

Chapter 2: Misconceptions and enabling conceptual change in science

Chapter aims:

By the end of this chapter, you should be able to

- Challenge the conception that science is not a creative subject
- Examine your own conception of the nature of science
- Explain the theories which underpin conceptual change in children
- Develop creative strategies for challenging children's naïve conceptions

Introduction

Anecdotal evidence from years of working with trainee primary school teachers is that there is a well held belief that science is about learning facts, with clear right and wrong answers and is in stark contrast to 'creative' subjects such as art and music, where other attributes such as individuality, interpretation and aesthetics are valued. This is a belief that science education teaching teams challenge as their teacher trainees' progress through their modules on initial teacher education programmes. By the time they leave, we hope that we have provided them with enough evidence, the right opportunities to discuss and develop their ideas and a positive classroom environment to change this concept of science. In a way, this is the biggest challenge we face as a science educators.

We all know about Leonardo da Vinci, who is known the world round as both an artist and inventor. More recently, Brian Cox is known for his integral role in 'sexing' up physics and astronomy as well as being the keyboard player for 1990s band D:Ream. Here we have two examples of well-known accomplished scientists having a definite creative side too. And these

two are not alone! Brunelleschi was the architect who made the beautiful and magnificent cupola of the Florence cathedral and he was also recognised for using geometric principles in creating perspective. American computer scientist Jaron Lanier is best known for popularising the term virtual reality as a pioneer in the field. He is also an accomplished classical composer, film director and author. And Root-Bernstein (1987) has identified over 400 such examples. Additionally, it is reported by Root-Bernstein et al. (2008 p.54) that Nobel laureates in the sciences are at least a factor of 7 more likely to be a visual artist, sculptor, or printmaker; at least a factor of 7.5 more likely to be a craftsperson engaged in woodwork, mechanics, electronics, glassblowing; at least a factor of 12 more likely to write poetry, short stories, plays, essays, novels, or popular books; and at least a factor of 22 more likely to be an amateur actor, dancer, magician, or other performer than the average scientist. Einstein furthermore sums up the interplay of science and art by saying,

“After a certain high level of technical skill is achieved, science and art tend to coalesce in esthetics, plasticity, and form. The greatest scientists are always artists as well” (cited in Kaplan, 2001, p. 37).

Therefore, the notion that the sciences and the more creative arts subjects are polar opposites of each other needs to be challenged. This is a misconception which we hope to address throughout this book. It is not helped by a legacy of national documents, reviews and initiatives which further embed the connection between the Arts and creativity such as the Creative Partnerships Programme (CCE 2002) managed by Arts Council England, the Excellence and Enjoyment framework (DfES 2003, 3) which states “primary education is about children...being creative in writing, art, music” and the Independent Review of the Primary Curriculum (2009) which reported that “Both at home and abroad there is little dispute that a primary curriculum must

develop young people's...artistic and creative development". 'Understanding the Arts' was one of the areas of learning in the proposed curriculum under the previous government, which was seen as a progression from creative development in the early years. (Rose 2009) Similarly, the Cambridge Primary Review (2009) suggested 'Arts and Creativity' as one of eight domains of knowledge, skill, enquiry and disposition (Alexander 2010 p. 267). Juliet Desailly discusses this and the historical journey of 'creativity' in the primary curriculum in more depth in her book 'Creativity in the Primary Classroom' (2012) and it is clear that there is an underlying assumption that creativity fits best with the Arts. On a final note, Figure 2.1 below shows the frequency of the words 'creative, creativity or creatively' across the 2014 National Curriculum for England (Department for Education 2013). It is clear that art and design has a strong creative focus along with music, whereas the core subjects of English, mathematics and science have a limited creative demand. Additionally, the instances in science were limited to the *creative use* of everyday materials, different magnets and new materials and this was in the non-statutory guidance. Interestingly, design and technology and computing have a clear expectation for creativity. As you have hopefully seen from Chapter 1, being creative is not just about generating creative products but also being creative in the process with a purpose and value attached to it.

[Insert Fig 2.1]

[Caption Figure 2.1: Frequency of the words 'creative, creativity or creatively' across the 2014 National Curriculum for England. (adapted from Department for Education 2013)]

Nonetheless, in this chapter we will consider children's own conceptions and how creativity can be used to challenge these often naïve conceptions and enable conceptual change towards

accepted scientific concepts. Initially however, we need to challenge the concept that science is a fact-based subject concerned with the acquisition of bodies of knowledge. Instead, science should be seen as a subject which is ultimately concerned with the very processes which lead to the development of such knowledge. Respecting evidence, asking questions, evaluating and arguing science is what science is really all about and certainly should be at the heart of all primary science lessons.

[start box]

Activity Box 2.1

Consider the following statements in relation to your own understanding of science and learning in science (or when you last studied science) - to what extent do you agree or disagree?

- Knowledge in science consists of many disconnected topics
- As scientists learn more, most science ideas we use today are likely to be proven wrong.
- It is possible for scientists to carefully perform the same experiment and get two very different results that are both correct.
- When studying science, I relate the important information to what I already know rather than just memorizing it the way it is presented
- I find that reading the text in detail is a good way for me to learn science.
- Why scientific phenomena happen the way they do does not usually make sense to me; I just memorize what happens.

(adapted from the CLASS survey <http://www.colorado.edu/sei/surveys/Faculty/CLASS-PHYS-faculty.html>)

[end box]

[start box]

Time for reflection Box 2.1

Do you see science as a fact driven subject or as a subject which by its very nature demands flexibility and creativity?

What experiences have led to this attitude?

How will this attitude impact on your teaching of science?

What evidence from the classroom, your own experiences of learning science or from your personal life can you think of to support the notion that science is a creative subject?

[end box]

Challenging the nature of science - how we know what we know

Let's start with science in the curriculum. In the 2014 National Curriculum for England (Department for Education 2013, p.144), it states 'all pupils should be taught essential aspects of the knowledge, methods, processes and uses of science'. This is supported by the aims of the curriculum which are to ensure that all pupils:

- develop scientific knowledge and conceptual understanding through the specific disciplines of biology, chemistry and physics
- develop understanding of the nature, processes and methods of science through different types of science enquiries that help them to answer scientific questions about the world around them
- are equipped with the scientific knowledge required to understand the uses and implications of science, today and for the future.

Additionally, it describes ‘working scientifically’ (p. 145) as specifying the understanding of the nature, processes and methods of science. It stresses it should always be taught through and clearly related to the teaching of substantive science content in the programme of study across both key stage 1 and upper and lower key stage 2. In this way, the 2014 curriculum is building on the 1999 National Curriculum (DfEE/QCA 1999) which states teaching should ensure that 'scientific enquiry' is taught through contexts taken from the sections on 'life processes and living things', 'materials and their properties' and 'physical processes'. This is best practice in science education. Furthermore, as much as possible children should be involved in all stages of the science process, in teaching and learning environments which encourage questioning and curiosity about the world around us. This requires active involvement of the children in their own learning, with opportunities for discussion and effective co-operative group learning. This discussion should allow for review and evaluation, with children recognising improvements and showing openness to others’ ideas. Osborne argues that debate and discussion with others are most likely to enable new meanings and that comprehending why ideas are wrong matters as much as understanding why other ideas might be right. (Osborne 2010 p. 464) Enabling children to come up with their own ideas to scientific questions and giving them ownership of how they want to go about their investigations as well as choice in how they communicate their results are vital to the success of such an approach. This also encourages the development of key scientific attitudes, such as creativity, flexibility, objectivity, open-mindedness and respect for evidence.

Conceptual change

We all have ‘gaps’ in our knowledge, a favourite TV programme of mine has a whole episode around the gaps in knowledge and ability of the key characters: Lily couldn’t throw, Ted

mispronounced 'chameleon' and Robin believed the North Pole was not actually a real place. Yes it's fictional, but no doubt most of us can remember a moment (or probably moments) when gaps in our knowledge were revealed. This is normal and probably a result of miscommunication at some point. The important thing to remember is that our ideas are very real to us and come from previous experiences; in the playground, school, youth club, in the pub, parents, siblings, friends and the classroom. This is not necessarily problematic so long as teachers start from children's ideas and move them forward. To do this we need to have an appreciation for the theoretical underpinning of conceptual change.

Theoretical framework

The teaching of science in schools, particularly in primary, has seen a shift in recent times, where teachers and researchers are recognising the value of children constructing their own knowledge and understanding, rather than merely receiving knowledge transmitted from their teacher. One leading theorist in the field, David Ausubel, has made clear distinction between rote learning and meaningful learning. Meaningful learning derives from the combination of ideas linked to any given concept and is further influenced by emotional associations, the experiences during which concepts were acquired and the context of the learning. To enable meaningful learning new material needs to be incorporated into existing cognitive structures. From Ausubel's perspective, this is the meaning of learning. He recognises two ways this can be done: correlative subsumption, where it is an extension or elaboration of what is already known and derivative subsumption, where new material can be linked to other concepts or ideas to create new interpretations or understanding. In this latter approach completely new concepts can emerge, and previous concepts can be changed or expanded to include more of the previously existing

information. Interestingly, Ausubel was a proponent of didactic, expository approaches, which is in sharp contrast to the current thinking on classroom methods. Conversely, Jerome Bruner, who had similar theories on how we learn, was a strong proponent of a discovery and problem-solving approach to teaching and learning. These and other approaches will be discussed in more depth in the next chapter. Bruner's sees learning as an active process, including selection and transformation of information, decision making, generating hypotheses, and making meaning from information and experiences. Bruner held similar views to Jean Piaget and was influenced by the work of Lev Vygotsky, both his peers. Piaget recognised 'schema' as the basic building block of intelligent behaviour. These can be seen as "units" of knowledge, each relating to one aspect of the world, including objects, actions and abstract theoretical concepts. Piaget emphasized the importance of schemas in cognitive development, and described how they were developed or acquired. He suggested a process of accommodation and assimilation, where by accommodation is using an existing schema to deal with a new object or situation and assimilation happening when the existing schema does not work, and needs to be changed to deal with a new object or situation. In this way, Piaget is often called the 'father of constructivism'. However, his view was somewhat limited in terms of the potential influence of external factors on learning and cognition. Lev Vygotsky, a peer of Piaget, put a lot more value on the role social interaction plays in the development of cognition. In essence, an individual can achieve a certain amount of understanding, but with others through social interaction can achieve more. This gap between what people can achieve on their own and what they can potentially achieve with the help of others is called the 'Zone of Proximal Development'.

Constructivism, as you will see throughout this book, is a key approach to effective science teaching and learning. A fundamental learning outcome of constructivist approaches to science education is the achievement of conceptual change in learners and there is a wealth of researchers who dedicate themselves to this. Children come to science lessons, just as we do to situations in everyday life, with conceptions that may differ from accepted scientific ones that we expect them to acquire. Using elicitation strategies, teachers need to explore their children's existing conceptions and use these to build new understandings. (Morton 2012) Posner *et al.* (1982) suggest that learners are more likely to accept new conceptions if they are dissatisfied with the old ones, and find the new ones make sense, offer solutions to other problems and fit in with other knowledge, and if they potentially open up new areas of inquiry. In this way, children need to be very much part of the process of constructing their scientific knowledge and understanding. Murphy suggests that many criticisms have been levelled against the constructivist approach to science teaching in the primary school, recognising that there is little advice for teachers regarding specific strategies to develop these ideas so that they become more 'scientific'. (Murphy 2003 p.3) Hopefully this chapter will go some way to rectify this.

Conceptual change needs to consider epistemological, ontological and social/affective factors (Treagust and Duit 2008, Venville and Treagust 1998). Epistemology considers the origin, nature, and limits of human knowledge. Of significance to this chapter is whether some human knowledge is innate or whether instead all significant knowledge is acquired through experience. Ontology is concerned with the nature of being and with various categories of being. It considers "What exists? And how can it be grouped as related to other things that exist? When individuals' experiences change, the relationships between things can change and the categories can change.

Social factors include the learning environment and the class organisation. Affective factors take account of the emotional factors which influence learning, these can be negative or positive.

Morton (2012) argues that as well as these factors the role dialogue plays in conceptual change needs to be considered. This links strongly with the constructivist perspective where there is a strong social dimension. Morton describes research by Mercer (2000, 2008) who advocates strongly for recognition of the role both participants have in the joint construction of new knowledge, or ‘thinking together’.

The importance of spoken language in science is emphasised in the 2014 curriculum (Department for Education 2013 p. 145), noting that “the quality and variety of language that pupils hear and speak are key factors in developing their scientific vocabulary and articulating scientific concepts clearly and precisely. They must be assisted in making their thinking clear, both to themselves and others, and teachers should ensure that pupils build secure foundations by using discussion to probe and remedy their misconceptions.” This is a welcome addition and recognises best practice in science education where the role of discussion, as mentioned earlier, is paramount in developing knowledge and understanding and enabling conceptual change. If discussion and working scientifically are the foundation of primary science classrooms, this will directly impact on children’s progression in scientific knowledge, concepts and processes and will develop their understanding of the nature of science.

Allen (2010 p. 12-13) offers some general qualities of a constructivist teaching approach when considering misconceptions. These are summarised here:

- assimilation
- accommodation
- experiential learning
- cognitive conflict
- social and collaborative learning
- student autonomy and independent learning
- open-ended questions
- higher level thinking
- peer dialogue
- responsibility with the learner

İpek and Çalık (2008 p. 145) suggest a 4-step constructivist teaching model to enable conceptual change. In the first phase, eliciting students' pre-existing ideas, the teacher tries to enhance students' motivation for the topic and to become aware of their pre-existing knowledge and alternative conceptions to allow identification of appropriate activities. In the second phase, focusing on the target concept, the teacher attempts to enrich the learning environment for the students through engagement in activities and experiences about the target concept. The teacher also encourages the students to think about related concepts by asking questions. However, they refrain from giving any clue. In the third phase, challenging students' ideas, students compare their prior knowledge with their newly structured one. The teacher makes reasonable explanations to confirm or refute their gained experiences. In the last phase, applying newly constructed ideas to similar situations, the students apply their newly structured knowledge to new situations to reinforce their understanding. This latter point is very important as it has long

been recognised that learners have an inability to transfer knowledge, giving rise to the notion of situated learning. (Novak 2002)

Reasoning skills that science education might seek to develop include the following abilities (Osborne 2010 p. 465):

- to identify patterns in data, such as covariation (how two variables change together), and to make inferences;
- to coordinate theory with evidence and to discriminate between evidence that supports (inclusive) or does not support (exclusive) or that is simply indeterminate;
- to construct evidence-based, explanatory hypotheses or models of scientific phenomena and persuasive arguments that justify their validity; and
- to resolve uncertainty, which requires a body of knowledge about concepts of evidence such as the role of statistical techniques, the measurement of error, and the appropriate use of experimental designs, such as randomized double-blind trials (See Chapter 6 – Key methods)

Children's naïve conceptions

There are many different ways to describe children's ideas in science: misconceptions, alternate conceptions, common sense, non-scientific ideas, intuitive conceptions, naïve conceptions. In reality these mean the same thing, ideas which are not yet developed into accepted science ones. Researchers are interested in the theories which underpin the barriers to, and strategies for, conceptual change in science; as teachers we are interested in the knowing what children's ideas are so we can use them as starting points to develop or where necessary change their ideas, thus

allowing children to make progress. Either way, both communities are very interested in children's ideas. We of course, need to exercise caution as sometimes children can have the 'correct' scientific idea in their head but may lack the language to communicate it. Chi and Roscoe (2002) also recognise the difference between naïve knowledge that can be readily revised or removed through instruction and naïve knowledge which seems highly resistant to change, referring to the latter as misconceptions. (p. 3)

Shtulman and Valcarcel (2012) investigated what happened to children's ideas when exposed to new ones. They found that children verified scientific concepts much more slowly and less accurately across 10 domains of scientific knowledge, when these concepts did not match with their intuitive ideas, suggesting that naïve theories survive the acquisition of a mutually incompatible scientific theory, coexisting with that theory for many years to follow. This means that we can tell a child that the water in a puddle has not disappeared, but instead changed state into a gas and evaporated into the atmosphere but unless we actually give them evidence and the opportunity to discuss and construct such meaning for themselves, their intuitive idea that the water has simply disappeared will stick. Chi and Roscoe (2002) also recognised this stating that such misconceptions can persist even when they are confronted by ingenious forms of instruction.

Research encourages secondary pre-service teachers to incorporate misconceptions into their teaching as learning platforms to build on, instead of obstacles to learning (Larkin 2012) and we would advocate this in primary science teaching too. Earlier strategies used to explore children's conceptions included minimal use of written language, using visual images and often the

presentation of alternative concepts or questions relating to one central idea or word. The use of concept cartoons is one such approach that has been, and still is, used effectively to explore children's conceptions (Keogh and Stuart 1999). Concept mapping (Liu 2004) and computer simulations (Trundle and Bell 2010) have also been used to explore concepts and promote conceptual change. Foster (2012) suggests the discussion of socio-cultural issues can be used as a means to explore concepts and enable conceptual change about evolution. His paper suggests that "teachers can be confident that evolution has nothing to fear from a free and frank discussion in which claims can be rebutted with to drive out pre-scientific superstitions. It also models the scientific process more authentically and develops students' ability to think critically". (Foster 2012) Research carried out by Montero *et al.* (2012) on children's conceptions of 'minerals' suggests that teachers need to promote the understanding of the evolution of the mineral concept through time, highlighting that "Definitions naturally change as a consequence of the growth of scientific knowledge and may, over time, become inappropriate due to new findings" (p 2721). This reflects the spiral curriculum advocated by Bruner, where basic ideas should be repeatedly revisited, building upon them until the student has grasped the full formal apparatus that goes with them. Finally, it is important to recognise the seminal work of Shayer and Adey (1981) on cognitive acceleration through science education (CASE) which draws heavily from a constructivist pedagogy and has cognitive conflict as a key factor in developing cognition. This means presenting children with something which is puzzling, unexpected perhaps, which makes them stop to think. It is not simply a matter of presenting difficult material, but rather of leading to certain expectations which are then not met, so we have to 'think again'.
(www.letsthink.org.uk)

Creative approaches to conceptual change

These are all useful approaches and strategies but we want to encourage creative approaches, which will lead to conceptual change and the development of creative thinkers. It has been already described how psychologists and social scientists recognise two forms of creativity: big-C creativity (BC); and little-c creativity (LC). Big-C creativity describes development of transformative performances or products, whereas little-c is concerned with the construction of novel solutions to problems of limited relevance. Within this framework, little-c creativity may be combinatorial, where new connections are established between old ideas or exploratory, operating within a limited domain, or limiting set of rules. (Schmidt 2010 p. 1016)

In this vein, little-c creativity can be developed and utilised in the primary science classroom to establish new connections between old ideas and when exploring ideas within a limited domain, for example exploring melting. Teachers need to see these naïve conceptions not as barriers to get over but productive starting points. One suggestion is to consider the resources we use when teaching. Textbooks can and do contain misconceptions and if we think a bit outside the box, we will be able to find resources that may unintentionally support children's naïve ideas. Why not explore and discuss this with children?

[start box]

Activity Box 2.2 - Resources

Look at the photo below. It is an orrery, a mechanical model of the solar system. Many schools will have one of these and possibly on display. List the scientific ideas that you could draw from this resource. Which of these might lead to alternative conceptions about our solar system?

[insert photo 2.1 – photo of an orrery - to be supplied by Orla]

Now look at this picture of the solar system. Again, list the scientific ideas that you could draw from this picture. How might this lead to alternative conceptions about the solar system?

[insert photo 2.2 hi-res solar system photo - to be supplied by Editorial]

[End of box]

As well as considering the classroom resources we use, another creative approach could be consideration of the textbooks and written resources that we use (or maybe shouldn't use). Traditionally, science teaching relied heavily on textbooks and worksheets and Van de Broek (2010) highlights the factors which can hinder the learning of science from texts, recognising a number of reader and text characteristics. Text characteristics include the organisation of the text, verbal complexity and typographical prompts. The reader's availability of working memory capacity and relevant background knowledge coupled with skills factors such as reasoning and reading impact on their ability to comprehend text. Taking into account a reader's personal motivation for the subject and task, it is clear how learning from texts may be hindered. This situation is not helped by the fact that school textbooks themselves often contain inaccurate knowledge (King 2010). Additionally, among the most commonly noted features of academic language are conciseness, achieved by avoiding redundancy; using a high density of information-bearing words, ensuring precision of expression; and relying on grammatical processes to compress complex ideas into few words. (Snow 2010 p. 450) Therefore, a creative approach to challenging misconceptions is to not use work sheets and textbooks in the traditional way.

Instead consider getting children to pick out words from worksheets or books that they think are scientific words and discuss their meaning in pairs or groups. Think of all the words which have more than one meaning and which we use in the primary science classroom for example bark, energy, force, mass, plant, shoot, the list goes on. Will the children pick these out or will they ignore them? We can probably all think about children who have spent the majority of a lesson with a totally different understanding of a particular word. Without exploring the meaning of such words, a perfectly planned, resourced and executed lesson will fail! Carefully selected images and visuals can be an excellent starting point for exploring children's ideas so long as discussion and then concrete experiences follow to challenge and move their ideas and conceptual understanding on.

Conclusion

The key message in this chapter is about enabling conceptual change in children to move their naïve conceptions to accepted scientific ones. Several strategies and suggestions were put forward to challenge children's misconceptions. Starting from children's ideas is crucial and strategies to elicit children's ideas are discussed in chapter 5. The key theories underlying conceptual change were highlighted, in particular constructivism.

The chapter started with a consideration for the dichotomy between the Arts and science when considering creativity. A case was made for this to be challenged. This highlighted the importance of teacher's consider their attitude and understanding of the nature of science.

Further reading

Allen, M. (2010) *Misconceptions in Primary Science*. Maidenhead: Open University Press, McGraw-Hill Education

This book offers clear support and practical advice for dealing with the common misconceptions encountered in the primary science classroom.

Hadjiachilleos, S., Valanides, N. & Angeli, C. (2013) The impact of cognitive and affective aspects of cognitive conflict on learners' conceptual change about floating and sinking, *Research in Science & Technological Education*, 31:2, p. 133-152

This research paper describes a small scale study into the contribution of cognitive and affective aspects on students' conceptual change in floating and sinking.

Marin, N., Benarroch, A. & Jimenez Gomez, E. (2000) What is the relationship between social constructivism and Piagetian constructivism? An analysis of the characteristics of the ideas within both theories, *International Journal of Science Education*, 22:3, p. 225-238

In this research paper, the authors consider the characteristics of social constructivism and 'piagetean' constructivism attempt to find connections and bridges between them for the benefit of science teaching.

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