

Diagnostic assessment: The BEST way to discover what children are really thinking about materials

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Abstract

The Best Evidence Science Teaching (BEST) (7-11) 'Materials and their properties' resources have been developed by the Centre for Industry Education Collaboration (CIEC), funded by the Horners' Charities. The resources bridge the gap between research on children's misconceptions in science and classroom practice through the creation of a suite of classroom resources to support effective formative assessment and the development of secure understanding about materials and their properties. The resources are generic and therefore support not only teaching and learning in England, but also across the UK and internationally.

This article explores in more depth how research informed the creation of key components of the resources, namely the learning progressions, diagnostic questions and response activities.

It draws together thinking from the research reading across the topic of materials and their properties, including states of matter, the water cycle, separating and changing materials, to identify common patterns in children's misconceptions about materials and their properties leading to a discussion of the potential implications for classroom practice. Finally, the article suggests areas for further research reading and resource development.

Introduction

If a child correctly gives the answer '*It has evaporated*' when asked why a puddle has apparently disappeared from the playground, can a teacher be sure that the child has understood the concept of evaporation rather than simply reiterating a remembered statement?

This example illustrates a key challenge for formative assessment in primary science: '*Young children are capable of delivering the appropriate answers to questions, however they may simultaneously hold misconceptions which they believe strongly*' (Smolleck & Herschberger, 2011).

A child may actually think that the water in a puddle has disappeared, or perhaps that it has risen up into the Sun, whilst still giving the teacher the answer that is expected.

In order to understand better what children are really thinking about science, researchers and educators have developed and used diagnostic questions. Unlike traditional assessment

questions, the wrong answers are carefully devised in order to reveal misconceptions. Once revealed, the misconceptions can then be responded to, to help children to develop secure understanding.

BEST (7-11) *Materials and their properties* resources

The Centre for Industry Education Collaboration (CIEC) has led the development of the Best Evidence Science Teaching (BEST) *Materials and their properties* (7-11) resources with funding from the Horners' Charities. Simultaneously, CIEC has developed the new primary science curriculum for Oak National Academy, incorporating BEST principles throughout. This was achieved by having a focus on progression, including diagnostic checks for understanding and planning subsequent learning to address any potential misconceptions. These BEST primary materials have been developed by CIEC from the approaches used in two earlier collaborative primary BEST projects with the University of York Science Education Group.

These resources cover four key concepts (ideas). Each key concept has one overarching learning focus that underpins secure understanding of the topic area (Table 1). All resources are freely accessible via <https://www.stem.org.uk/primary/resources/collections/science/best-evidence-science-teaching/materials-and-their-properties> and, in addition from Spring 2026, via <https://www.york.ac.uk/ciec/school-support/>

“This was achieved by having a focus on progression, including diagnostic checks for understanding and planning subsequent learning to address any potential misconceptions.”

▼ **Table 1** An overview of the key concepts and learning foci of BEST (7-11) *Materials and their properties*.

Key concept	Learning focus
1. States of matter	Materials can exist in different states and can change from one state to another.
2. Water cycle	The movement of water in the water cycle may be both visible and invisible.
3. Separating mixtures	Solids can be separated from liquids according to their solubility.
4. Changing materials	Changes can be reversible or irreversible (when one or more new materials are made).

The Best Evidence Science Teaching (7-11) resources have been specifically designed to support effective formative assessment in primary science by providing not only diagnostic questions but, critically, also response activities to address any misconceptions identified.

The learning progression for each key concept breaks down the key learning focus into five steps, with a learning outcome for each. Each step clearly identifies the corresponding diagnostic question and response activity (see Figure 1).

▼ **Figure 1** Progression toolkit for Key concept 4: *Changing materials*, including the learning focus, learning progression and titles of the related diagnostic questions and response activities.

Progression toolkit: Changing materials

Learning focus	Changes can be reversible or irreversible (when one or more new materials are made).				
As pupils' conceptual understanding progresses, they can:	CONCEPTUAL PROGRESSION				
	Recognise that all changes of state are reversible because the material can return to its original state.	Recognise that dissolving is reversible because the dissolved material can be recovered by evaporation.	Recognise that some changes are not reversible.	Recognise that, after an irreversible change, the original material is no longer present.	Recognise that, after an irreversible change, one or more new materials are made.
Diagnostic questions.	Reversible changes	Sugar cubes	Making toast	Matchstick muddle	Fizzing fun
Response activities.	Changing state	Recovery response	Observing changes	Observing burning	Fire extinguisher

BEST is not a traditional scheme of learning. It is designed to be integrated into normal planning and teaching of a materials-related topic. Teachers should use BEST's learning progressions as a planning backbone, rather than an additional layer, to break topics into learning steps that reflect how children develop understanding over time. They should match each learning step with their own curriculum objectives. In this way, the BEST resources can be used to inform long-term planning and teaching approaches.

The child-facing resources have been devised to be age-appropriate and as accessible as possible in both the language and contexts used. These are accompanied by detailed teacher guidance that provides support for and clarification on both the science being explored and interpretation of children's responses.

All the resources are underpinned by a review of the research literature into children's misconceptions around each key concept. A summary of the research that informed the writing of each resource is provided in the teacher guidance, so that teachers can clearly see how the resources draw from this research base. The teacher guidance also provides suggestions of ways to use each activity, as well as tips on adaptive teaching.

The article will now explore how research informed the development of the key components of BEST (7-11) *Materials and their properties*.

The structure and development of the learning progressions

Each learning progression was devised following a review of the research literature on children's misconceptions about the topic in question. This review included articles about research into the development of understanding of primary-aged children about specific ideas such as dissolving (Kikas, 2001) or burning (Rahayu & Tytler, 1999), as well as literature reviews on broader areas such as the weather (Henriques, 2002) and matter (Knel, Glažar & Watson, 1998). In addition, a few papers were included that focused on the nature of understanding of a specific concept in order to support thinking about how a learning progression at primary

could provide a secure foundation for later learning about, for example, chemical reactions (De Vos & Verdonk, 1985). The resulting ‘Research Overview’ then informed the identification of the key learning focus and the steps along the progression.

In their review (Duschl *et al*, 2011) of learning progressions on science topics, the authors included examination of the boundaries of the learning progressions. They reviewed the start of the progressions (‘lower anchors’) for the accessibility of the target concepts and the end of the progressions (‘upper anchors’) for the abstractness (effectively, level of challenge) of the learning goals.

When developing the learning progressions, these two anchors were decided first, fixing the start and end of each learning progression. The central steps were then devised to address the core understanding of the key concept (see Figure 2).

▼ **Figure 2** Outline of the common structure used to develop the learning progressions.

Step 1	Step 2	Step 3	Step 4	Step 5
Lower anchors ensure secure understanding of ideas essential to access the learning focus.		Central steps develop core understanding of newly taught ideas.		Upper anchor sets expectations of secure understanding ready for progression to later learning.

Fixing the lower anchors

The collated misconceptions for each topic were first reviewed to identify those that were linked to children’s experience and understanding prior to formal teaching on the topic, which could impede access to the key understanding of a topic.

For example, in *Key concept 1: States of matter*, several misconceptions were identified relating to the liquid state. One misconception found was thinking that a powder is a liquid (Stachel & Stavy, 1986). This may arise from children’s play with sand, which can flow through their fingers and be poured from container to container. Another paper (Krnél *et al*, 1998) refers to earlier research (Jones, 1984, 1989), which revealed that some children were less sure that a viscous liquid that pours more slowly, or coloured or opaque liquid, are liquids. The authors make arguments for the idea that the ‘primitive actions’ of children (to hold, move, pour, etc.) help them to develop prototypes for the states of matter. Just as a model may be made as a prototype of a product, so a liquid that children experience at an early age may form their ‘prototype model’ of any liquid. If children perceive water as a prototype model for a liquid, this could explain the challenge for them in classifying liquids that look or pour differently from water as also being liquids. This suggests that it may be beneficial to introduce the properties of liquids using a range of liquids and not only water.

The interpretation of this research led to the first learning outcome for the progression focusing on the identification of materials in the liquid state. Without this foundational understanding, children could struggle to understand the overall learning focus relating to changes of state.

This example is illustrative of the approach taken to devise the first two learning outcomes in each progression. The first two learning outcomes for Key concepts 1 to 3 are derived from these everyday misconceptions. Only the starting point for Key concept 4 links back to earlier key concepts, a pattern that then continues upwards through BEST 11-16 Chemistry, where each key concept builds on earlier learning.

Determining the upper anchors

The upper anchors have been constructed based on a scientifically accurate science explanation that is appropriate for the children's age and typical curriculum expectations. An understanding of the particle model is not included in the current curriculum expectations for children aged 7-11 in England, Wales, Scotland or Northern Ireland. Furthermore, a proposed Framework for Future Primary Science Curriculum (Turner *et al*, 2023) specifically identifies 'particles and particle theory' as an area not to include in a primary science curriculum. The research review identified a large number of misconceptions related to observable properties of materials in the solid, liquid and gas states. Addressing these misunderstandings is critical in ensuring a secure foundation of understanding before moving on to the particle model when aged 11-14. It was therefore decided that the upper anchor points would not include the idea of particles. Ideas relating to particles are found in the BEST 11-14 Chemistry resources.

The upper anchors are not without challenge, as the expectation is that the response activities will be used to overcome any latent misconceptions identified in the related diagnostic question. These final steps have been designed to secure a strong foundation ahead of progression to later key concepts and learning (see Table 2).

▼ **Table 2** Upper anchor learning outcome and related misconceptions.

Key concept	Misconceptions*	Upper anchor learning outcome
1. States of matter	When water 'disappears' on a sunny day, it will cease to exist. Mass is not constant (not conserved) if a liquid evaporates in a sealed container.	Explain the observed decrease in volume of water during evaporation in terms of a change into the gas state.
2. Water cycle	A cloud is made of a material that looks like a cloud, such as smoke or cotton wool. A cloud is made of the precipitation that falls from it (e.g. rain, snow, hail, sleet). Clouds are made of water vapour (rather than condensed water vapour, forming as water droplets).	Explain that clouds are formed by the condensation of water vapour.
3. Separating mixtures	A solid dissolved in a liquid can be separated using a filter. A soluble substance cannot be separated from a solution.	Describe how to recover a soluble substance from a solution using evaporation.
4. Changing materials	After an irreversible change, the original material is still the same material, it has just changed in some way.	Recognise that after an irreversible change, one or more new materials are made.

*References for all misconceptions can be found in the resources for each key concept

Devising the central steps

The learning outcomes for steps 3 and 4 of the learning progression have been derived from the misconceptions in the literature that connect to core understanding about the newly taught topic (see Table 3).

▼ **Table 3** Learning outcomes 3 and 4 from the *States of matter* learning progression, with the reason for their inclusion.

Learning outcome	Reason
Recognise that when water boils, it changes into the gas state.	The concept of a gas is particularly challenging for children, and a common misconception is that a gas is nothing. The bubbles formed during boiling are made of water vapour and are visible evidence of a change of state. However, many children think that the bubbles are made of nothing, or air.
Recognise that air takes up space and has mass and is therefore matter.	Air does have mass and it does take up volume; recognition of this could support children to understand that gases are also made of matter.

These misconceptions could form a barrier to learning about the current topic and the diagnostic questions have been devised for use during teaching to pick up quickly when a child has misunderstood a new idea.

The linked response activities can then be used to help address these sticking points. It is also possible that the recognition of misconceptions could inform future teaching and learning.

Diagnostic questions

The research literature on misconceptions is not unanimous regarding the terminology that should be used, or the exact meaning of each term. Various articles describe the use of terms such as *misconceptions*, *alternative conceptions*, *pre-conceptions* and *naïve conceptions or ideas*. One paper (Blosser, 1987) discusses the connotation of the terms, suggesting that misconception implies a ‘wrong idea’. The paper acknowledges that children come to school with existing beliefs about how things happen. The paper cites an earlier paper (Osborne & Gilbert, 1980), saying that children hold conceptual structures that provide a ‘*sensible and coherent understanding of the world from the child’s point of view*’.

“The teacher guidance for the diagnostic questions supports teachers to create a supportive and inclusive classroom climate...”

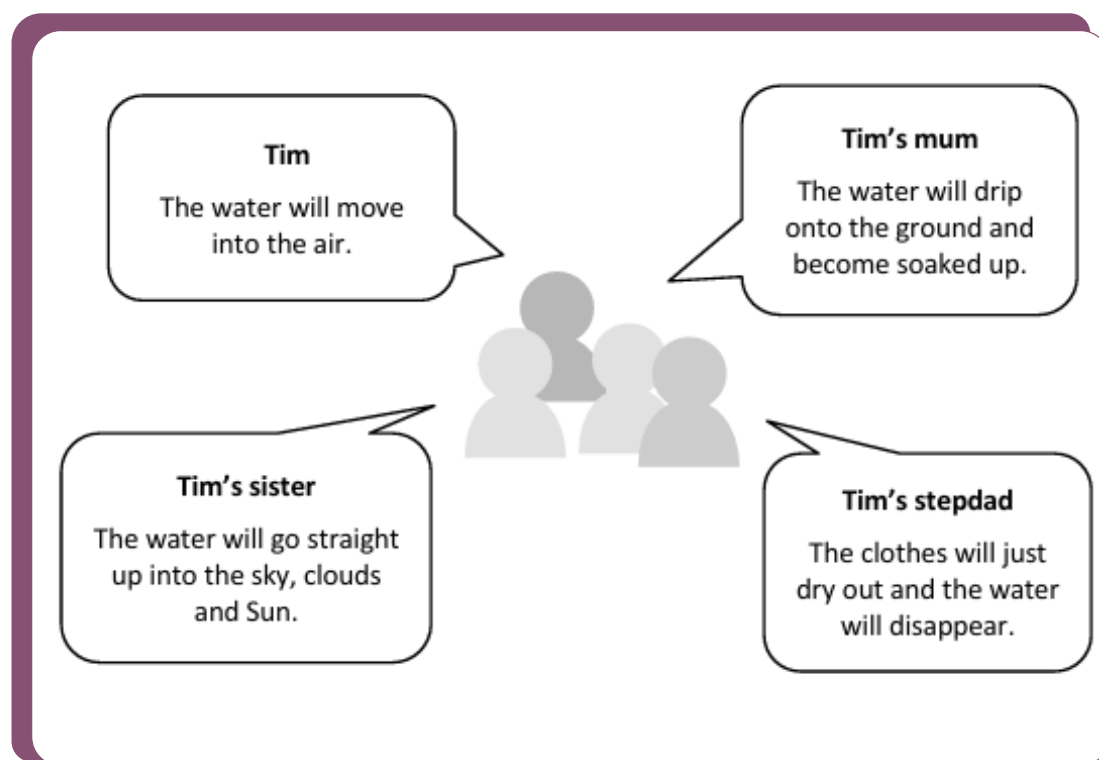
Although the terms ‘misconception’ and ‘misunderstandings’ have been used in BEST, the approach is not one of error identification and correction; rather, the aim is to uncover children’s thinking in an environment where they feel safe to share their ideas. The lower anchors of the learning progressions are more linked to what some call ‘naïve conceptions’ (Blosser, 1987), those that stem from everyday experience before formal teaching.

The teacher guidance for the diagnostic questions supports teachers to create a supportive and inclusive classroom climate by fostering a learning environment where children feel safe

to express themselves, have a go at suggesting ideas and learn from mistakes. Phrases such as *'That's an interesting idea – let's explore it together'* or *'Mistakes help us to learn'* can support children to feel safe to think and work scientifically. All answers should be acknowledged respectfully before moving on to further exploration.

Unlike a test question, the 'wrong' answers to a diagnostic question reveal misunderstandings that the children may have, which is why they should be accepted as 'their ideas' at this initial stage. However, this approach may initially feel very unfamiliar to both teachers and children. It is important that teachers recognise that, whilst the children's ideas may be initially welcomed and accepted, there should be an opportunity during and after the response activity to reflect on these early ideas from the class as a whole and how they may have changed.

The diagnostic questions use scenarios that are familiar to children's everyday lives, which enables children to be guided to more scientific understanding. For example, the first diagnostic question 'Wet Washing' in *Key concept 2: Water cycle* is set on washing day. Tim has taken the wet clothes out of the washing machine and is hanging them outside. Tim and his family then talk about where they think the water in the clothes will go as the clothes become dry. Children must decide which family member's ideas (shown with speech bubbles) they agree with. The responses in the speech bubbles are all constructed based on the research reading into misconceptions, and the teacher notes section 'How to respond – what next?' explains what misconceptions a child may hold if they agree with any of the incorrect speech bubbles.



The diagnostic questions use a range of question formats, including the 'talking heads' that are depicted here. Other formats include confidence grids (where children must say how confident they are of each answer) and multiple-choice questions (where children are asked to select an option and then explain why they think this is).

Response activities

Formative use of assessment becomes effective when the evidence of misunderstandings gathered from a diagnostic question is used to adapt teaching to meet children's needs. The response activities have been written to anticipate what these needs are likely to be and provide a structured, evidence-based sequence that aligns with the key scientific concept to be understood, and common misconceptions targeted in the diagnostic question.

The response activities are often practical, hands-on activities so that children can observe first-hand what is happening and find out for themselves using situations where they may have had misunderstandings originally. The response activity guidance supports teachers to guide children in being '*hands-on and minds-on*' (Abrahams & Millar, 2008) in order to develop and deepen their understanding.

For example, children may think that direct heating is necessary for evaporation to occur. In the response activity 'Oil burner' from *Key concept 2: Water cycle*, a small volume of an essential oil is poured into the bowl of an oil burner without a lighted candle (or onto a saucer). The children can, in time, detect the scent of the oil when it evaporates at room temperature. The children can therefore experience for themselves that the oil does not need direct heating for evaporation to occur.

Implications for science teaching

According to one author (Talanquer, 2006), teachers may perceive the 'vast inventory' of children's misconceptions as isolated pieces of information. For some, the author suggests, this risks becoming a 'list of common mistakes' that teachers feel obliged to fix.

Talanquer attempts to rationalise apparently disparate misconceptions into a more organised form. Whilst this paper was related to the education of older students, it still provokes the question 'Are there any common patterns in the misconceptions found in the research reading for BEST (7-11) *Materials and their properties*?'

"Some misconceptions appeared to arise from confusion between language that has an everyday and scientific meaning."

Some misconceptions appeared to arise from confusion between language that has an everyday and scientific meaning. For example, a child may think that the word *gas* means a fuel used for cooking rather than the meaning intended by their teacher where *gas* means a state of matter. Alternatively, an everyday expression such as 'an empty bottle' can contradict the scientific interpretation that it contains air. The most significant pattern that emerged is that the underlying basis of many of the misconceptions is invisibility. Gases exist; you can feel the wind on your face. Dissolved salt exists; you can taste it in sea water. Evaporation must exist; you can see the formation of clouds and feel humidity in the air. However, you cannot see any of them and this appears to present particular challenges to children.

The reading of the literature that informed CIEC's wider misconceptions research base suggests that there are other places in the 7-11 primary science curriculum where the issue of invisibility could lead to misconceptions.

In the case of a biological topic such as digestion, the parts of the body are clearly not invisible; however, they are not seen by children, and this also appears to lead to

misconceptions. An example of such a misconception is that some children may think that the abdominal area is an open space that receives food that has been chewed up into small pieces (Teixeira, 2000). In the case of electricity, children may be able to see a bulb, plug and wire but not the flow of electric current. There are numerous related misconceptions, including that electricity exists in the disconnected plug of an appliance (Pilatou & Stavridou, 2004) or that the origin of electric current is in the wall socket. The latter exemplifies the challenge of both the unseen (hidden wires) as well as the invisible (electric current).

Future directions

This generalised finding of the difficulties raised by the invisible and unseen in science, as well as the numerous misconceptions found in the research literature about materials and their properties, suggest that there would be benefit in the further development of learning progressions linked to other areas of science that are typically part of the curriculum for children aged 7-11 (in the UK and internationally), as well as accompanying diagnostic questions and response activities to identify and address the related misconceptions.

“A review for this younger age group (children aged 5-7) may need to include a broader range of journals.”

A more in-depth review of the research literature of the development of understanding of science concepts of children aged 5-7 may also be of benefit. This could reveal whether children of this age form misconceptions in a similar way to children aged 7-11, or whether issues arise that are linked more generally to child development. A review for this younger age group may need to include a broader range of journals. This could inform the tailoring of potential BEST resources to the specific needs of this age group.

Acknowledgement

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