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Ofsted Research and Analysis

Research Review Series: Science

Summary of Key Findings (Primary Perspectives)

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Curriculum Progression:

What it means to get better at science…

The journey from novice to expert relates to the learning and structuring of knowledge. When learnt knowledge is well structured, it becomes meaningful, flexible and easier to access.

There should be a carefully planned interplay between substantive and disciplinary knowledge.

The school curriculum should exemplify 'progression'– this may also be seen as how children' know more and remember more.

Learning should be structured in a way that develops knowledge around key concepts and ideas.

The curriculum should be planned and sequenced in a way that allows children to develop increasingly sophisticated knowledge of the products *(substantive knowledge)*, practices and processes *(disciplinary knowledge)* of science.

Disciplinary knowledge should never be taught in isolation or assumed to be a by-product of engagement in practical activities.

Children should experience success at all stages in their development of knowledge – this is crucial in any quest to build interest in the subject.

The teaching of substantive knowledge should develop children's awareness of biology, chemistry and physics as scientific domains, as well as their similarities and differences.

Teachers and the curriculum should promote an appreciation of the ways in which scientific enquiry allows knowledge to grow over time.

Knowledge should not be reduced to a single scientific method or simply the data collected during experiments or investigations.

Scientific enquiry integrates substantive and disciplinary knowledge into an overall strategy to answer questions about the material world.

What is substantive and disciplinary knowledge?

	Substantive Knowledge	Disciplinary Knowledge
Conceptual… know that… because…	Liquids expand when they are heated (for example, the liquid inside a thermometer).	All measuring instruments, such as a thermometer, have a built-in degree of uncertainty.
Procedural… know how to… and be able to…	Draw a particle diagram for a liquid.	Use a thermometer to measure the temperature of a solution.

Organising Knowledge Within The Subject Curriculum

- A high-quality science curriculum not only identifies the important concepts and procedures for pupils to learn, it also plans for how pupils will build knowledge of these over time.
- High-quality science curriculums are coherent – they should be organised so that pupils' knowledge of concepts develops from component knowledge and this should be sequenced according to the logical structure of the scientific disciplines.

Substantive Knowledge

The learning of substantive knowledge should be broken down into meaningful components and introduced sequentially. It must not be an arbitrary collection of topics introduced in an ad-hoc fashion.

Disciplinary Knowledge

The sequencing of disciplinary knowledge must consider its hierarchical nature and the progression of substantive knowledge. It should be practised in different substantive contexts so that it is not forgotten but is built on.

Vocabulary

Pupils should be introduced to vocabulary that is appropriate for their age and stage of development. In the early years, this vocabulary should not be too technical but provide the 'seeds' for developing scientific concepts that will be built on in later years.

Coherence

Planning for progression takes account of what is taught in other subjects. For example, the science curriculum should be coherent with what is taught in mathematics. Where there are differences, these should be made explicit to pupils and teachers.

Key Points – A Strong Science Curriculum

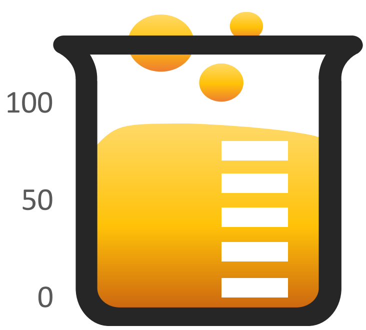
- *Strong curriculums begin with teaching a few of the most fundamental topics of science, such as classification of matter, and these should be added to over time.*
- *Revisiting does not involve repetition of previously taught knowledge – this is expected to be remembered as new knowledge becomes part of an emerging conceptual structure.*

Other Curricular Considerations

A high-quality science education should ensure that sufficient curriculum time is allocated for pupils to embed what they have learned in long-term memory.

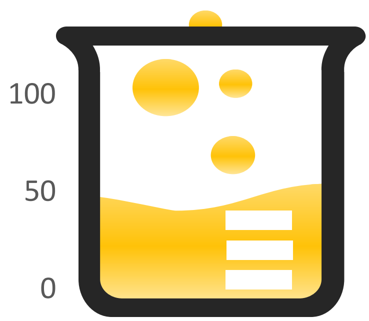
The curriculum should...

Ensure that knowledge builds incrementally → *Identify and plan to address scientific misconceptions* → *Allow sufficient time to consolidate knowledge* → *Teach how models and rules can be used effectively* → *Introduce new learning when prior learning is secure*



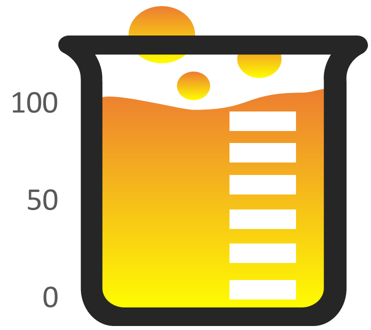
Practise and Consolodation

A well-structured science curriculum must include time for extensive practice of the concepts taught and learned - this helps pupils consolidate knowledge before moving on to new content.



Engagement and Disciplinary Literacy

To learn about science, pupils need to learn about the different ways in which scientists engage in their work: through reading, talking, writing and representing science. This is called disciplinary literacy.



Misconceptions and the Curriculum

Some substantive concepts are more difficult to learn because the scientific knowledge conflicts with everyday knowledge. These misconceptions are not just 'errors' because they are functional in everyday life and so therefore get reinforced.

IN FOCUS Scientific Misconceptions

Research shows that experts are better than novices at suppressing misconceptions, as opposed to not having them. The implications of this for curriculum design are twofold.

First, pupils will not only need to know why a scientific idea is correct, they will also need to know why their misconception (prior knowledge) is scientifically wrong.

Second, pupils will need repeated opportunities in the curriculum to practise activating the scientific conception while suppressing the misconception.

- If a misconception is challenged too early – before pupils have a scientific conception – it is likely they will rely on the misconception to make sense of the problem.

- The curriculum should identify which substantive concepts pupils are likely to hold misconceptions in and these should then be explicitly addressed.

Curriculum Materials

The implementation of the intended curriculum can either support or undermine its coherence, and the use of high-quality resources has a significant role to play in promoting this.

- *Resources themselves should not act as the curricular goal…*
  - *They should maintain a sharp focus on developing disciplinary and procedural knowledge.*

The resources used to implement a curriculum should match what the curriculum is intending pupils to learn and not act as a source of errors or misconceptions.

01 Textbooks and Worksheets

Textbooks can, but should not be, narrowly driven by summative assessment indicators. Instead, they should be chosen based on the extent to which progression in content is coherent, and the clarity in which they present key concepts and knowledge.

02 Online Resources

There is a growing trend of using website resources to support currciculum implementation. Teachers must ensure that these are well-matched to curriculum intent and ensure they are used coherently.

03 Science Kits

Science kits should not be used as a substitute for CPD in any quest to improve children's access to experiments and enquiry activities. Instead, they may be more effective when used to supplement high-quality CPD programmes.

The availability of and access to high quality resources can 'free up' teachers' time and in some cases, may be particularly valuable in supporting the developing subject knowledge of early career teachers.

There is a need to effectively utilise good quality science texts and resources that are accurate and don't contain misconceptions.

Limitations to look out for…

		Limitation
1	The quality of resources	Poor quality resources are unlikely to provide the tools required to successfully implement or achieve curriculum intent.
2	A wide range of resources	Using too broader range of resources from many different sources is likely to disrupt curriculum coherence.
3	Activity-led resources	Resources that focus attention on activities, rather than underlying content, are not associated with positive science achievement.

Practical Work

What are the characteristics of high-quality practical work?

- It always has a clear, identified purpose;
- It forms part of a wider instructional sequence;
- It takes place when children have enough prior knowledge to learn from the activity.

Practical work and substantive knowledge

Millar (2004) identified five purposes of practical work in helping pupils learn substantive knowledge but stressed that sufficient time should be allowed before / after a practical for children to make sense of the observations and measurements made, or about to be made.

Practical work and disciplinary knowledge

Although pupils need to carry out their own scientific enquiries to learn about the nature of a scientist's work, sufficient underlying substantive and disciplinary knowledge must taught first as scientific enquiry requires knowledge of the concepts and procedures to guide what is done and why.

Practical work: curricular content and objects of study

Practical work forms an important part of a science education by connecting concepts and procedures to the phenomena and methods studied. It should have a clear purpose that is defined in the school's curriculum and take children beyond everyday experiences – both in the laboratory (classroom) and in the field - this promotes a more authentic view of science.

Practical work to help pupils learn substantive knowledge (Millar, 2004)

Purpose	Helps pupils to…	Curriculum Intent (E.g.)
1	Identify objects and phenomena	Opposite poles of a magnet repel
2	Learn a fact	Pure water boils at 100°C
3	Learn a concept	Photosynthesis
4	Learn a relationship	Brightness of a bulb and number of cells in a circuit
5	Learn a model or theory	Newtonian theory of gravity

Demonstrations can…

- Allow children to encounter scientific phenomenon with a reduction in (or without) distractions associated with handling apparatus and recording data.
- Be quick to set up and draw children's attention to specific features.
- Allow for high-quality questioning.

It should not be assumed that pupils acquire knowledge simply by taking part in a practical activity. Practical work should instead form part of a wider instructional sequence and pupils should have sufficient prior knowledge to learn from the activity.

Pedagogy:
Teaching the curriculum…

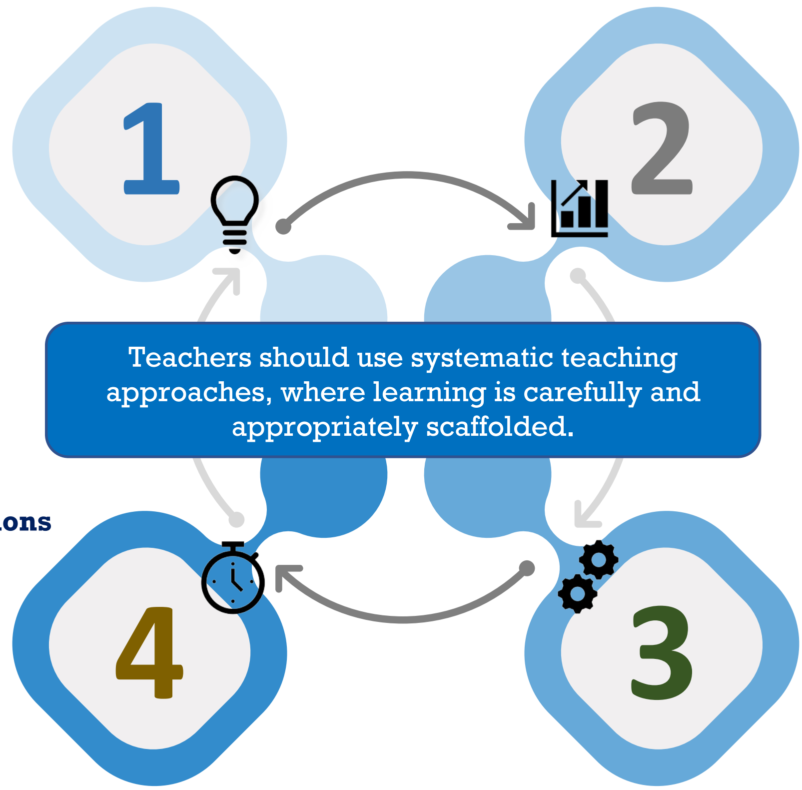
Teaching is the single most important factor in schools' effectiveness and this is especially important in science given the abstract and counterintuitive nature of many of the ideas being learned.

1

Explanations
Pupils report that 'explaining things well' is the most important thing that science teachers do to help them learn.

2

Models
Models may be used to link observations to explanations and representations but should only be used if they aid understanding.



4

Other Representations
Representations should be well-structured and should help pupils retrieve and reorganise knowledge, whatever their form.

3

Analogies
Teachers should teach pupils about the analogies used and their structure, whilst also using a range of these to represent a single concept.

Consider… Plan… Teach… Outcome

Evidence shows that unguided 'discovery' approaches are not effective in the teaching and learning of science.

- Teachers should plan **activities that are carefully chosen** to match the curriculum intent.
- When planning, teachers should consider how **children's limited working memory capacity** may limit their ability to learn and remember scientific knowledge.
- **Vocabulary development should be planned for, taught explicitly** and taught regularly using systematic approaches.
- Teachers should not expect children to acquire an **understanding of scientific concepts** without sufficient scientific schemata / prior learning.
- Pedagogy should help children to **acquire, organise and remember scientific knowledge** – both conceptual and procedural.

Research highlights the importance of teacher explanations in science that build on what pupils already know.

Assessment

Evidence shows that, despite the best curriculum and teaching, pupils may draw different conclusions and learn different things from what was intended. This means that teachers need to frequently check pupils' understanding to identify 'gaps' and misconceptions.

Time

Assessment should not place undue burden on teachers' time or add unnessecarily to their workload. This could be through excessive marking, feedback or data-recording requirements.

Purpose

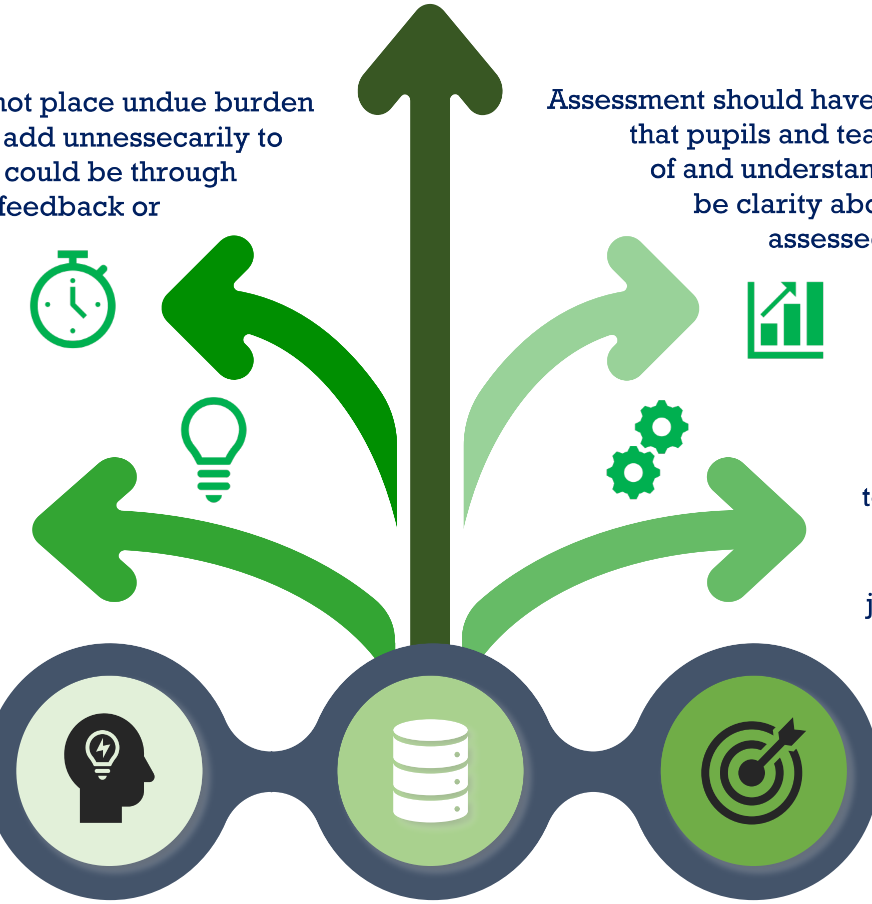
Assessment should have a clear purpose that pupils and teachers are aware of and understand. There should be clarity about what is being assessed and why this is being assessed.

Focus and Feedback

Once teachers and pupils understand what is being assessed and why, feedback should be provided to advance learning – this should focus on specific substantive or disciplinary knowledge.

Systems

School systems should enable teachers to make accurate assessment judgements, and may include assessment frameworks, sufficient training and development, and moderation.



Assessment for Learning

Assessment as Learning

Assessment of Learning

Formative Assessment	The Testing Effect	Summative Assessment
Involves providing feedback that is then used to improve teaching and learning. In science, this is most effective for pupils when it is embedded within a lesson sequence.	Draws on the principle that pupils are more likely to remember knowledge if they practise retrieving it successfully from long-term memory into their working memory over extended periods of time.	In science, this consists of assessing pupils' substantive and disciplinary knowledge and identifying whether specific curricular goals have been achieved.

Distractor-driven assessment tools can be especially helpful, such as multiple-choice questions that present pupils with both the scientific conception and misconception. This is because misconceptions are not always identified in questions that assess general science content.

Systems at School and Subject Level

A high-quality science education depends on effective subject and school leadership.

➡ Teachers will not 'pick up' subject knowledge through time spent teaching – they require access to high quality, subject-specific CPD to develop their content knowledge and understanding of how it should be taught.

➡ An important first step in developing primary science expertise is for every primary school to have at least one teacher who specialises in teaching science.

Content knowledge is at the heart of successful science teaching. Without this, teachers do not have the understanding of scientific concepts that is required in order from them to transform their knowledge into something that pupils can learn from (pedagogical content knowledge).

- ✔ Subject-specific CPD
- ✔ Specialist teachers and leaders
- ✔ Engagement and responsibility
- ✔ Early-career support and responsibility
- ✔ Status and profile
- ✔ Access to resources and practical experiences

Weak content knowledge is not only a barrier to clear explanations, but also a source of pupils' misconceptions in science.

➡ Schools and teachers should take responsibility for engaging, and subsequently engage, with professional bodies and subject associations in order to take advantage of high-quality professional development.

➡ School leaders should acknowledge the need for teachers to develop expertise in the early stages of their career; these teachers should be well acquainted with the curriculum across several year groups but should not be expected to teach across too many year groups in a short period of time.

➡ Science should be given sufficient teaching time to reflect its status as a core National Curriculum subject.

➡ Pupils should be given access to resources that are appropriate for their purpose as a tool that enables first-hand, scientific experiences.

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Conclusions:

The Foundations of Subject Quality

In their review, Ofsted identify 3 principles that play a central role in influencing many aspects of science education that lay the foundation for subject quality….

(1) ***A high-quality science education is rooted in an authentic understanding of what science is.***

Science is a discipline of enquiry, underpinned by substantive and disciplinary knowledge, that seeks to explain the material world.

There is diversity of approaches used to establish knowledge in science, and both teacher and pupil should recognise that there is not just one scientific method.

(2) ***A high-quality science curriculum prioritises pupils building knowledge of key concepts in a meaningful way that reflects how knowledge is organised in the scientific disciplines.***

The effectiveness of practical work can be increased by making sure that pupils have the necessary prior knowledge to learn from the activity.

By carefully selecting what pupils learn, when they learn it, and how they learn it, the likelihood of misconceptions forming can be reduced.

(3) ***A high-quality science curriculum should be planned to take account of the function of knowledge in relation to future learning.***

A high-quality science education carefully balances several competing priorities and tensions.

*- Pupils learn that science is a body of established knowledge **but** is also a discipline of enquiry.*

*- Complex concepts and procedures must be broken down into simpler parts, **but** knowledge must not become fragmented or divorced from the subject discipline.*

*- Curriculum is distinct from pedagogy, **but** what you learn is influenced by how you learn it.*

To navigate these tensions (above right) successfully, teachers and subject leaders require an in-depth knowledge of science and how to teach it, as well as an understanding of how pupils learn.

Building teachers' knowledge is therefore a central pillar of high-quality science education.