School)

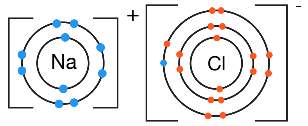
Lauren Stephenson (Blackpool Research School)

Recommendations | Research Base | Examples

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

Research base: 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.

Examples: *Teachers can sometimes inadvertently introduce misconceptions. For example, pupils can imagine 'molecular ionic compounds', prompted by the dot/ cross models used to introduce them.*

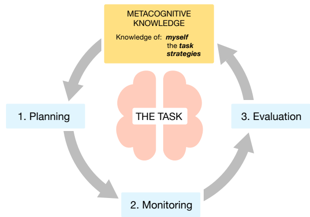


Use diagnostic questions to find out which misconceptions are held by your pupils. Sometimes these can be anticipated, as many are common at different stages. Address misconceptions, and allow time for pupils' understanding to develop and change.

2 Self-regulation: Help pupils direct their own learning

Research base: 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.

Examples: *The planning-monitoring-evaluation cycle.*

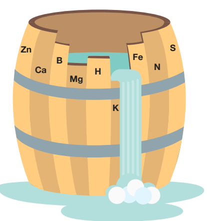


Metacognition includes monitoring your learning and changing your approach to a task as a result. This is summarised by the Planning-Monitoring-Evaluation cycle, and pupils may need to go through it more than once to complete a task fully. Expert learners may do this unconsciously, but novice learners might need to be taught these processes explicitly.

3 Modelling: Use models to support understanding

Research base: 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.

Examples: *Barrel analogy to explain the effect of limiting nutrients on plant growth.*

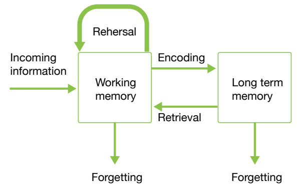


Good teachers use models all the time to provide a bridge between pupils' current ideas and new understanding. Models are ways of thinking about the 'real thing'. By being explicit about models, you can help your pupils understand their own thinking. Make sure pupils are familiar with the underlying idea that the intended model is based on, or the model may hinder rather than help teaching.

4 Memory: Support pupils to retain and retrieve knowledge

Research base: 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.

Examples: *A simplified model to show how working memory interacts with long-term memory.*



There are two important components of memory—long-term memory (a 'store of knowledge') and working memory (where 'thinking' happens). Working memory means that it can quickly become overloaded, resulting in cognitive overload and this increases the possibility that the content may be misunderstood and not effectively encoded in the long-term memory.

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

Research base: 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.

Examples: *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'.*

Adapted from Millar and Abrahams, 2009.

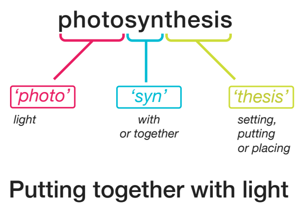
	Assessing if a practical activity is 'hands on'	Assessing if a practical activity is 'minds on'
Do the pupils do what is intended?	Pupils do what was intended with the objects and materials provided, and make the intended observations.	During the activity, pupils think about what they are doing and observing, 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.

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. Each time you do an experiment, model an aspect of scientific reasoning.

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

Research base: 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.

Examples: *Teach pupils to segment and manipulate words according to their morphemes (unit parts) so that new words with similar morphemes are more easily recognised.*



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. Focus on the words that pupils really need to understand, and make sure they understand them well. Teach new scientific vocabulary explicitly, and show pupils how words are linked, and how to use them in a range of contexts.

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

Research base: 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.

Examples: *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.*

The four types of feedback that teachers can give

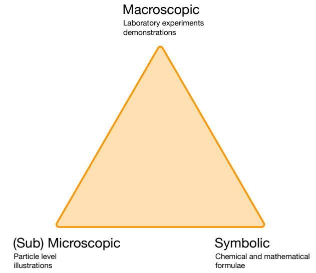
Adapted from Fletcher-Wood, 2018.

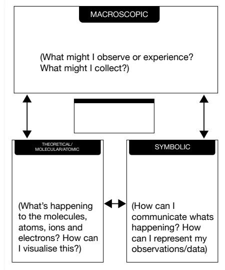
Level of feedback		Type of feedback	The questions it helps pupils to answer	Examples in science
Specific	Concrete	This task	How can I get this done? How can I make this better?	'Your understanding of Ohm's Law is good, but be careful to use the correct units.'
	Reflective	The subject	How can I do better 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.'

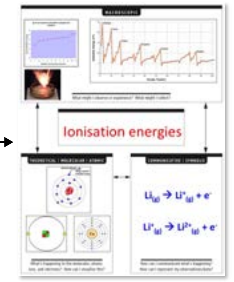
Feedback should help the pupil develop as a learner, not just improve on the specific task that you are providing feedback on. Teachers can provide feedback at different levels, and the most useful feedback is at the 'subject' and 'self-regulation' levels. Try to find common mistakes which lots of pupils make, then feed back on these to the whole class.

Applications

Johnstone's triangle refers to the three conceptual levels that must be linked, for pupils to understand Chemistry.







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.

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)

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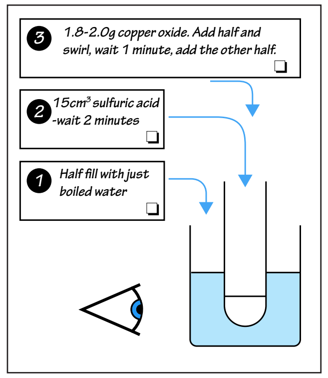

Instructions for practical work, where written methods are displayed separately to diagrams, can add to extraneous cognitive load. Combining them could free up pupils' working memory. (2)

Integrating practical instructions can reduce the split-attention effect.

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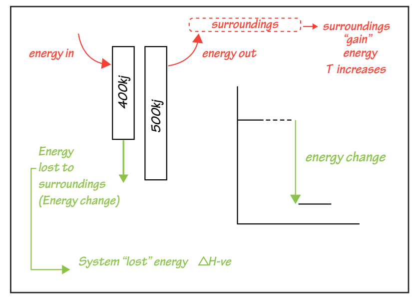

Bar models can be used to support teaching of mathematical processes.

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)

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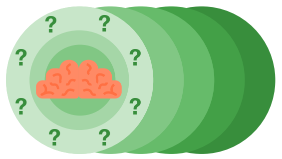

Regular low-stakes quizzing supports memory / retrieval.

Regular retrieval practice of previously learned material strengthens memory, and frees up working memory for other processes. (4)

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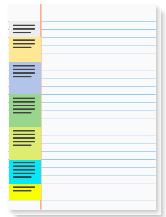

Structure strips can help pupils organise their scientific writing.

You can use structure strips to support pupils with longer scientific writing. They can also prompt metacognition. (5)

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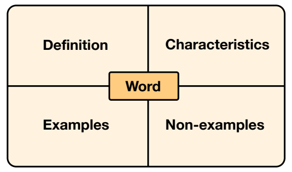
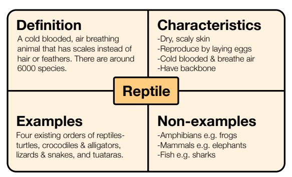


Summarising examples and non-examples can help to manage intrinsic load when teaching new vocabulary. The Frayer model dsiplays these alongside characteristics, to aid understanding. (6)



Frayer models can support teaching of scientific vocabulary.

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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 1138296899

Applications (figures and examples)

(1) Niki Kaiser chemdrk.wordpress.com/2018/12/29/cerg-fellowship-notes-2-its-just-a-worksheet-right/

(2) David Paterson dave2004b.wordpress.com/2018/07/09/integrated-instructions-for-aqa-required-practicals/

(3) Niki Kaiser https://chemdrk.wordpress.com/2018/05/11/energy-bars-and-threshold-concepts/ via Ben Rogers https://eic.rsc.org/ideas/theyll-learn-more-with-bar-models/3010292.article

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

(5) Bernie Delahunty and Greensward Academy Science Team

(6) Alex Quigley https://www.theconfidentteacher.com/2018/04/vocabulary-knowledge-and-the-frayer-model/ Many other examples taken and ideas taken from members of #CogSciSci 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.

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