

JES

ROLE MODELS

**A scientist just
like me**

CRITICAL THINKING

**'What if...'
scenarios**

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Kelsey Byers, *Evolutionary Biologist, from A Scientist Just Like Me, a Primary Science Teaching Trust Resource* (see article on p.44)

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About the journal

The *Journal of Emergent Science* (JES) is an 'open access' biannual e-journal designed to bridge the gap between research and practice, complementing the ASE's professional journal, *Primary Science*. JES was founded in 2011 by Jane Johnston and Sue Dale Tunnicliffe of the Emergent Science Network. The journal has since been transferred to ASE and is published in partnership with the Primary Science Teaching Trust (PSTT). JES focuses on research and the implications of research for practice and provision of science (including health, technology and engineering) for young children from birth to 11 years of age. JES welcomes contributions from its audience of early years practitioners, primary school teachers, teacher educators and researchers.



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Editorial Sarah Earle

Welcome to this November issue of the *Journal of Emergent Science*. Each article in this issue looks to apply research to practice, to consider how research can inform practice or how research-based principles can be enacted in specific contexts.

In the first article, **Helen Harden** and **Nicky Waller** explore how research on children's misconceptions informed the development of new *Best Evidence Science Teaching* (age 7-11) resources. They note the way in which children's common-sense explanations of the world are more likely to differ from the accepted scientific view when phenomena are unseen or invisible. For example, processes such as evaporation are invisible, making them more challenging for children to describe, hence the need for additional attention and diagnostic resources. In the second article, **Ana Leonardo** and **Bento Cavadas** also address a topic strewn with issues of invisibility, in their study of children's ideas about microorganisms. By discussing the beneficial, as well as the harmful, effects of microorganisms, together with observing Petri dish colonies, deeper understanding was demonstrated in the children's later annotated drawings.

The following articles also seek to consider how research-based principles can be applied to classroom practice. **Sally Howard** found a disparity between teachers' positive views of enquiry-based science and a more teacher-led enactment in the classroom, resulting from, for example, curriculum coverage and accountability pressures. **Kulvinder Kaur Johal** shares her experience of developing *A Scientist Just Like Me*, a free online resource to support Equity, Diversity and Inclusion (EDI) principles. She describes how the search for role models moved from looking for a range of scientists, to looking for scientists whose background and accents are more similar to those of the children in the class. Finally, drawing on research from *Thinking, Doing, Talking Science* and *Explorify*, **Layla Hewitt** worked through 'What if...' scenarios with her class, to develop their critical thinking skills.

In this collection of articles, authors describe examples from particular topics, year groups and contexts. Such examples help us to think about applications in our own contexts and experiences. We would like to continue to share further examples of research-informed practice in future issues of *JES*. Researchers, practitioners and teacher educators are all encouraged to join in the sharing of practice. Please find submission deadlines in Table 1, or get in touch to discuss ideas: s.earle@bathspa.ac.uk

▼ **Table 1** Submissions for the next issues of *Journal of Emergent Science*.

Issue	Submission to editor	Review and updating	Publication
JES 30	By 30 th January 2026	February/March	April 2026
JES 31	By 4 th September 2026	September/October	November 2026

Professor Sarah Earle, Professor of Primary Science Education, Bath Spa University, UK.

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

Helen Harden and Nicky Waller

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:					
	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 & Stav, 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 (Krnell *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...”

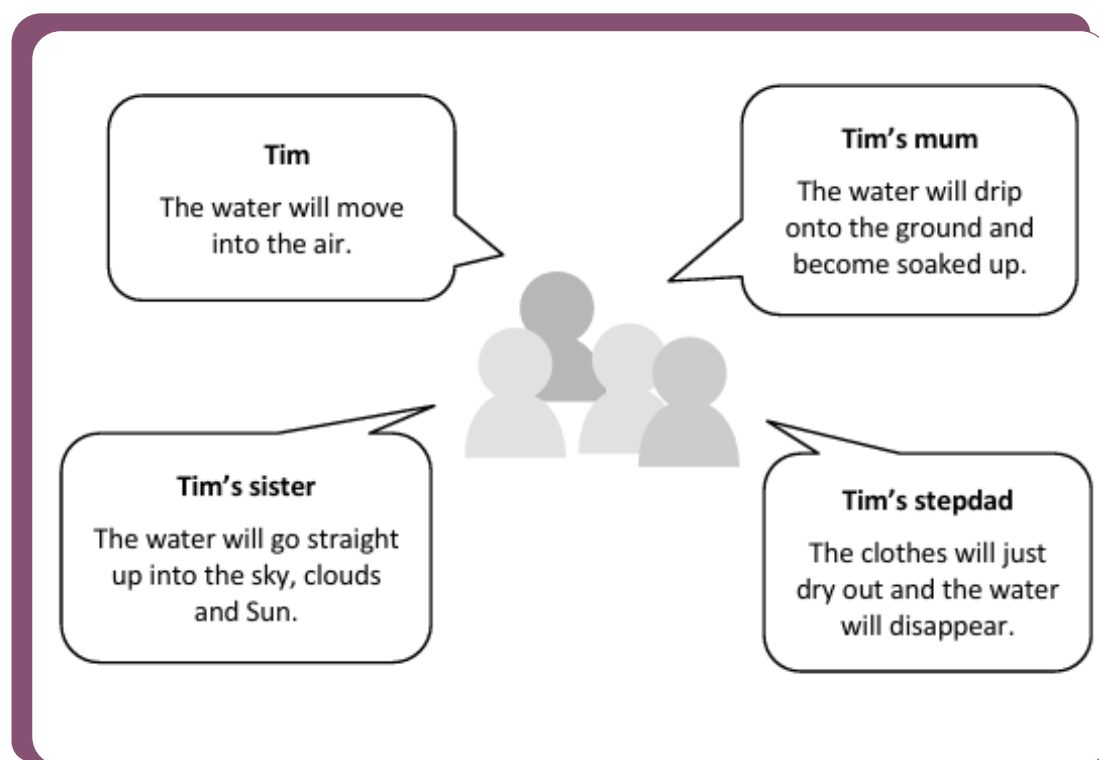
Although the terms ‘misconception’ and ‘misunderstandings’ have been used in BEST, the approach is not one of error identification and correction; rather, the aim is to uncover children’s thinking in an environment where they feel safe to share their ideas. The lower anchors of the learning progressions 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

The Best Evidence Science Teaching (BEST) for primary teachers is a collaboration between the University of York Science Education Group (<https://www.york.ac.uk/education/research/uyseg>) and the Centre for Industry Education Collaboration (<https://www.york.ac.uk/ciec>). BEST is a major research-informed curriculum development project that aims to transform science education research into practice by making research-informed resources open access and freely available to teachers of science. The current materials are funded by the Horners' Charities, extending the suite of materials previously funded by the Salters' Institute and Ogden Trust. All will be available on the STEM eLibrary (<https://www.stem.org.uk/primary/resources>) and CIEC websites by Spring 2026.

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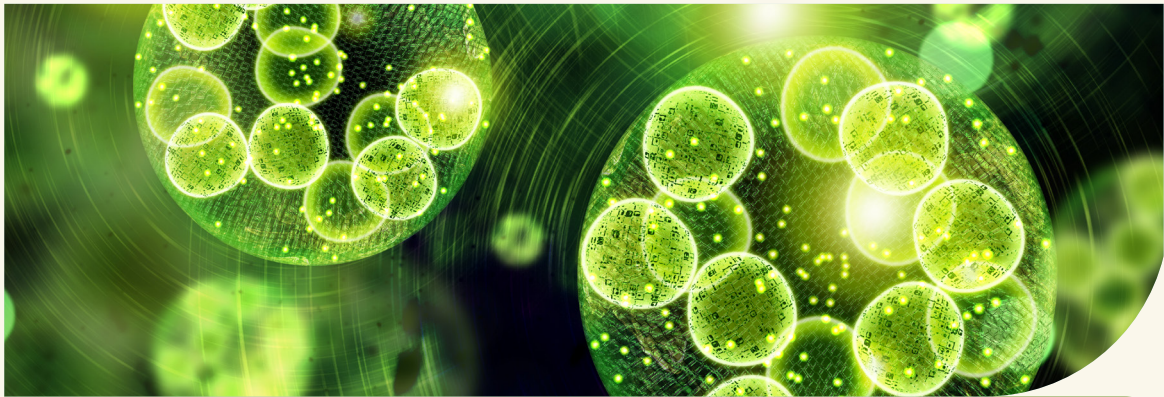
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Assessing the impact of an enquiry-based learning intervention on primary school students' conceptions about microorganisms



Ana Leonardo and Bento Cavadas

Abstract

Microorganisms are almost ubiquitous, but their small size often makes them difficult for children to conceptualise. This study aimed to assess the impact of an enquiry-based learning intervention on the conceptions of primary school students (ages 9-10) regarding microorganisms. The intervention included practical activities involving the cultivation of microorganisms in Petri dishes, collected from various surfaces. The students' ideas were gathered through drawings and their descriptions before and after the intervention. The results indicated that, post-intervention, the association of bacteria and viruses with microorganisms increased, demonstrating a deeper understanding of specific types of microorganisms. Additionally, there was an increased awareness of the actions of microorganisms, with students illustrating specific diseases caused by them, as well as recognising their general and specific beneficial effects on humans.

Keywords

Conceptions, enquiry-based learning, microorganisms, primary school

Introduction

Microorganisms are ubiquitous, found in nearly every environment on Earth. Despite their prevalence and the fact that they play crucial roles in ecosystems, human beings are unable to perceive them with the naked eye. Instead, specialised magnification instruments, such as microscopes, are required to observe these micro life forms, contributing to the awareness of their existence.

Understanding microorganisms is particularly challenging for children, as shown by Nagy's (1953) pioneering study about the representation of germs by children. These challenges are due to their invisible nature, the complex scientific concepts involved and the existence of myths and misconceptions that make them difficult to understand and learn about (Ballesteros *et al*, 2018; Carvalho, 2017; Fraga, 2018; Navy, 1953; Simard, 2023), as discussed further below.

Although some research has been conducted to better understand children's conceptions of microorganisms (e.g. Ballesteros *et al*, 2018; Carvalho, 2017; Fraga, 2018; Navy, 1953; Simard, 2023), it is still necessary to change the teaching and learning process about microorganisms at the level of the primary school (Carvalho *et al*, 2017). This study aims to contribute to that goal, presenting part of a research project designed to identify children's initial conceptions about microorganisms and the impact of an enquiry-based science learning sequence on their prior ideas. The following research question (RQ) guided the study:

RQ: *How does an enquiry-based learning intervention affect primary school students' conceptions about microorganisms?*

The importance of science teaching about microorganisms

Experimental science activities, such as those involving microbiology, significantly boost students' interest and motivation (Brown, 2002; Xu, 2024). For instance, the use of a co-operative learning approach in an oral microbiology laboratory course at Wuhan University led to improved student performance and positive feedback (Xu, 2024). Similarly, a study involving primary school students in Portugal showed that practical microbiology activities helped students to understand the importance of dental hygiene and the role of microorganisms in dental caries (Mafra *et al*, 2014). However, teachers conduct few practical microbiology activities, citing a lack of knowledge, technical difficulties and health or safety concerns (Redfern *et al*, 2013). For this reason, it is necessary to address teachers' negative emotions regarding microorganisms so that they do not transmit these feelings to their students, and to promote positive emotions that facilitate their teaching (Marcos-Merino *et al*, 2019).

“Introducing science education in primary schools can include activities focused on microorganisms, thereby enhancing children’s understanding of the world around them”

In Portugal, the study of microorganisms is not explicitly outlined in the curriculum of Environmental Studies for primary school (ages 6-10), although it can be associated with several indirect themes (Mafra & Lima, 2009). What is evident is the existence of implicit content when addressing issues related to hygiene and health, with no direct reference to microorganisms (Mafra *et al*, 2016).

However, Mafra and Lima (2009) suggest that these themes can be explored with students through hands-on experimental activities. Introducing science education in primary schools can include activities focused on microorganisms, thereby enhancing children's understanding of the world around them (Mafra & Lima, 2009). In other countries, microorganisms are included in the science curriculum, thereby acknowledging their importance (Byrne & Sharp, 2006).

Conceptions of primary school students about microorganisms

Microorganisms are very small living beings, most of which are invisible to the naked eye and only observed using a binocular loupe or microscope. Microorganisms are part of the three domains of life: *Archaea*, *Bacteria* and *Eukarya*. Microbiology, the science that studies microorganisms, organises them into various groups: algae, bacteria, fungi and protozoa. They can be unicellular (like bacteria) or acellular (viruses) (Parker *et al*, 2018). Viruses are considered acellular organisms because they do not have cells and thus depend on other living cells to reproduce (Parker *et al*, 2018).

Although many microorganisms play an essential role for life on the planet (Gonçalves, 2012), children tend to have a negative perception, limited and distant from scientific knowledge. Children tend to classify microorganisms as a type of animal, such as small insects (Nagy, 1953), and associate them with diseases and lack of hygiene (Ballesteros *et al*, 2018; Byrne, 2011; Nagy, 1953; Ruiz-Gallardo & Paños, 2018). According to Ruiz-Gallardo and Paños (2018), this negative connotation is due to the frequent association of microorganisms with pathogens. Byrne *et al* (2009) point out that this view can become more pronounced with age. This limited perception may be related to the way in which microorganisms are approached in the primary school curriculum, such as in the Spanish curriculum, which tends to emphasise their harmful aspects while omitting their benefits. For this reason, most children are unaware of these benefits (Ruiz-Gallardo & Paños, 2018).

Some studies on this topic highlight students' conceptions about these organisms in terms of classification, the environments in which they live, connotation, and application in health. According to Byrne (2011), children classify these organisms as abstract entities or animals, specifically insects or caterpillars. Through their drawings, Byrne (2011) also identified that some students associate microorganisms with small monsters. Additionally, the study by Gonçalves (2012) showed that most students depict microorganisms with anthropomorphic traits.

“Students tend to perceive microbes as a human concern rather than recognising microorganisms as integral components of the ecosystem”

Students often associate microorganisms with the human body, especially the hands (Faccio *et al*, 2013), but they tend to relate them mainly to dirty, poor hygiene and dangerous places for health (Byrne *et al*, 2009; Karadon & Sahin, 2010). According to Ruiz-Gallardo and Paños (2018), students also refer to environments such as the ground, the schoolyard and the air as places conducive to the transmission of diseases, which contributes to reinforcing their negative perception of these living beings for humans (Gonçalves, 2012). Students tend to perceive microbes as a human concern rather than recognising microorganisms as integral components of the ecosystem (Jones & Rua, 2006).

However, students aged around 14 years are more aware that not all microorganisms are pathogenic (Byrne, 2011). The results from Ruiz-Gallardo and Paños (2018) also show that, while children from the two age groups studied (ages 7-8 and 11-12) recognised the existence

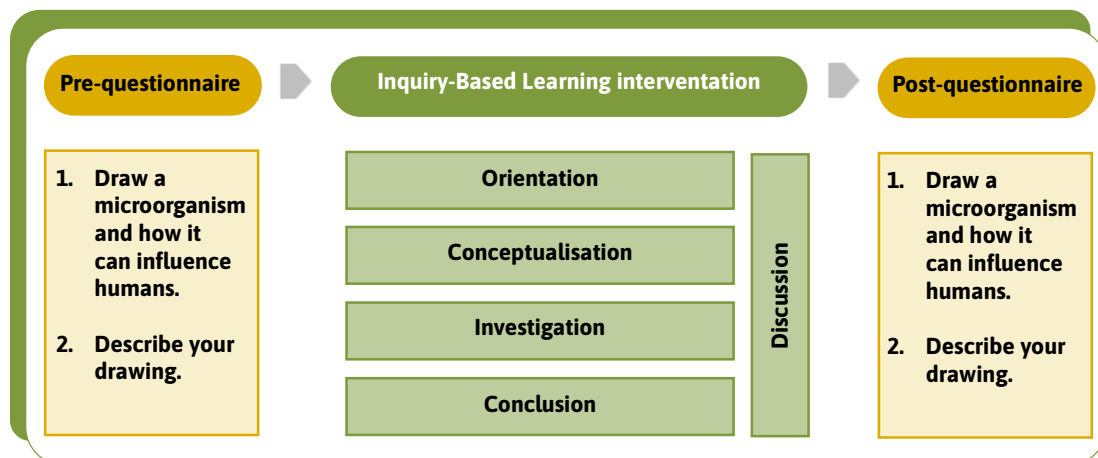
of beneficial microorganisms, only a small fraction, from the 6th grade (ages 11-12), could identify some functions, particularly those related to food. Nonetheless, many students were unaware of the applicability of microorganisms in medicine or of their role in chemical cycles and environmental protection (Ruiz-Gallardo & Paños, 2018).

An aspect that students appear to perceive clearly relates to the size of these living beings, with some students highlighting their microscopic nature (Byrne, 2011; Ruiz-Gallardo & Paños, 2018; Simmoneaux, 2000).

Research methodology

The present research, based on an intervention study, aims to develop a didactic experience and reflect on its impact on student learning. The research design used is presented in Figure 1. It consists of three main phases: pre-questionnaire, enquiry-based learning intervention, and post-questionnaire.

▼ **Figure 1** Research design.



In the first phase, 'Pre-questionnaire', students were asked to create a drawing about microorganisms and explain it. This phase was crucial for assessing the students' prior knowledge.

Following this, the enquiry-based learning intervention was implemented based on the five main phases of enquiry proposed by Pedaste *et al* (2015). In the orientation phase, essential concepts related to the meaning of microorganisms, the types of microorganisms, their beneficial effects, harmful effects and their locations were introduced. Next, in the conceptualisation phase, students were asked to define what a microorganism is and where microorganisms can be found.

Subsequently, in the investigation phase, students participated in a practical activity organised in two parts, in which the notion that unicellular microorganisms can be seen with the naked eye when organised into colonies was mobilised. In the first part, students used a cotton swab to collect samples from various surfaces, objects and parts of their bodies into a Petri dish. The students used their swabs to swipe across a Petri dish containing sugar-free gelatine. The second part corresponds to the study of the results, where students analysed and interpreted the outcomes, particularly the development of microorganism colonies in the Petri dishes. In the conclusion phase, students needed to identify which reasons explain the colonies' formation on the Petri dishes.

Finally, the process concluded with the post-questionnaire, which asked students to create a new drawing about microorganisms and explain it again. This last stage serves to evaluate the students' learning and compare it with the knowledge presented in the pre-questionnaire to determine if conceptual changes have occurred.

Participants and ethics

The study was conducted in a 4th grade (ages 9-10) class in a Portuguese public school. The classroom teacher authorised the students' participation. Written permission was requested from tutors to allow their children's participation in this research, according to the school protocols. Children were also informed about their role in the activities. The participants from primary school comprised 19 students, aged between 9 and 10 years old. The identities of the participants were kept confidential to ensure the privacy and anonymity of their contributions. To achieve that aim, students were identified as S1 to S19.

Data collection

The data collection instrument used was a questionnaire. The same questionnaire was administered before the intervention (pre-questionnaire) and after the intervention (post-questionnaire). The questionnaire aimed to collect students' conceptions of microorganisms. It included two tasks: a drawing prompted by the instruction '*Draw a microorganism and [explain] how it can influence humans*' and a written description about the drawing, using the students' own words.

“The students' explanations of their drawings were utilised to further clarify their reasoning and refine the categories and sub-categories..”

Data analysis

The drawings were subjected to content analysis. The categories and sub-categories were developed *a posteriori*. Specific misconceptions identified in the literature review were carefully examined and gave origin to some categories and sub-categories. The careful examination of the patterns across students' drawings produced other categories and sub-categories of analysis. The students' explanations of their drawings were utilised to further clarify their reasoning and refine the categories and sub-categories. Initially, one author created the initial categories and performed the first round of categorisation. Subsequently, this work was reviewed by the second author, with any discrepancies discussed and resolved. The number of occurrences of each sub-category was quantified in the pre- and post-questionnaires.

Results and discussion

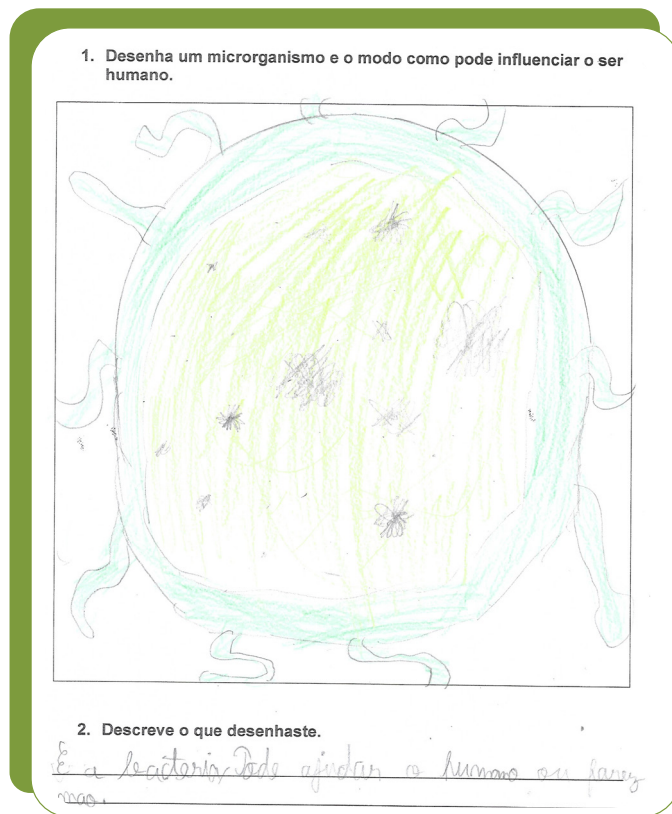
The results are presented and discussed in this section. The categorisation of the primary school students' drawings is presented in Figure 2 to facilitate a comparison between the pre-questionnaire (PreQ) and the post-questionnaire (PostQ). Whenever necessary, students' explanations of their drawings have been included to provide better insight into their thinking.

▼ **Figure 2** Categorisation of primary school students' drawings regarding the meaning of microorganisms and their influence on the human body, in the pre- and post-questionnaire.

Categories	Subcategories	PreQ	PostQ
1. Representations of microorganisms			
	• Unidentified microorganism	4	3
	• Bacteria	1	3
	• Virus	5	11
	• Associations of microorganisms with cells (unidentified)	5	0
	• Attribute of microscopic dimensions to microorganisms	4	0
	• Microorganisms organized in colonies	0	1
2. Representations of the actions of microorganisms			
2.1. General harmful effects		1	4
2.1.1. Causes of diseases			
	• Infections or disease caused by viruses	2	2
	• Infection or disease caused by bacteria	0	1
	• Specific infectious diseases caused by microorganisms	0	9
	• Transmission	1	0
2.2. Beneficial effects			
	• General beneficial effects	0	3
	• Specific beneficial effects (e.g., assisting digestions)	0	2
3. Representations of the locations of microorganisms			
	• Human body	5	2
	• Other locations	0	1
4. Other representations of microorganisms			
	• Instruments used to observe microorganisms	2	0
	• Researchers who study microorganisms	1	0
5. Representations not related to microorganisms		3	0

Representations of microorganisms

The sub-category 'Unidentified microorganism' saw a slight decrease from the pre-questionnaire to the post-questionnaire, indicating an improvement in students' ability to identify specific types of microorganisms. In contrast, the association between microorganisms and bacteria increased in the post-questionnaire drawings. For instance, student 19 (S19) described their illustration as *'It is the bacteria; it can help humans or cause harm'*, suggesting that the intervention effectively reinforced students' understanding of bacteria as a type of microorganism (see Figure 3).

▼ **Figure 3** Post-questionnaire drawing from S19.

The sub-category 'Virus' showed an increased presence in the post-questionnaire drawings. Student 6's (S6) drawing illustrated their understanding of viruses as microorganisms and highlighted one of their effects on humans – causing diseases, specifically the 'flu' (Figure 4). These changes are likely a result of the intervention, which included discussions about viruses as examples of microorganisms.

▼ **Figure 4** Post-questionnaire drawing from S6.

In the pre-questionnaire, five students drew structures resembling cells but did not identify them as bacteria. For example, student 1 (S1) noted: 'I think microorganisms are cells that exist in our body' (PreQ). However, this idea did not appear in the post-questionnaire, indicating that the intervention may have facilitated learning about the association of microorganisms, such as bacteria, with cells. Figure 5 (see next page) demonstrates this conceptual change for student S1.

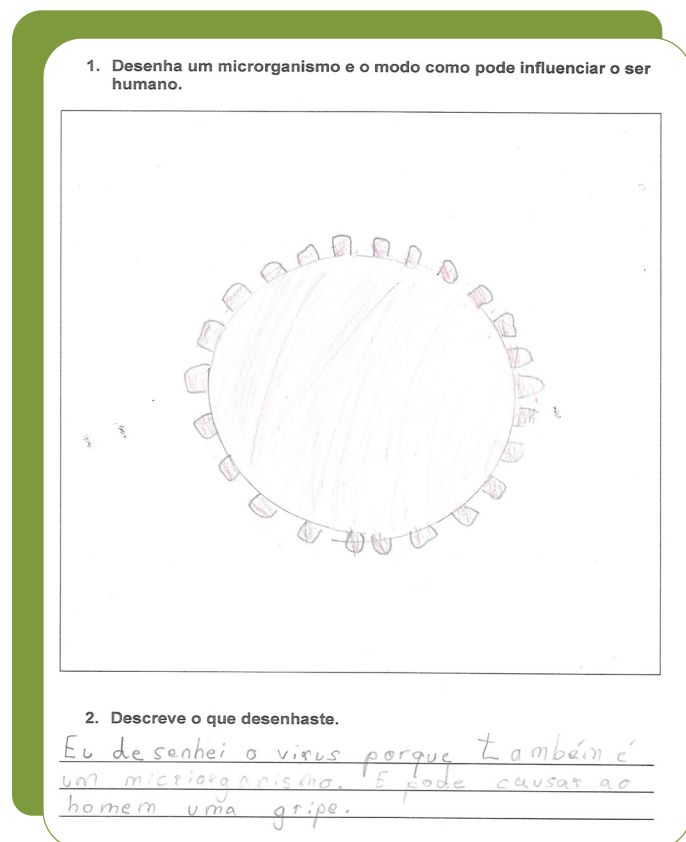
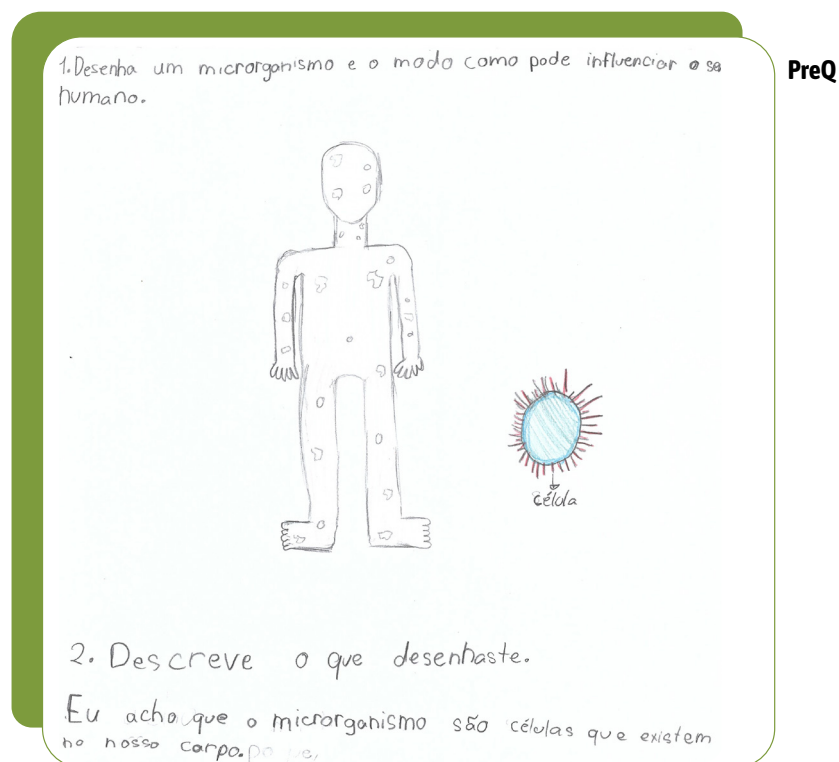
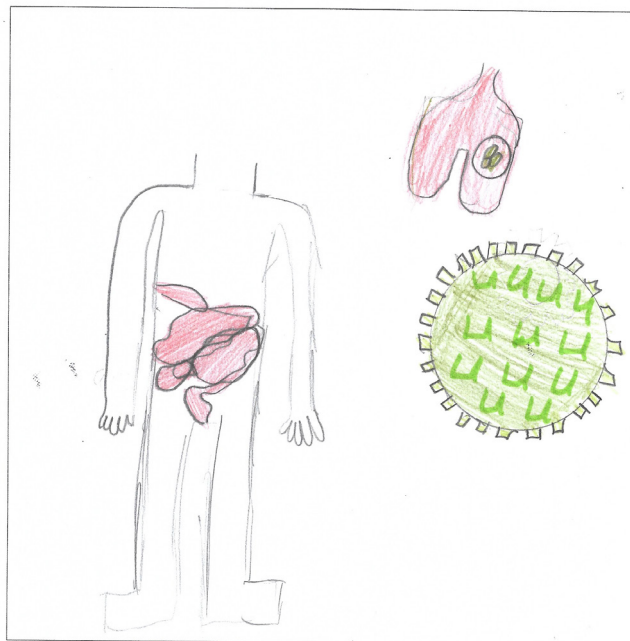


Figure 5 Pre-questionnaire and post-questionnaire drawings from S1.



PostQ

1. Desenha um microorganismo e o modo como pode influenciar o ser humano.



2. Descreve o que desenhaste.

Eu desenhé vírus, bactérias mde ficas e bactérias benéficas.

In the pre-questionnaire, there are four representations in which some students associate microorganisms with microscopic size. For example, student 12 (S12) described their illustration as follows: '[...] when I read the word *microorganisms*, I thought that "micro" meant small, so I tried to think of small organisms in the human body' (PreQ, Figure 6). The association of microorganisms with microscopic size was not mentioned in the post-questionnaire, because the intervention did not focus on their size but highlighted other characteristics.

▼ **Figure 6** Pre-questionnaire drawing from S12.



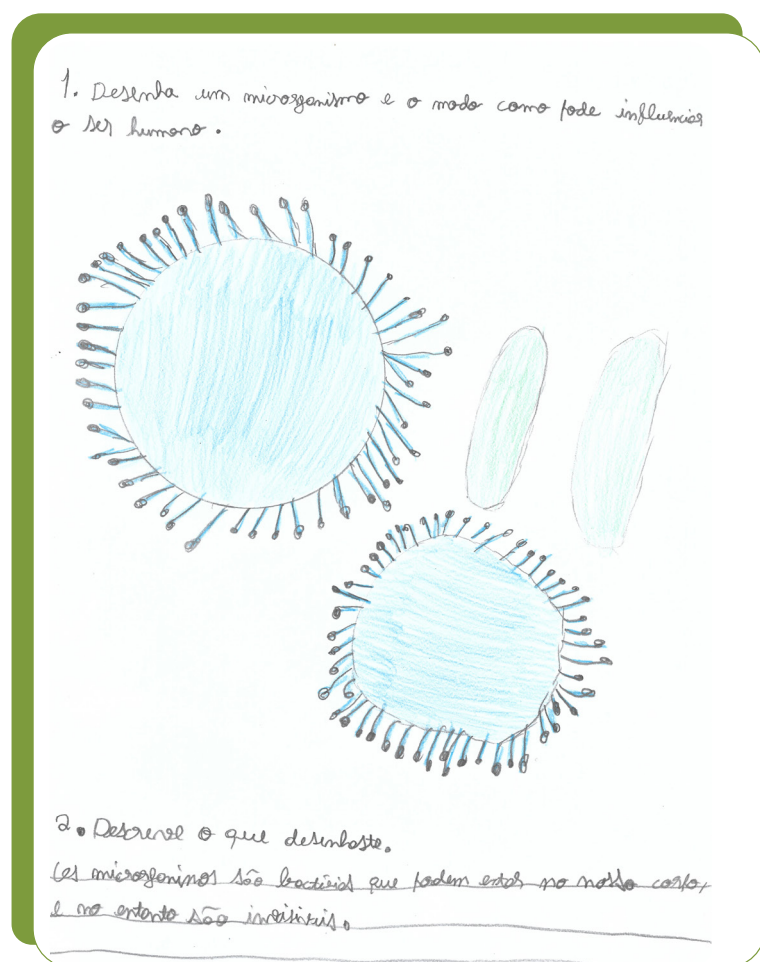
The organisation of microorganisms into colonies was noted in the post-questionnaire by student 13 (S13), who stated: 'I drew a colony of microorganisms'. This understanding likely emerged after the practical intervention, where students observed the growth of microorganism colonies on Petri dishes associated with various body parts and objects.

Microorganisms such as fungi and algae or microorganisms with anthropomorphic traits were not mentioned in pre- or post-questionnaires.

Representations of the actions of microorganisms

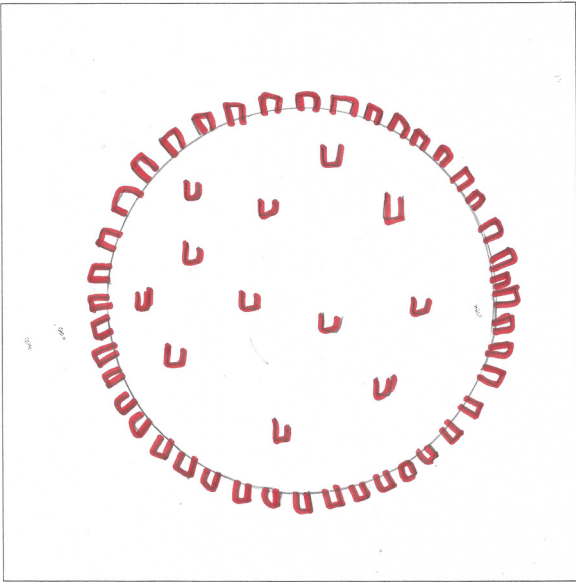
The harmful effects of microorganisms were represented in the students' work in both questionnaires. In the pre-questionnaire, student 8 (S8) noted: 'Microorganisms are bacteria that can be in our body and are invasive' (Figure 7). In the post-questionnaire, student 14 (S14) mentioned: '[...] one harmful effect is that it makes us sick' (Figure 7). The increased occurrences in the post-questionnaire may be linked to the learning from the intervention, which covered a discussion about diseases caused by microorganisms.

▼ **Figure 7.** Pre-questionnaire drawing from S8 and post-questionnaire drawing from S14 (on next page).



PreQ (S8)

1. Desenha um microrganismo e o modo como pode influenciar o ser humano.



2. Descreve o que desenhaste.

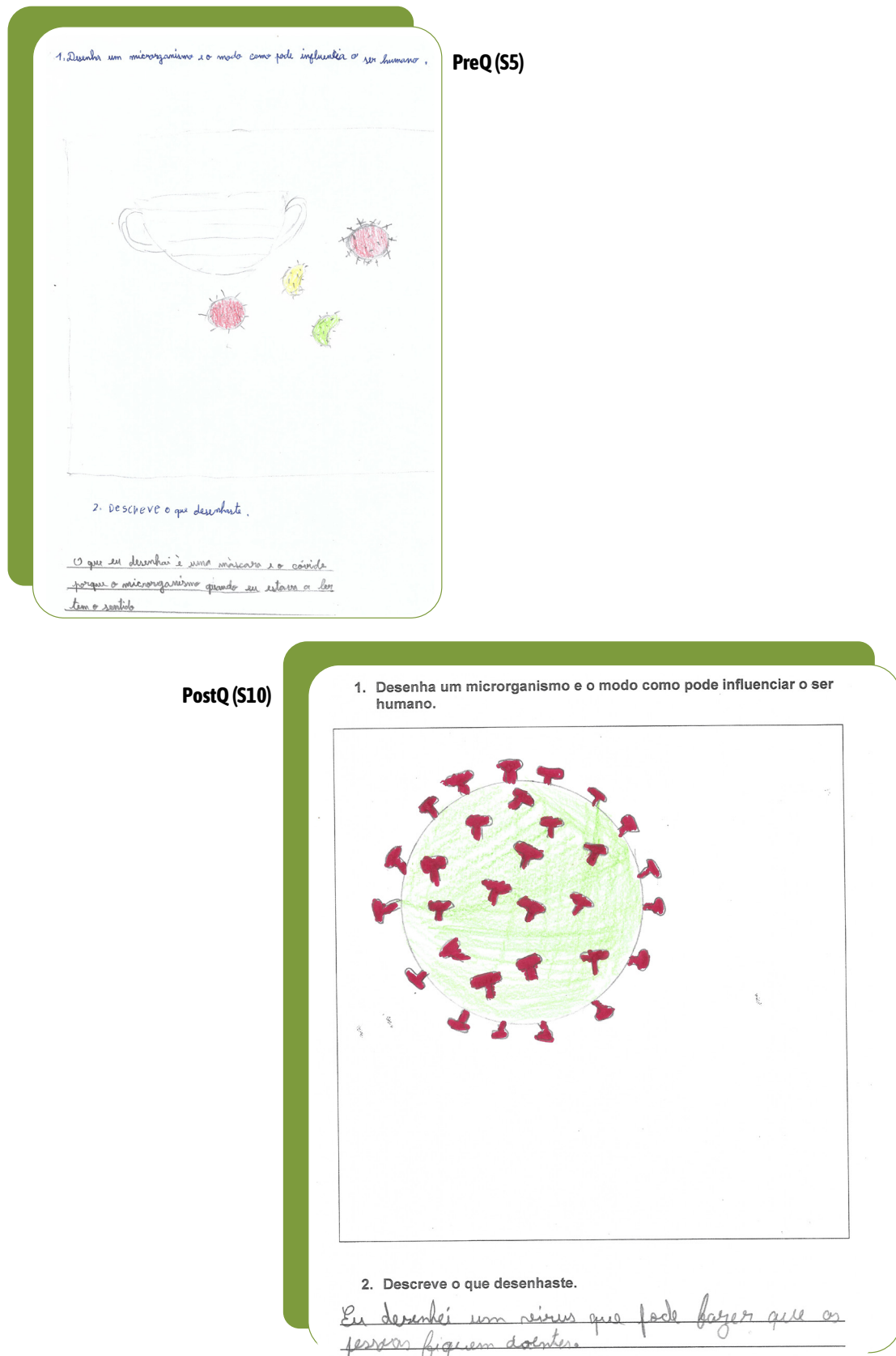
É desenhado um vírus. Porque existe benéfico e prejudicial. Um benefício é que nos ajuda a fazer a digestão. É um prejudicial é que nos faz ficar doentes.

PostQ (S14)

The sub-category 'Infection or disease caused by viruses' showed consistent occurrences in both the pre- and post-questionnaires. In the pre-questionnaire, student 5 (S5) noted: 'What I drew is a mask and COVID' (Figure 8) while, in the post-questionnaire, student 10 (S10) stated: 'I drew a virus that can make people sick' (Figure 8). The lack of increase in occurrences may indicate that some students began to associate microorganisms with specific diseases, such as the 'flu, instead of a general notion of causing illness.

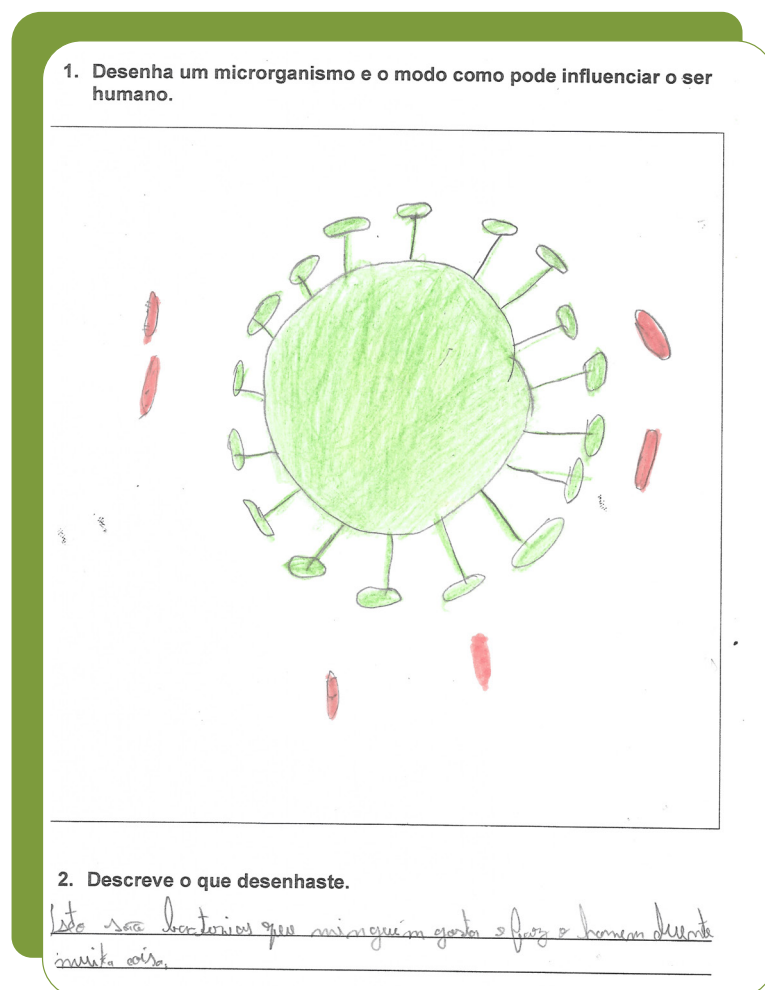
"Regarding infectious diseases, nine students specifically identified some caused by microorganisms. Examples include descriptions such as: 'I drew a virus. The virus can cause the flu' (PostQ, S13; Figure 10) and 'I drew a boy with a fungal infection' (PostQ, S12; Figure 10). These findings are consistent with the topics covered during the intervention, which presented diseases associated with different types of microorganisms. "

▼ **Figure 8.** Pre-questionnaire drawing from S5 and post-questionnaire drawing from S10.



As in the previous category, student 7 (S7) recognised the infection caused by bacteria in the post-questionnaire, describing their drawing as: *'bacteria that nobody likes and make people sick [...]'* (Figure 9).

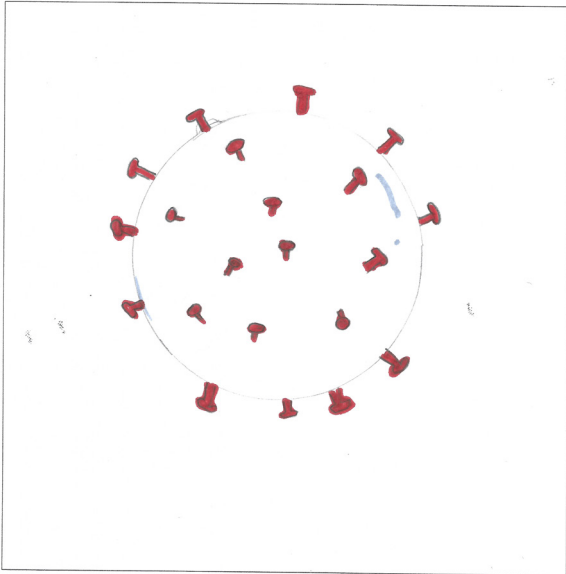
▼ **Figure 9.** Post-questionnaire drawing from S7.



Regarding infectious diseases, nine students specifically identified some caused by microorganisms. Examples include descriptions such as: *'I drew a virus. The virus can cause the flu'* (PostQ, S13; Figure 10) and *'I drew a boy with a fungal infection'* (PostQ, S12; Figure 10). These findings are consistent with the topics covered during the intervention, which presented diseases associated with different types of microorganisms. This change suggests that students learned about specific diseases caused by microorganisms. Notably, the most frequently depicted illness in the illustrations was the 'flu.

▼ **Figure 10.** Post-questionnaire drawings from S13 and S12.

1. Desenha um microrganismo e o modo como pode influenciar o ser humano.



2. Descreve o que desenhaste.
Eu desenhiei um vírus o vírus pode causar
uma gripe.

PostQ (S13)

1. Desenha um microrganismo e o modo como pode influenciar o ser humano.

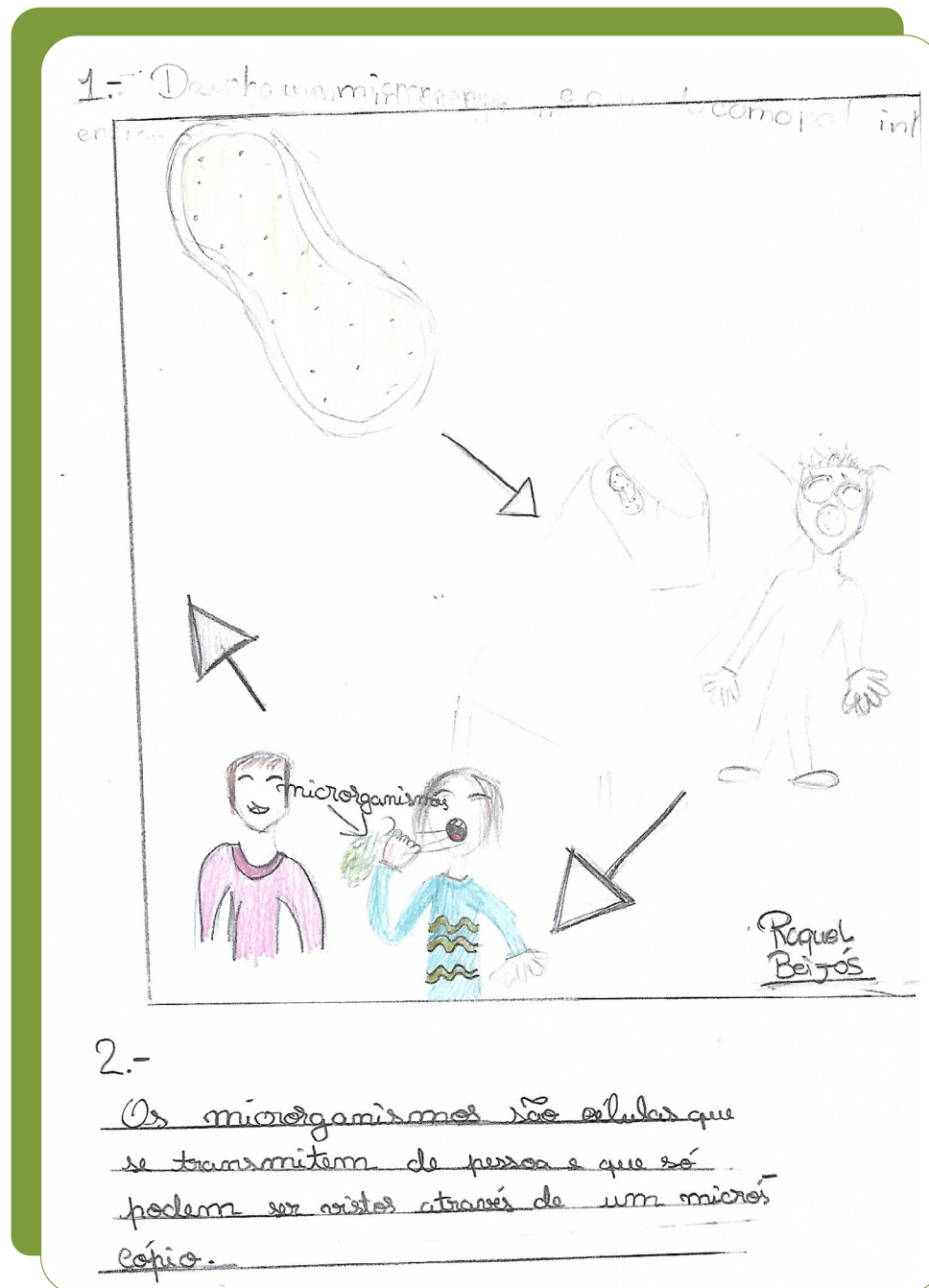


2. Descreve o que desenhaste.
Eu desenhiei um menino com micro.

PostQ (S12)

Transmission was an action related to microorganisms that was rarely represented. However, student 16 (S16) noted this in their drawing on the post-questionnaire, acknowledging that microorganisms are transmitted through droplets from one person to another (Figure 11).

▼ **Figure 11.** Post-questionnaire drawing from S16.

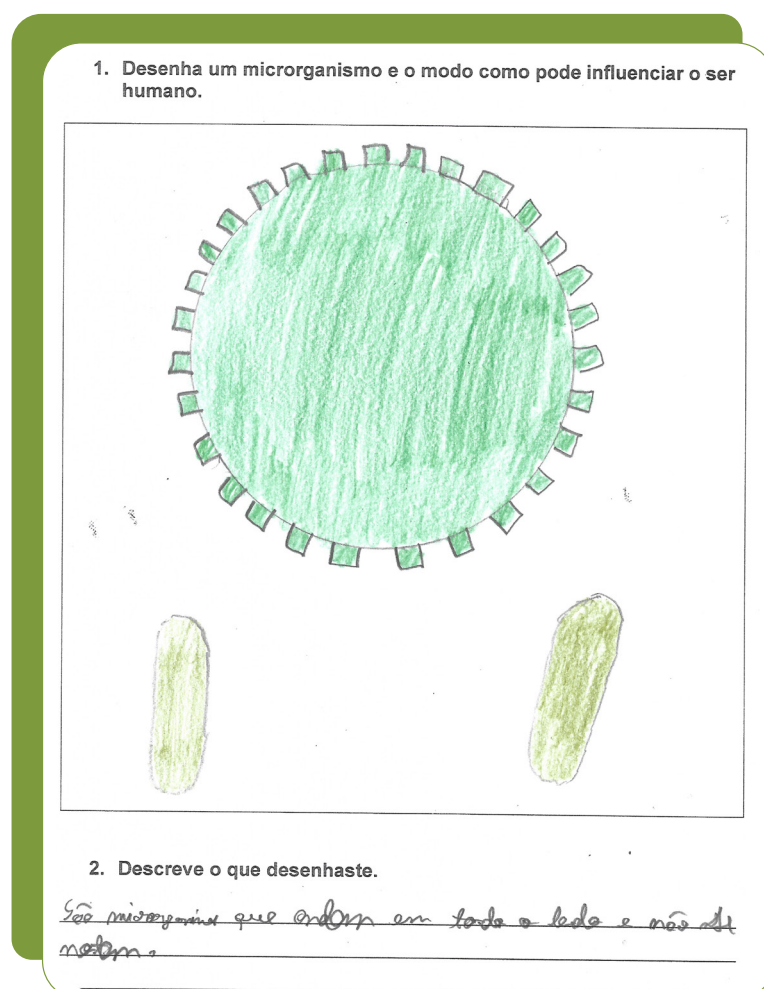


The sub-category 'General beneficial effects' was noted only in the post-questionnaire drawings, likely due to the intervention that emphasised the positive actions of microorganisms. Additionally, the role of bacteria in aiding human digestion was also represented in the post-questionnaire. This concept was expressed in the drawing by student 14 (S14), who mentioned: *'[...] a benefit is that it helps us digest'* (PostQ; Figure 7). This understanding may have emerged from the intervention, which highlighted microorganisms' beneficial effects on digestion.

Representations of the location of microorganisms

The location of microorganisms was depicted in various drawings, both in the human body and elsewhere. Their presence in the human body was primarily noted in the pre-questionnaire. Results regarding the location of microorganisms in the human body were less pronounced in the post-questionnaire because the intervention aimed to illustrate that these organisms are present in all environments. This approach was adopted due to students primarily associating microorganisms with the human body, leading the intervention to emphasise their presence in various objects and surroundings. In this regard, the sub-category regarding the location of microorganisms in other places emerged, which was identified in the post-questionnaire. One example is the description: *'They are microorganisms that are everywhere and are not noticeable'* (PostQ, S8; Figure 12).

▼ **Figure 12.** Post-questionnaire drawing from S8.



Other representations of microorganisms

The category 'Other representations of microorganisms' included drawings related to 'Instruments used to observe microorganisms' and 'Researchers who study microorganisms,' which were only present in the pre-questionnaire. The absence of occurrences in these sub-categories in the post-questionnaire can be attributed to the practical intervention, which focused on observing microorganisms with the naked eye in colonies rather than through magnifying instruments, and did not emphasise the work of researchers in the field.

Conclusions

Addressing the research question, '*How does an inquiry-based learning intervention affect primary school students' conceptions about microorganisms?*', it was noted that, initially, students had limited and imprecise conceptions regarding the type, action and location of microorganisms. These findings are consistent with those of Ballesteros *et al* (2018) and Ruiz Gallardo and Paños (2018). After intervention, the association of bacteria and viruses with microorganisms increased in the post-questionnaire drawings, revealing a deeper understanding of specific types of microorganisms. There was also a greater understanding of the actions of microorganisms post-intervention, with students depicting more specific diseases caused by them. Additionally, the focus of the representations of microorganisms' actions shifted from being primarily about disease causation to also including their general and specific beneficial effects, such as aiding digestion. While some students initially represented the location of microorganisms on the human body, these occurrences declined after the intervention, likely due to the emphasis placed on the presence of microorganisms on other surfaces and objects.

Implications for practice

As students often have preconceptions that make learning about microorganisms difficult, teachers should adopt strategies that challenge these conceptions. One approach that can be effective involves starting by identifying these ideas and then promoting practical activities that motivate students. The proposed enquiry-based learning intervention, centred on practical experiences, could contribute to improving understanding of the different types of microorganisms and their actions through active participation. By taking samples from surfaces in their everyday lives and observing the growth of colonies in Petri dishes, students can develop concrete knowledge about the environments in which microorganisms thrive.

The take-home message for the science community is that, while practical experiences can improve young students' basic knowledge about microorganisms, it is important to focus on exploring concepts that build a solid and accurate scientific understanding from an early age. For practitioners, this underscores the need to develop age-appropriate, engaging and scientifically sound educational activities that not only increase awareness but also foster curiosity and a more accurate perception of microorganisms and their importance in the world. This can help to establish a stronger foundation for more advanced scientific understanding of microbiology and related scientific concepts.

Limitations of the research

The study involved a small sample of 19 students from a single 4th-grade class in a Portuguese public school, which limits the generalisability of the findings. The lack of a control group makes it difficult to attribute any observed changes solely to the enquiry-based intervention, as other external factors could have influenced the results, although still providing valuable pedagogical insights. The assessments were only conducted immediately before and after the intervention, so long-term retention and conceptual understanding were not evaluated.

Future research

Future research with larger, more diverse samples and control groups is suggested to strengthen the validity of similar studies. Incorporating aspects of the Nature of Science (NoS) could further enrich and deepen the research.

Safety note

Reasonable care has been taken to ensure that articles in this journal do not suggest practices that might be dangerous. However, ASE has not tested the activities suggested and can therefore give no guarantee of safety. For further advice on health and safety matters in primary science education, see *Be safe! Health and safety in school science and technology for teachers of 3- to 12-year-olds* (4th edition, ASE, 2011), or contact CLEAPSS (or SSERC in Scotland).

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Exploring teachers' beliefs, inquiry pedagogy and pupil agency in practical inquiry-based science

Sally Howard

Abstract

This paper shares my recent PhD research on how teachers in England understood and taught practical inquiry-based science (IBS), using mixed and multiple methods, including anonymous questionnaire and case-based study. It highlights gaps between teachers' positive views of IBS and their teacher-led practices. Findings indicated that curriculum and testing demands limit pupil decision-making and open-inquiry opportunities, particularly in lower secondary lessons. My study suggests revising curriculum policies, providing targeted teacher professional development, and offering clearer guidance to support more effective IBS implementation through dialogic opportunities.

Introduction

After the Rocard Report (2007), European initiatives focused on promoting inquiry-based science education and 21st Century skills (Ananiadou & Claro, 2009). Furthermore, as global change accelerates, education systems must better equip pupils with relevant skills for the future (Abd-El-Khalick, 2012; Bocock, Sharp & Ritchie, 2025; Dawson, Venville & Donovan, 2024; OECD, 2022). These key skills include critical reasoning, problem-solving, collaboration and autonomous thinking.

Inquiry-based science (IBS) teaching includes developing these skills, which has long been promoted internationally, and also a means to enhancing pupils' engagement in school science, understanding the nature of science (NOS), fostering high degrees of scientific literacy, and nurturing essential capabilities for future citizenship and employment (e.g. Bächtold, Cross & Munier, 2024; Capps, Shemwell & Young, 2016; Furtak *et al*, 2012; NRC, 1996, 2000, 2013).

IBS has been and continues to be central to many educational reforms (Anderson, 2000; Tang *et al*, 2020). In England, inquiry (enquiry) has featured in England's National Curriculum since 1989 (DfEE, 1989) and remains integral through the current 'Working Scientifically' strand (DfE, 2015) of the national science curriculum.

Effective IBS is frequently misunderstood and not well integrated into classroom practice (Morris, 2025). IBS is complex and not just an investigation or a practical activity. For example, 'inquiry IN science' is considered an instructional approach to developing an understanding

of specific science content by the end of the activity. 'Inquiry ABOUT science' relates to pupils undertaking the process of inquiry as a means to better understand the tentative nature of science (NOS) and to build knowledge while developing inquiry-based skills and competencies (Capps & Crawford, 2013). Therefore, IBS is both a process and a way to understand science.

Inquiry-based teaching can be categorised by levels based on where the locus of control lies. This ranges from teacher-centred, closed inquiry at one end of the spectrum to child-centred, open inquiry at the other (Minner, Levy & Century, 2010; Wenning, 2007; Tafoya, Sunal & Knecht, 1980), with many opportunities for pupils' decision-making.

Drawing on the Next Generation Science Standards (NGSS) (2013) documentation, Crawford (2014, p.515) proffers the following definition of inquiry teaching, upon which my research drew: *'Engaging students in critical thinking skills, which includes asking questions, designing and carrying out investigations, interpreting data as evidence, creating arguments, building models, and communicating findings in the pursuit of deepening their understanding by using logic and evidence about the natural world.'*

My research examined the perspectives and practices of inquiry-based science education among upper primary (UP) (ages 10-11) and lower secondary (LS) (ages 11-12) teachers in England. The process and findings may also be relevant to early years and all primary and secondary age groups.

Research questions (RQ)

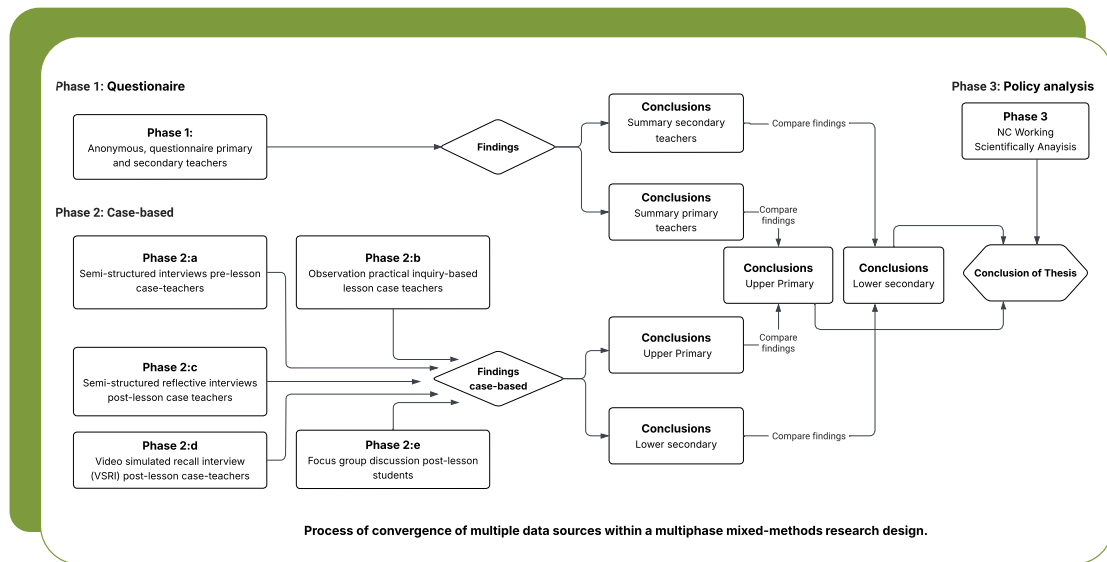
- RQ1:** What are the differences and similarities in the ways that upper primary and lower secondary teachers in England:
- (i) understand practical inquiry-based science?
 - (ii) enact practice to support practical inquiry-based science in their classrooms?
- RQ2:** How do science teachers in upper primary and lower secondary classrooms in England describe, set up and support students' decision-making opportunities in practical inquiries?
- RQ3:** How do students' reported experiences of decision-making opportunities within practical inquiries compare with their teachers' stated intentions and reflections?
- RQ4:** How far can the National Curriculum policy documents for working scientifically help explain similarities or differences observed in upper primary and lower secondary classrooms?

Methodology

I adopted a complex mixed-methods study (Tashakkori & Creswell, 2007, p.4), which had multiple phases, multiple data sets and drew on multiple frameworks for analysis. This multi-phase research design enabled a degree of comparison between and across teachers in UP and LS.

My research was grounded in a constructivist interpretive stance, recognising the multiple realities of educational practice and drawing on both quantitative and qualitative tools to gather data and analyse. Verbatim transcripts from each interview and focus group discussions were analysed using multiple frameworks to indicate where pupil decision-making opportunities arose or where missed opportunities occurred.

▼ **Figure 1.** Showing the convergence of each phase.



Phase 1 involved a questionnaire distributed to numerous UP and LS teachers through a range of gatekeepers, such as science subject associations, and initial teacher training establishments across England. Sixty-six teachers met the criteria for inclusion in the study. The questionnaire was anonymous and gathered data on the year group whom they taught most, these teachers' beliefs, perceived benefits, and challenges related to IBS, along with their understanding of curriculum expectations for 'Working Scientifically'.

Phase 2 involved four primary Year 5/6 (age 9-11) case teachers and three secondary Year 7 (age 11-12) case teachers, who had volunteered from across three counties in England. In addition, a small group of pupils from each observed lesson was involved in a focus group discussion. Each case teacher worked in different geographical and socio-economic areas, serving pupils with varying needs. This provided a wide lens through which to consider patterns and themes within this group of teachers, rather than seeking generalisability (Tight, 2017, pp.31-33).

Each volunteer teacher needed to meet the following criteria:

- Currently teaching science to upper primary, i.e. Years 5-6, or lower secondary, i.e. Year 7, in England;
- Using the statutory National Curriculum Working Scientifically objectives (DfE, 2015) within their school's schemes of work; and
- Be willing to be observed teaching a practical inquiry-based science lesson of their choice within their normal school programme of science.

The teachers in my study illustrated the transition year groups from upper primary to lower secondary schooling.

Besides interviewing teachers, focus group discussions with pupils, and observing classroom practices, the English science National Curriculum documents for Working Scientifically were also scrutinised to assess how policy advice might orient practice guidance. This is relevant when considering the need to foster a coherent programme of science education across compulsory ages of upper primary to lower secondary (Ofsted, 2015, 2023), along with the importance of teachers designing positive and relevant experiences of practical science for the children (Abrahams & Sharp, 2010; Murray & Reiss, 2012).

Phase 3 involved a document analysis of 'Working Scientifically' in the primary and secondary policy documents. I drew on both inductive and deductive approaches to compare and contrast the two policy documents.

The term 'inquiry' (enquiry) is used in the research questions instead of 'investigation' to reflect the complexity of practical inquiry-based science and the varying levels of teacher and pupil control involved. While the UK spelling 'enquiry' was used in teacher questionnaires and participant documents, to align with the National Curriculum, the internationally-recognised spelling 'inquiry' is adopted throughout this paper, as it is increasingly being recognised even in the UK.

“The term ‘inquiry’ (enquiry) is used in the research questions instead of ‘investigation’ to reflect the complexity of practical inquiry-based science and the varying levels of teacher and pupil control involved.”

Frameworks for analysis

The various frameworks used for analysing the multiple data sets included Robin Alexander's (2006) teacher talk types, Suarez *et al's* (2018) framework to determine where student agency might arise, and Tafoya, Sunal and Knecht's (1980) typology to help determine the level of inquiry being described by the questionnaire teachers and observed in the case-based teachers' lessons (see Table 1). This typology can be easily utilised across all stages of school education.

▼ **Table 1.** Levels of inquiry (adapted from Tafoya, Sunal & Knecht, 1980).

	Type of inquiry	Question/problem provided by	Procedure designed by	Solutions determined by
1	Confirmation	Teacher	Teacher	Teacher
2	Structured	Teacher	Teacher	Student
3	Guided	Teacher	Student	Student
4	Open	Student	Student	Student

Drawing on multiple datasets strengthened my findings and provided an opportunity for a degree of triangulation.

However, limitations are recognised through the self-selection bias among questionnaire respondents and volunteer teachers in the case-based phase, along with time constraints on classroom access, and the challenge of capturing real-time pupil collaboration and argumentation during practical lessons is acknowledged.

A further limitation could be argued as researcher bias in the approaches undertaken to analyse, or the choices made when reporting findings. However, the high level of description gathered through the verbatim transcripts of interviews and the audio from the observed lessons provides a reasonable degree of transparency and trustworthiness in the findings and conclusions that I have drawn. I do not argue that findings are generalisable to the broader population of teachers, although this does not mean they are not. Generalisability was not the focus of my study.

Results and analysis

Teacher beliefs vs. classroom reality

While both UP and LS teachers expressed support for IBS and described it as enjoyable and beneficial for pupils, observed lessons revealed a significant gap between teacher intention and practice in terms of pupils' decision-making experiences and their learning of science.

In practice, most lessons were teacher-directed, with limited pupil agency or opportunities for critical reasoning and reflection. Teachers retained control over key decisions, particularly during the conclusion and evaluation phases of inquiry, a pattern consistent with previous research (Abrahams & Millar, 2008).

A lack of conceptual clarity was identified, such as the teachers commonly using terms such as 'experiments', 'investigations' and 'inquiry' – all being used interchangeably as if they were synonyms.

More child-centred approaches were indicated by the UP teachers in both Phase 1 and Phase 2, such as involving pupils in raising their researchable questions, and showing greater willingness to allow pupils to explore open-ended questions. UP teachers planned their IBS over a series of lessons compared to LS, where the focus was on developing science knowledge within a single 'stand-alone' lesson. Most LS practicals were structured or guided inquiry, with fixed outcomes and limited pupil choices. However, even in these UP settings, opportunities for pupils to engage in dialogic exchanges, critically interpret data, or collaborate meaningfully were limited.

Lesson observations in UP and LS showed limited teacher scaffolding to develop pupils' skills in evaluating evidence or engaging in scientific reasoning. The emphasis, especially in LS lessons, was on task completion, rather than reflection or justification of findings. Opportunities for dialogic talk, cognitive challenge and cognitive engagement were minimal, particularly during the plenary aspect of the observed lessons. This suggests that, despite positive beliefs about the learning potential for pupils, IBS pedagogical enactment often draws on traditional teacher-directed instruction.

Pupils' perspectives on inquiry and decision-making

Pupils in both UP and LS settings reported enjoying practical science lessons more than their other science lessons and indicated that their teachers made most decisions. LS pupils particularly viewed teachers as the experts responsible for safety and accuracy, reinforcing a perception of science as a dangerous, risky experience. These findings highlight a disconnect between pupils' roles in IBS and the aims of inquiry pedagogy, which promotes greater learner autonomy and ownership of the investigative process, including data analysis.

The limited dialogic talk and argumentation in observed lessons suggest that opportunities for collaborative sense-making (which is crucial to developing scientific reasoning in IBS) were curtailed. Pupils often worked in groups for logistical reasons rather than to engage in structured collaborative thinking.

Focus group interviews revealed that pupils were not taught how to discuss, question, or critique evidence effectively. This suggests a need for the explicit teaching of discussion and argumentation skills, which concurs with recent findings that many pupils struggle with effective communication in group settings (Mercer, Hennessy & Warwick, 2025).

Interestingly, Year 7 pupils often reported that they had done little science in Year 6 due to a lack of 'labs' and 'bunsen burners' and a high focus on SATs preparation and statutory testing.

The UP teachers also stated that there was a reduction in time for practical science teaching in Year 6. This might adversely impact science learning and inadvertently reinforce a view that science is factual and test-driven. It also indicates a missed opportunity for using IBS to maintain curiosity and build foundational skills necessary for effective transitioning to a secondary science curriculum.

Curriculum policy and transition challenges

Analysis of the two 'Working Scientifically' (WS) curriculum policies shows inconsistencies in vocabulary and terminology, and a lack of clear progression guidance, which likely disrupts continuity between primary and secondary education.

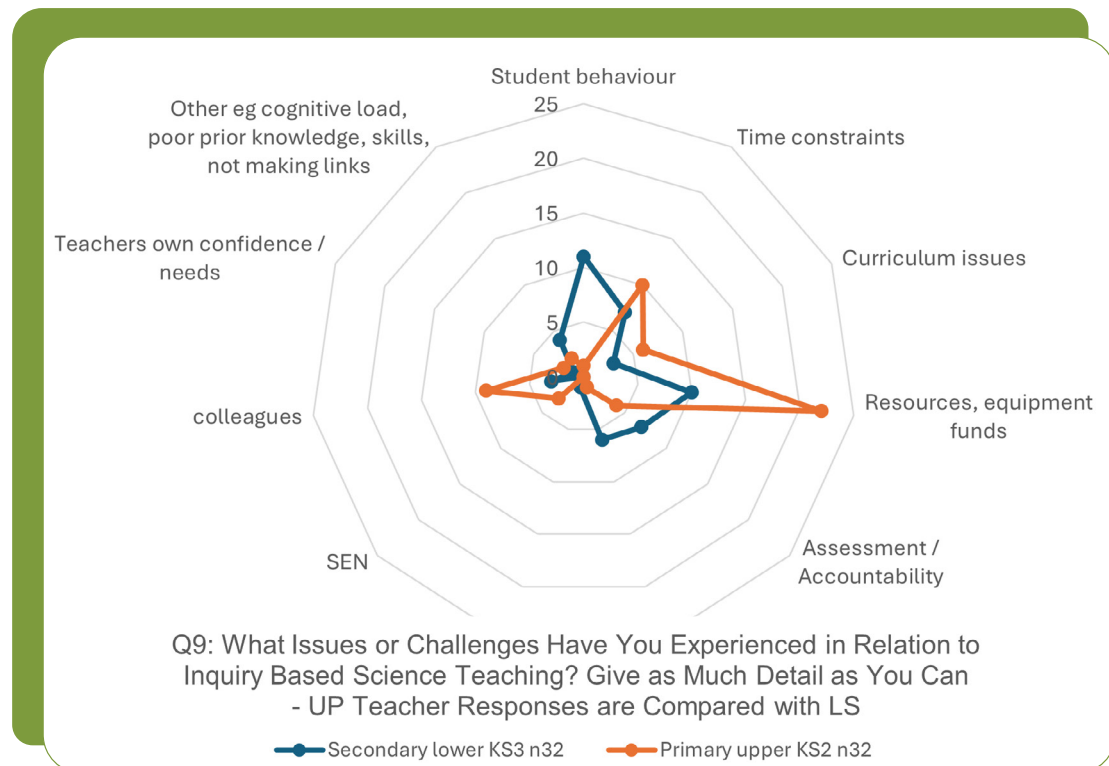
While teachers in primary phases are trained as generalists, they do have science training and have supplementary guidance in the Key Stage 2 (ages 7-11) WS documents. However, LS teachers, although subject specialists, often need to teach outside their degree expertise, yet their policy document has no equivalent non-statutory guidance to support their enactment of WS. Teachers involved in both phases of the research indicated awareness of WS expectations for their respective year groups, but had limited understanding of adjacent key stages. This limited familiarity may result in challenges with curriculum alignment during classroom instruction, particularly for LS teachers who are expected to build on content taught in UP.

All teachers reported pressure to cover the science curriculum, and heavy assessment requirements hinder practical science and IBS practice. LS teachers especially identified high-stakes testing and curriculum demands as ongoing barriers to open inquiry (Quick, 2024).

Issues and challenges in relation to IBS

In Phase 1, UP teachers cited their biggest challenge with IBS as a lack of resources. In contrast, LS teachers cited poor student behaviour (see Figure 2).

▼ **Figure 2.** The issues and challenges of IBS: UP and LS teachers' views compared.



Harlen (2013) and Furtak *et al* (2012) argue that inquiry practices improve science learning outcomes, but that implementation is frequently undermined by curricular rigidity and assessment pressures (OECD, 2018). Abd-El-Khalick and Lederman (2000) emphasise that understanding the NOS is essential for scientific literacy, yet this is often neglected in inquiry-based lessons, which focus too much on data collection and results tables without the critical reflection needed from raising a question to reviewing evidence. Furthermore, Anderson (2002) and Crawford (2007) highlight the importance of teacher knowledge about different inquiry levels and the importance of learner agency. My findings align with the extensive international literature highlighting the affordances and constraints of IBS pedagogy (e.g. Strat *et al*, 2023; Tao & Chen, 2024). In addition, without explicit policy guidance and training support for teachers, the crucial elements of pupil agency and cognitive challenge, essential in effective IBS, will remain under-exploited in classroom practice.

Professional development needs

My research findings suggest that effective implementation of IBS requires professional development for teachers that extends beyond technical knowledge or single workshops. Effective IBS is complex, and professional learning is more likely to be successful when incorporated into initial teacher training and maintained (Crawford, 2000, 2007) as a component of continuous professional development (CPD).

Effective CPD should include:

- Opportunities to experience inquiry-based science pedagogy as learners themselves;
- Structured reflection time on practice, including video-stimulated dialogue; and
- Peer collaboration and mentoring within communities of teacher practice.

Teachers also deserve support to develop the dialogic competencies necessary for facilitating greater frequency of open-ended inquiries. This involves training in questioning strategies, feedback techniques, and managing cognitive conflict. Without this, even well-intentioned IBS lessons can revert to procedural activity.

My study supports a model of CPD that is locally led but nationally supported, enabling teachers to integrate inquiry skills progressively and align them with curriculum goals. A national strategy should consider developing communities of practice of teachers across schools who can model, mentor and help embed inquiry-based pedagogies across departments and phases.

Policy recommendations

To better support inquiry-based pedagogy, national curriculum policy should:

1. Clarify terminology related to practical science, distinguishing between types of inquiry, experiments and demonstrations.
2. Provide explicit progression pathways for inquiry skills and IBS principles from Key Stage 1 (ages 5-7), Key Stage 2 (ages 7-11), to Key Stage 3 (ages 11-14).
3. Include glossaries and exemplars to support teachers' understanding.
4. Reduce the over-emphasis on content coverage, linked to high-stakes testing.
5. Introduce expectations for dialogic practice and argumentation as part of scientific inquiry and understanding the NOS.

Enhancing curriculum policy with constructivist approaches and emphasising process skills and pupil agency should help to bridge the gap between policy directive and classroom practice. Additionally, inspectorate frameworks should recognise and support inquiry-led teaching that promotes skills development and depth of understanding over curriculum coverage.

Reflections

Effective IBS is recognised as complex, requiring adaptable pedagogies, coherent policy support and sustained professional development. The teacher's role is not as a passive observer but an active partner with a shift from that of a 'knowledge giver' to a facilitator (Crawford, 2000) who promotes active engagement at a cognitive level and pupil decision-making. A greater degree of dialogic interactions would mirror the practices of professional scientists. In doing so, pupils become more agentive and work collaboratively, leading to deeper learning and greater engagement with school science (Tao & Chen, 2024; Tang *et al*, 2020).

The findings from my study resonate with current calls for educational reform, including the current curriculum review in England, to reduce the amount of content. There is an opportunity to highlight the relevance of inquiry-based principles and pedagogy in preparing pupils for the challenges of the 21st Century. This is not suggesting that there is no place for direct instruction. It is suggesting a better balance, where the focus is on pupil understanding of science knowledge and process skills, with high degrees of pupil engagement.

Although the study teachers were enthusiastic about practical IBS, they often lacked a full understanding of IBS pedagogy and aims, which likely contributed to missed opportunities for pupils' decision-making and critical reasoning. Pupils greatly enjoyed inquiry-based science, but were unclear about their roles and how these might differ in other science lessons that they might undertake.

My findings suggest that a shared understanding of the core principles of IBS, and explicitly indicating how it differs from other practical science activities, is needed, rather than a unified single definition.

Future research directions

Further research is needed in the UK and could explore:

- A longitudinal study of IBS implementation across the transition phases of UP and LS;
- Pupils' experiences of IBS and their perspectives on their role, including making decisions, leading their inquiries and reflections on their learning;
- Effective models of inquiry-based CPD across different school contexts and pupil ages; and
- The impact of school leadership and culture on supporting teachers and sustaining inquiry practices.

There is scope for comparative international research examining how different systems support or constrain inquiry-based teaching and how continuity is supported across different key stages.

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Equity, Diversity and Inclusion – Needing ‘to see it to be it’ is an over-simplification



Kulvinder Kaur Johal

Abstract

Equity, Diversity and Inclusion (EDI) has been centre stage for many years now. We are regularly told that we need ‘to see something to be it’, i.e. we need visible role models. Raising awareness of the importance of role models was a good EDI starting point, but there is much more that needs to be considered. This paper discusses the importance of relevant role models, as well as the aspects of role models that people may not think about. It is not enough to just have role models who we look like, but we also need role models who we sound like, or who have the same background. We will discuss the origins and journey of the creation of a free EDI online resource, ‘A Scientist Just Like Me’ (ASJLM), which seeks to go beyond the standard framing of a role model and takes a more in-depth approach.

Keywords Equity, Diversity, Inclusion, primary science, role models, accents, EAL, science capital

Introduction

As teachers, our main role is to teach, educate and nurture the children in front of us. The aim of that teaching and nurturing is for those children to go on in life and make a positive mark for themselves in the wider world. In a primary setting, we need to widen our children’s aspirations, find ways of inspiring, motivating and giving them options. Most of us who have been in the classroom can think of several children who wanted to be footballers, YouTubers or social influencers, as the study from Padwick *et al* (2020) describes. These are careers that children are more familiar with, therefore we need to build in an awareness of the wider working world and a greater variety of the roles that are out there.

My teaching career started in a very large multicultural school. There were high pupil premium numbers (a disadvantage measure in England), with most children living in an area of social economic deprivation in densely populated high-rise flats, and 92% identified as having English as an additional language. The aspiration of many children when I first arrived at the school was to become pregnant by 16 so that they could gain access to a council flat. This was typical of the London borough in which I worked during the 1990s. As the population of the school has diversified, so too have the aspirations of the children changed. As a senior leader and new science leader, I felt that it was important that children saw a range of role models in a range of careers. We started by sharing posters across the school of various prominent STEM males and females, such as Neil Armstrong and Katherine Johnson. As the staff shared a range of different science careers with the children, the children began to wonder whether these were careers that were actually possible for them. Many had not heard of these careers, or hadn’t known of anyone working in these jobs. Those role models were not visible to the children, parents and teachers. This was highlighted in *The 10 Key Issues with Children’s Learning in primary Science in England* report (Bianchi *et al*, 2021). For many children, the example of a working parent had not been visible, so the concept of parents going to work and having a wage or salary was unfamiliar to many in this context.

“It is a great feeling to hear a nine-year old child look up at you and say, ‘Miss, I’d like to be an astronaut, can I be an astronaut?’ As teachers, we want to validate and recognise that response, and my gut reaction was to reply with ‘Yes, you can’”

It was, and is, important to demonstrate a range of careers within the STEM fields with young children and to share a range of role models (Trew *et al*, 2020). It is a great feeling to hear a nine-year old child look up at you and say, ‘Miss, I’d like to be an astronaut, can I be an astronaut?’. As teachers, we want to validate and recognise that response, and my gut reaction was to reply with ‘Yes, you can’. This was something repeated in many classrooms as children became aware of the roles of mechanical engineers, chemical engineers and other scientists, through science lessons, wider reading opportunities, science trips and various enrichment activities. Our children were meeting, talking and linking with scientists using Google Hangouts, and *Skype a Scientist* (offering a choice of scientists from a database and arranging a time to chat).

Research has found that children decide whether science is ‘for them’ by the age of 10 (Godec *et al*, 2017). There continued to be a group of children wanting to be social influencers and footballers but, because of the raised profile of science, there was also a growing group of children who were really hooked onto science, loved science, wanted to choose science for a career and wanted to know what their options were, even as young as 10 years old.

We looked outside for role models in the real world: scientists from a range of ethnicities and who spoke other languages. How could we find role models who the children could relate to? In a recent study from the British Science Association, Only 12% of young people believe that scientists genuinely represent their views and values (<https://www.britishsociety.org/news/new-findings-young-people-feel-about-science-society-future>). Only 8% believe that scientists look like them, which reiterates a perceived and actual lack of representation in science.

It was only after leaving the classroom that I had the headspace and time to think about what we could do for those children who wanted to be involved in a STEM career, but could not see themselves or others like them in that role, so they could not place themselves up there. For them, it was not achievable because it was a step too far for them. Because – it is very true, if you cannot see it, you cannot be it. So the children could not envisage it. They could compete with children of their own age and they could emulate and revere adults who they could see and hear on the television or electronic devices, but they did not see themselves fitting into certain spaces as they had not seen anyone like them in the STEM space.

What we did about it

As part of my role at the Primary Science Teaching Trust (PSTT), we had an idea to create a resource that showcases diverse role models and widens the reader’s career knowledge. Experienced teachers and school leaders have, for many years, struggled to find these role models for their students. The English National Curriculum (DfE, 2013) mentions several scientists, the majority of whom are dead, white men. Although giants of the science world, we should not be limited to studying or looking up to those unreachable, extraordinary scientists.

So, here came the creation of the PSTT resource, *A Scientist Just Like Me* (ASJLM, website below). By this point, almost 30 years into my teaching career, I knew of a few scientists who were not that stereotypical lab coat-wearing, white, British male. But those scientists I could name on one hand. So, we sought out scientists who were living and were potentially contactable. We looked for scientists ideally from within the UK, so that children would feel that they were nearby and accessible, to a degree.

“We sought to create a database of scientists who were diverse in the sense of gender, ethnicity, neurodivergence and sexuality. Each scientist completed a profile, in which they shared what they liked to do at school and in their leisure time, so that children could relate to them.”

Seeking out living, current role models proved to be quite challenging. The easiest group to connect with were white female scientists in the UK. It was harder to find diverse scientists based on sexual orientation and neurodivergence and also physically impaired scientists. In some instances, we did have to look overseas where scientists were more open and confident in sharing such personal information about themselves and had a social media presence. By far the most challenging group to connect with were the black, male scientists. This actually took years rather than months. The challenges facing this group in particular have been reflected in several reports, for example, from the Royal Society of Chemistry (RSC, 2022a, 2022b) and Gibney (2022). In 2018, Professor Robert Mokaya discovered that he was the only black chemistry professor in the UK. For a decade, he had assumed that there were others whom he hadn’t met — until investigations by the RSC revealed his lonely status (Gibney, 2022).

We sought to create a database of scientists who were diverse in the sense of gender, ethnicity, neurodivergence and sexuality. Each scientist completed a profile, in which they shared what they liked to do at school and in their leisure time, so that children could relate to them. The scientists then went on to describe what their job entails, what they enjoy about their job and, importantly, they discussed what their job has to do with the wider world, connecting the role to our lives. There is also a section on challenges that the scientists have faced, which is very important to ensure that children can appreciate that life is not always a straight line; there are bends, curves and even steps backwards, before you get to your designated career point. Lastly, scientists discussed key skills required in order to do this work.

▼ **Figure 1.** An example of a scientist’s profile: Dr. Kelsey Byers, Evolutionary Biologist.

A Scientist just like me



Dr Kelsey Byers
Evolutionary Biologist



A Scientist just like me

Hi there! I am Dr Kelsey Byers – an evolutionary biologist



Where do I work?
I work at the John Innes Centre in Norwich where I study how the smells of flowers (both nice and not so nice!) affect plant evolution and pollination.

What did I like doing when I was at school?
I have wanted to do something with nature my whole life. I originally wanted to be a vet, but realized I liked biology a lot and now I study it.

What do I like doing in my spare time?
I love birdwatching, looking at insects, trees, and flowers, cooking and baking, and reading books. Anything where I can explore the outdoors is fun for me!

A Scientist just like me

What do I do as an evolutionary biologist?



I collect smells from different flower species and try to understand them: what kinds of smells are there, how they are made in the flower, and how insects can smell them. I also try to understand how related groups of flowers are related in their smells.

How does what I do make the world a better place?
Understanding how flowers smell is important for a couple of reasons. Firstly, it can help understand how new species come to be. Secondly, many fruits and vegetables rely on pollinators like bees, and we want to help farmers by understanding why bees prefer certain flowers.

A Scientist just like me

What I like about my job

I love that I can come up with a cool idea and test it! I also get to be in a variety of places - my lab, the glasshouse, and outdoors in the field. I am a very curious and passionate person and I get to use these which is great.



Challenges I have faced

I am disabled (I use a wheelchair) and sometimes my co-workers think I can do less than I really can, for example they might think I can't do work outdoors. This isn't true - everyone's abilities are different, and I can do a lot more than people sometimes think.

A Scientist just like me

If you want to be an evolutionary biologist, you need:

- to be a very curious person - someone who is constantly asking themselves questions about how things came to be like they are in nature and why.
- to enjoy looking at plants and animals and to think about how they fit into their environment.
- to be interested in nature and the natural world.
- to enjoy coming up with new ideas.




A Scientist just like me

Discussion time

- Would you like to be an evolutionary biologist like Dr Kelsey Byers?
Why? Why not?
- What skills and interests do you already have that would help you become an evolutionary biologist?
- What new skills and knowledge would you need to develop?



The process of creating the resource involved the scientists completing forms and sending in photos that were then formatted to produce the resource seen in Figure 1. With some additional funding, we were also able to add videos, to really bring the scientists to life. The resource is ever-expanding and currently holds 130 science profiles and 12 videos – all freely available on the PSTT website.

Practice – how teachers are using ASJLM

Teachers have been using ASJLM as a starter activity or as an introduction to a new topic in science. They can then introduce a career related to that element of science. For instance, when teaching the topic of space, a teacher could focus on Emily Rickman, an astrobiologist, or Professor Helen Mason, a solar physicist.

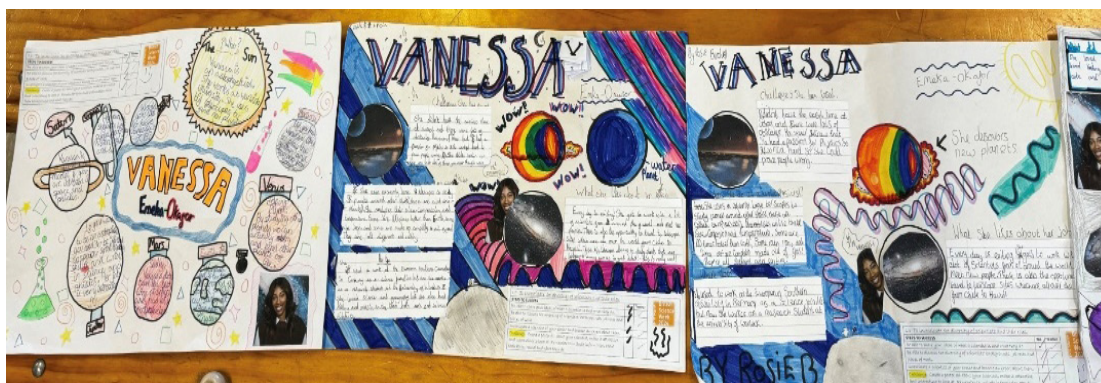
Some teachers have been using the resource as a guided reading activity whereby a small group of children read through the resource as a group. Some teachers are using it as a whole-class reading activity, so making it a shared experience for all the children. Examples and feedback from teachers who have used the resource are included in Figure 2 and the text boxes below.

▼ **Figure 2.** Examples of teacher feedback about using the resource.



"School science display board - I use a featured scientist and have an area for a pupil to be our school scientist."

"I used the slides as a display and my class loved it. I chose examples where it was either linked to topic or if one of them had a hidden disability like dyslexia so the children could see they were still able to have success. I love this resource. We would also have a class discussion about each one before they went up - really helped with science capital."



“I’ve used them as a research tool at the start of science week. They had time on iPads deciding which scientist they would like to be. Then made a name plaque for their desk with their job title on it. They shared why they chose that role.”

“I have used them in an assembly asking the children what all these people have in common (just used their photos to start with).”

“We have linked a scientist to each of our science units so the pupils can see a modern day scientist each unit. We made QR codes so the pupils can link directly to that scientist and read about them and learn about their work.”

Children can make posters, create fact files or collate questions to then ‘hot seat’ each other, pretending to take on the persona of the scientist.

As the scientists are alive and are accessible to a degree, some teachers and parents have taken it upon themselves to reach out to these scientists and provide opportunities where the scientists can use Zoom or Teams to link with the classroom and talk to the children in real time. Students are also able then to ask questions and have them answered directly by the scientist in question. An example is given in Figure 3.

▼ **Figure 3.** An example of a message from a scientist about being invited into school.



“I received the most wonderful email the other week! A teacher from a local primary school asked me if I could pay a visit because the students have been studying me for two weeks. This is so surreal – I feel so blessed to be able to inspire and share my passion for astronomy!”

“I should mention in addition to the virtual visit I got a thank you from the parent of one of the students, who found my Twitter account and reached out that way...”

Discussion: It’s not just what you see...

When creating this resource, which now features over 130 scientists, there were some key points for reflection. It was, and is, important for us to see a wide range of role models in all careers and we needed to see representation. When we created the ASJLM videos, we began to consider the various accents and dialects that we were hearing. Certain accents are not regarded as prestigious and indeed are frowned upon (Sharma *et al*, 2022). To be fully representative, we felt that we needed to be hearing a range of different accents in the resources too. In this way, children listening to the scientists could see that they not only looked like them, but also sounded like them. That sound, that dialect, that accent makes you realise that this person, this scientist has something in common with you – they come from where you come from.

“To be fully representative, we felt that we needed to be hearing a range of different accents in the resources too.”

Accents and geographical representation became an important consideration whilst listening to a group of female chemists at Burlington House in London. We identified them as having Birmingham accents and immediately we were familiar with where they had come from and could associate them with a geographic setting. This led us to then consider geographic diversity. We often hear about a north-south divide in England, referring to socio-economic advantages, improved access and opportunities perceived in southern UK, partly because London and the UK government are based there, and also about areas of social economic deprivation being predominantly in the north. We realised that we needed to find scientists from across the four nations of the United Kingdom. We need children to understand and appreciate that science is happening near them and they need to know that they have options, and those options could be down the road, within the local town, but they could also be further afield, or even overseas.

How diverse can the resource be?

There are three conversations that come to mind in this instance. The first occurred at the very onset of creating the resource, when we discussed sexuality. Our question was: should we be having sexuality as a filter? For a predominantly primary-aged resource, our initial feeling at that point was yes, because we teach about diverse family grouping as part of the primary curriculum and this is very much a lived experience for some of our students. We stand by our initial feelings around why diversity is important and, if we are honouring diversity in the truest sense, it must be in the widest sense and include all parts of society. In the same way, there was another conversation with several white male scientists. A few asked about whether they were allowed to be a part of this resource as we were working on breaking stereotypes. This surprised us, as this resource is about including everybody and not about excluding anyone. The older scientists and the white male scientists who got in touch were told that, of course, we wanted to include them in our resource and we wanted to show a balance. Is there a limit on being diverse? No, by definition there cannot be, as every individual is a part of and makes up that diverse group.

Does seeing it make a difference?

Emphatically yes. Many of the scientists with whom we have been in touch said that they wished they had had a resource like this when they were younger. One of the teachers in an additional learning needs unit stated that children were so emotionally touched and heartened to see a

wheelchair-using scientist like them, and whose words resonated with them. The teacher said that the scientist gave them hope and inspired them. Another parent emailed:

‘Back in British Science Week this year, my daughter’s school had some of its (Year 4, age 8-9) pupils choose A Scientist Like Me video to watch. My daughter came home and wanted to watch more, so we watched all of the available videos together. These have further piqued my daughter’s interest in science and she is now saying that she wants to become an immunologist. As a scientist/engineer myself, this is of course pleasing to hear.

I would just like to thank you for putting this scheme together. As you can see, it can have a lasting impact.’

Seeing role models has begun to make a difference, but this is just the start of the journey, and it is a long road that we are walking down. Teachers are now able to find, access and even welcome scientists into their classroom, in person and virtually. Children are beginning to see scientists as real people, accessible people, hence making those careers seem achievable and accessible. This is not to say that we want our children to all be scientists, but they should have a choice, they should have options and have a clear picture of the varied roles in the science world. There is change and it is visible in the primary classrooms that I visit locally. We will need to watch further along the pipeline to see whether changes are seen for older children.

There is hope, there is positivity and there are smiling, relatable faces who inspire us all.

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Fostering critical thinking in primary science through ‘What if...’ scenarios

A Year 5 classroom study in an independent all-girls school

Layla Hewitt

Abstract

This practitioner study investigates the use of ‘What if...?’ scenarios as a strategy to promote critical thinking in Year 5 (ages 9-10) science lessons at an independent all-girls school (Reception – Year 11). The intervention was framed by enquiry and discovery learning theories (Bruner, 1960; Harrison & Howard, 2022). It drew on pedagogical strategies from ‘Thinking, Doing, Talking Science’ (TDTS), a primary science teaching approach that emphasises structured dialogue, hands-on exploration and reflective questioning as drivers of critical reasoning (Hanley *et al*, 2020). The findings from this study aligned with outcomes from TDTS research and indicate that ‘What if...?’ questions are a low-resource, high-impact tool for developing scientific thinking within tight curriculum timescales. Implications for practice include their scalability for teaching other science topics at Key Stage 2 (ages 7-11), alongside recommendations to explore cross-curricular opportunities.

Over a six-week unit on forces and space, children engaged with weekly imaginative prompts (e.g. ‘What if gravity only worked at night?’). Responses were scored using a three-point rubric assessing predictability, reasoning and creativity. Results showed a clear progression from simple, predictable answers to diverse, well-reasoned and imaginative solutions. In addition, quieter and lower-attaining children displayed greater confidence and engagement over the six-week period.

Introduction

Critical thinking – the ability to evaluate evidence, construct reasoned arguments, and reflect on ideas – is a core skill for learners and practitioners alike (Facione, 1990; Elder, 2022). In education, and particularly in science, it extends beyond acquiring knowledge to engaging with enquiry, problem-solving and hypothesis-building. In the classroom, this means that children are encouraged not just to recall facts but to question, analyse and apply knowledge in new contexts, fostering deeper understanding and resilience in problem-solving. For teachers, embedding critical thinking underpins children being able to have effective judgement and communication, enabling them to question assumptions, weigh evidence and make informed, adaptable decisions.

Within my Year 5 class (ages 9-10) at an all-girls school, children demonstrated strong attainment in areas requiring memorisation and structured tasks, but were less confident in problem-solving and reasoning. Developing these skills is especially important for girls,

who, as research shows, may be less likely to take risks or contribute speculative answers in science (Kitmitto *et al*, 2018). During lessons on forces and space, many struggled to engage deeply with abstract or open-ended questions. Instead, they tended to rely heavily on teacher guidance and avoided sharing imaginative ideas. When looking for research-informed classroom resources to address this issue, I came across Explorify's *What if...?* scenarios (Leonardi *et al*, 2023) and an enquiry-oriented teaching approach, *Thinking, Doing, Talking Science* (Hanley *et al*, 2020).

Explorify's *What if...* scenarios

Explorify (website below) is a digital science teaching resource designed to foster classroom dialogue. Explorify's *What if...?* activities present children with imaginative, open-ended questions so that they can explore possibilities and explain their reasoning. Rather than seeking correct answers, these prompts encourage discussion, curiosity and creative thinking (Leonardi *et al*, 2023).

For example, questions such as '*What if humans could breathe underwater?*' or '*What if the Sun never sets?*' create space for children to hypothesise, draw on prior knowledge and justify their ideas. This approach supports:

- **Critical and creative thinking** – children practise connecting ideas, identifying consequences and reasoning through unfamiliar situations.
- **Oracy and collaboration** – activities encourage structured talk, listening to peers and co-constructing explanations.
- **Science capital and engagement** – children are given the freedom to see science as imaginative and relevant, building confidence without the pressure of being right or wrong.

In practice, *What if...?* scenarios provide a low-stakes but high-engagement opportunity to embed scientific thinking and develop children's communication skills, making them a suitable tool for fostering critical thinking.

Thinking, Doing, Talking Science (TDTs)

Thinking, Doing, Talking Science is a primary science teaching approach developed to raise attainment by making science more interactive, discussion-rich and conceptually challenging. It emphasises higher-order thinking, dialogue and hands-on enquiry to deepen children's understanding (Hanley *et al*, 2020).

Key features include:

- **Conceptual challenge** – encouraging children to think beyond recall and grapple with 'big ideas'.
- **Scientific reasoning** – developing skills such as predicting, hypothesising, testing and evaluating.
- **Dialogic teaching** – structured opportunities for children to articulate, justify, and build on each other's ideas.
- **Practical enquiry** – hands-on activities where children actively investigate and apply their thinking.
- **Creativity and imagination** – integrating playful scenarios, stories and thought experiments to spark curiosity.

To address the gap that I had identified during my teaching practice, I implemented a short intervention using Explorify's *What if...?* scenarios, integrated with strategies from *Thinking, Doing, Talking Science* (TDTs).

The intervention aimed to nurture curiosity, foster higher-order thinking and increase children's confidence when approaching unfamiliar or imaginative challenges.

The objectives were to:

1. Build children's scientific knowledge through imaginative questioning;
2. Encourage creative application of knowledge to unfamiliar contexts; and
3. Develop critical thinking through open-ended, dialogic exploration.

By embedding *What if...?* scenarios into the curriculum, I sought to create a supportive space for children to test out imaginative reasoning, while remaining aligned with statutory curriculum requirements.

Context and rationale

The project was conducted in a Year 5 (ages 9-10) class at an independent all-girls school, where I serve as both the class teacher and science/STEM lead. I had observed a significant gap in critical thinking skills within this cohort, particularly a reluctance to engage with problem-solving tasks and new questions.

Research from TDTs highlights the effectiveness of dialogic, exploratory strategies in enhancing children's engagement and confidence in talking about science (Kitmitto *et al*, 2018). Similarly, Explorify's *What if...?* scenarios are designed to provoke curiosity and encourage speculative reasoning by presenting hypothetical challenges such as '*What if humans could breathe underwater?*' or '*What if plants didn't need sunlight?*'.

These resources align with research by Minner, Levy and Century (2010), which suggests that engaging children in speculative reasoning enhances their ability to connect concepts and think flexibly – key components of critical thinking. By combining TDTs-inspired practices with Explorify's *What if...?* questioning, the intervention aimed to create an inclusive, dialogic environment where children felt empowered to explore imaginative possibilities.

Methodology

Research design

A mixed-methods approach was employed to capture both quantitative and qualitative data. This included:

- Pre- and post-intervention questionnaires (quantitative) (see Figure 1);
- Classroom responses to *What if...?* scenarios (qualitative);
- Rubric-based assessment of creativity and reasoning (quantitative and qualitative); and
- Teacher observations and reflective notes (qualitative).

This design allowed for a variety of data, providing a richer understanding of how the intervention influenced children's critical thinking.

Participants and setting

The study involved 19 Year 5 children (ages 9-10) at an independent all-girls school. The single-class sample provided a manageable group for close observation and individualised analysis, though the small size inevitably limited generalisability.

Intervention

The intervention took place over six weeks during the autumn term. Weekly science lessons on forces and space incorporated scenarios linked to curriculum content. Examples included:

- What if gravity only worked at night?
- What if there were two Suns?
- What if you had magnets for fingers?
- What if there was no Moon?

Each 15-20 minute session followed a consistent structure:

1. Introduction of the *What if...*? question.
2. Paired or small-group discussion.
3. Use of the Plus, Minus, Interesting (PMI) framework to structure responses.
4. Sharing and whole-class reflection.

I provided a PMI framework (see Figure 2) to help the children to focus their answers. Each pair had to read the *What if...*? question and think about a positive answer, a negative answer and an interesting way to answer the question posed. I also gave examples of more creative ideas to support the children's learning. I went through the examples at the beginning of each session after I had introduced the *What if...*? question. The PMI framework helped children to consider multiple perspectives, moving beyond surface-level answers to more thoughtful and reasoned responses.

Data collection methods

1. Baseline and final questionnaires (quantitative)

Children completed questionnaires at the beginning (4th November) and end (13th January) of the intervention. These measured confidence, engagement and attitudes toward reasoning, using multiple-choice questions. The aim was to capture changes in their confidence and attitudes toward critical thinking (see Figure 1).

▼ **Figure 1.** Critical thinking questionnaire.

Please put a circle around your answer.

1. When I have to solve a problem in science, I usually:

A) Think of only one way to solve it and stick to that.

B) Think of a few different ways and choose the best one.

C) Try to think of lots of different ideas, even if they are unusual.

2. When I am asked a "what if?" question (like "What if the Earth had two moons?"), I:

A) Find it difficult to come up with any ideas.

B) Think of one or two ideas quickly.

C) Think of many different ideas and possibilities.

3. How do you feel when the teacher asks questions that don't have a single correct answer?

A) Confused, because I like questions with only one correct answer.

B) Okay, but I find it hard to think of different answers.

C) Excited, because I like thinking of lots of possible answers.

4. When working in groups and solving problems, I usually:

A) Wait for others to come up with ideas before sharing my own.

B) Share my ideas, but only if I feel really confident.

C) Share all my ideas, even if they are unusual or not fully formed.

5. When I think about a problem or a new idea, I:

A) Mostly think about things I already know.

B) Sometimes think of new things I haven't learned before.

C) Try to imagine new possibilities and different outcomes, even if they seem a bit strange.

6. When you hear a science question that makes you think, like "What if we could live on Mars?", how do you usually feel?

A) A bit nervous, because I don't always know the answer.

B) Curious, but I only think of one or two ideas.

C) Excited, because I love imagining lots of different possibilities.

7. When you try to solve a science problem, do you:

A) Usually try to solve it the same way as everyone else.

B) Sometimes try different ways, but stay close to what I've been taught.

C) Always try to think of new and different ways, even if they are a bit unusual.

8. How do you feel about sharing creative ideas in class (like answering "what if?" questions)?

A) I feel nervous and don't like to share.

B) I feel okay, but only share ideas I'm sure are right.

C) I feel confident and like to share all kinds of ideas, even if they're not perfect.

9. When faced with a difficult science question, like "What if gravity disappeared?", I usually:

A) Find it too hard and don't know what to say.

B) Think of one or two answers and stick with them.

C) Think of different answers, even if they sound strange at first.

10. How do you feel when you are asked to think of many different solutions to a problem in science?

A) Frustrated, because I prefer just one answer.

B) A little unsure, but I try my best to think of a few ideas.

C) Excited, because I enjoy thinking of lots of different solutions.

2. Classroom 'What if...' scenarios (qualitative)

Written responses and discussions during the scenario work were collected and analysed. This provided insights into the diversity, creativity and reasoning within children's ideas.

▼ **Figure 2.** Plus, Minus, Interesting (PMI) framework to structure responses.

What if there was no Moon?		
Plus	Minus	Interesting
Example: Without the Moon, there would be no extreme tidal waves, making some coastal areas safer from flooding.	Example: The lack of the Moon would disrupt Earth's tidal patterns and possibly destabilize its axis, leading to chaotic climate changes and shorter days.	Example: Without the Moon, humanity might have developed different myths, beliefs, or scientific advancements based on observing other celestial phenomena instead.

Plus	Minus	Interesting

3. Creativity rubric (quantitative/qualitative)

Children's responses were assessed using a four-point rubric (see Figure 3):

- 1 = Needs improvement
- 2 = Developing
- 3 = Good
- 4 = Excellent

Criteria included originality, depth of reasoning and diversity of responses

▼ **Figure 3.** Rubric for creativity.

Rubric for Creativity Assessment				
Criteria	4 - Excellent	3 - Good	2 - Developing	1 - Needs Improvement
Originality of Ideas	Very creative and unique solutions that show deep thinking.	Creative ideas, with some unique solutions.	Some ideas are predictable or common.	Ideas lack creativity or are repetitive.
Number of Ideas	Provides 3 or more detailed solutions.	Provides 3 solutions with some details.	Provides 2 solutions or fewer, some details missing.	Provides only 1 solution, lacks detail.
Divergent Thinking	Solutions explore different directions and possibilities.	Some solutions are different, but others are similar.	Solutions are somewhat similar, not very diverse.	Solutions are very similar or repetitive.

Ethical considerations

The project was conducted as part of normal classroom teaching, with oversight from the school's Deputy Headteacher, therefore no separate parental consent was sought; however, the learning was referenced in their end-of-term reports. Children were given the option to withdraw at any time, though none chose to do so. Activities were adapted to ensure inclusion of children with learning needs.

Challenges and adaptations

Initially, many responses to the *What if...?* scenarios were predictable and lacked depth. To address this, I introduced scaffolding techniques (Wood, Bruner & Ross, 1976):

- PMI framework for structuring thought.
- Guided questioning to encourage multiple perspectives.
- Emphasis on imaginative 'thinking beyond the obvious'.

These adaptations proved effective, leading to more varied and thoughtful discussions.

Findings

Engagement and participation

From the first session, children were intrigued by the novelty of the scenarios. By week three, most children offered two or more plausible ideas per session. Quieter children and those with lower prior attainment became more willing to share ideas, showing improved confidence.

Creativity and reasoning

Rubric analysis showed steady improvement:

- Week 1: Most children scored 1–2 (predictable or simplistic answers).
- Weeks 4–6: Majority scored 2–3 (reasoned, imaginative responses).

Example answers from PMI:

In weeks 1 and 2, answers given were more simplistic:

Week 1 question – What if we used machines like this?

- 'It's fun to play with.'

Week 2 question – What if an astronaut gets thirsty?

- 'They have to come back to the space station to take off their spacesuit.'

From week 4 onwards, the answers given were more detailed and were definitely more connected with the knowledge that had been given in lessons

Week 4 question – What if you had magnets for fingers?

- 'If you had magnets for fingers, you could climb the walls like Spiderman.'

Week 5 question – What if there was no Moon?

- 'If there was no Moon, scientists might discover new ways to make light at night.'

Week 6 question – What if there were two Suns?

- 'If there were two Suns, people would have to invent ways to keep crops from overheating.'

Quantitative results

- Questionnaire data showed increased self-reported confidence in problem-solving.
- Rubric scores reflected a clear upward trend, with most children moving from low (10–15) to moderate (16–22) ranges across the six weeks.

This study investigated the impact of *What if...?* scenarios in Year 5 science lessons on children's critical thinking and creativity. Children completed a 10-question questionnaire (Figure 1) designed to assess different aspects of thinking. Questions 1–5 focused on imaginative idea generation, Q6–Q7 assessed collaborative problem-solving and flexibility in approaching science problems, and Q8–Q10 measured confidence in sharing ideas and generating multiple solutions. Specifically, Q6 evaluated emotional responses to challenging questions, Q7 measured the tendency to try new problem-solving approaches, and Q8 captured willingness to share creative ideas in class.

Quantitative analysis revealed an overall upward trend across the six-week intervention. Children increasingly selected responses reflecting higher-order thinking (C options) across most questions. On 13th January (the end of the intervention), scores were higher for imaginative and independent idea generation (Q2, Q5), but slightly lower for collaborative problem-solving (Q6, Q7), suggesting early challenges in group work that improved over time.

The creativity rubric supported with these findings. On 11th November (near the beginning of the intervention), 10 children scored 2 for originality of ideas, 8 children scored 3, while divergent thinking scores were spread across 1–3. By 12th December, more children achieved higher scores, with 12 children scoring 3 for originality of ideas, and divergent thinking scores increasing overall.

The number of ideas generated per scenario given also rose, demonstrating greater creativity and willingness to problem-solve. Observations supported these trends, showing a shift from teacher-dependent responses to more autonomous and collaborative engagement. Structured frameworks such as Plus, Minus, Interesting (PMI) helped children to organise and communicate their thinking clearly.

Overall, the findings indicate that *What if...?* scenarios, combined with structured support, effectively foster critical and creative thinking. Children became more confident in generating original ideas, considering alternatives, and exploring multiple solutions, showing measurable growth in cognitive flexibility and imaginative reasoning.

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Practitioner reflections

I observed that children became more curious and confident, eagerly sharing original ideas and exploring alternative possibilities during *What if...?* activities. Group discussions became more dynamic, though collaborative problem-solving and generating multiple solutions remained challenging for some children. Overall, I noted that structured scenarios effectively supported critical and creative thinking, enhancing engagement and participation in the classroom.

Conclusion

The findings from this enquiry showed that using *What if...?* scenarios in Year 5 science lessons supports Bruner's discovery learning theory by encouraging exploration and higher-order thinking, while also using strategies like PMI to scaffold children's ideas (Wood, Bruner & Ross, 1976).

The girls-only setting appeared to enhance children's willingness to take risks, echoing evidence that dialogic approaches are especially effective for girls in science (Hanley *et al*, 2020).

This approach was found to be sustainable within curriculum time and effective in fostering creativity, reasoning and confidence, particularly for quieter children. However, the small sample size, short timeframe and subjective rubric assessments limit the generalisability of the findings.

Overall, a majority of children moved from predictable answers to more reasoned and imaginative responses, with structured frameworks improving both depth and organisation. The study demonstrated that *What if...?* questions can significantly enhance critical thinking, creativity and confidence in science lessons, offering a resource-light strategy. Future research could focus on extending the *What if...?* scenarios to other curriculum topics, assessing longer-term impacts, exploring cross-curricular applications and providing differentiated scaffolding to ensure accessibility for all learners.

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Russell, T. & McGuigan, L. (2016) Exploring science with young children. London: Sage.

Chapter in book

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Journal article

Reiss, M. & Tunnicliffe, S.D. (2002) 'An international study of young people's drawings of what is inside themselves', *Journal of Biological Education*, 36, (2), 58–64

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