Chapter 4 – The importance of teacher knowledge in science

Chapter aims:

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

- Recognise the various aspects of teacher knowledge required for effective teaching in science
- Explore your own knowledge and understanding of the core concepts underpinning the National Curriculum for England
- Develop a working knowledge of the key indicators of progression in working scientifically across the curriculum

Introduction

Typically when we ask our initial teacher education students 'what is science?' we get a large number who recognise science as a study of the three main subject areas – biology, chemistry and physics and an encouraging number who identify science as a study of the world around us and sometimes the processes by which we do this. At the other end of scale we get that science is about learning facts from textbooks! This is perhaps not surprising since many people can identify with this view of science from some stage in their life. Our experiences were a little different as we were naturally inquisitive and interested in science and enjoyed the various aspects but we certainly remember science lessons which were of the textbook kind. Unfortunately, it often appears that students who once had positive experiences of science, particularly in primary, have been left with negative feelings and memories from their formal education in science at secondary level and beyond.

Science is both a body of knowledge and a process and as you progress in science, the knowledge and understanding of particular disciplines and the core concepts that underpin them become increasingly important. This coupled with the demands of assessment procedures, over-loaded curricula and practical and resource issues can be to the detriment of scientific, student-led enquiry, leading to the over reliance on textbooks. Luckily, in primary science we are not constrained by such factors, particularly given the slimmed down 2014 National Curriculum for England (Department for Education 2013a) and would strongly advocate for the enquiry side of science taking the central position, embedding the thinking, attitudes, values and ways of working scientifically. It is therefore right and appropriate that working scientifically (formerly scientific enquiry) is central to the National Curriculum in England. A similar focus on the processes of science is seen in the national curricula in Scotland, Wales, Northern Ireland and Ireland. So when thinking about what you need to know to teach primary science effectively, it is important to recognise and value the key role the processes of science play.

[start box]

Time for reflection box 4.1

Think about the following statements, do what extent do you agree or disagree with them?

- I'm no good at science
- I enjoy practical science
- I never liked chemistry (or biology or physics as the case may be)
- I know how to carry out a scientific investigation
- I get nervous when I think about teaching science
- I look forward to teaching practical science

[end box]

Ask most science enthusiasts and educators and they will probably tell you they have a preferred discipline within science and maybe one which they struggled with or still struggle with, or maybe even that they don't like. However, despite this they should acknowledge the key role engaging in scientific enquiry will have played in developing their understanding and enjoyment of that area of science. Additionally, for educators they will certainly value the process of planning for and teaching the subject had on their enjoyment and conceptual understanding, particularly if there was a shared hands-on, investigative approach with their students. So if you enjoy practical work and are developing your understanding of working scientifically and what it is to carry out a scientific investigation, you are well on your way to developing your subject knowledge and enjoyment of science. Alternatively, if you get nervous when thinking about teaching science or feel you are no good at science, hopefully this book will give you confidence to take an enquiry approach to your science teaching. This will enable you and your children to immerse yourselves in the processes of science and through this develop knowledge and understanding. Chapter 3 had described a range of approaches for effective science teaching and learning through enquiry.

However, subject matter knowledge does play a part and this shall be explored in more detail now.

Subject matter knowledge

Gilbert (2010) recognises three necessary characteristics of a science teacher**;** subject matter knowledge, pedagogic knowledge and pedagogic content knowledge**.** Within subject matter knowledge, Gilbert (2010 p. 279) further recognises three components; substantive, syntactic and beliefs. The substantive component is the concepts that make up the core of the curriculum such as forces, materials, plants, and so on. The syntactic component is the knowledge concerned with the processes of science. The beliefs component is to do with the beliefs held about the nature of particular sciences and of science itself. Teachers' perceptions of a discipline have been shown to significantly influence their teaching of the subject (Parker 2004). According to Gilbert (2010), each of these, substantive, syntactic and beliefs, play a crucial role in developing the necessary characteristics for effective science teaching. This supports the notion that knowledge and understanding of scientific enquiry and working scientifically are important aspects of science subject knowledge.

In a review of the first ten years of compulsory primary science in England and Wales, Harlen (1998) identified concerns around teachers' subject knowledge and the balance between process skills and science content among other factors. It is interesting that the latter continues to be an issue with each of the last Ofsted reports on science (Ofsted 2013, 2011, 2008) identifying scientific enquiry and child-led investigations as areas for development. Conversely, according to the latest report (Ofsted 2013 p. 12) 'Despite concerns raised by various government agencies and professional associations about the lack of science subject specialists in primary schools, the evidence from this survey indicates that this (teachers' subject knowledge) was not a serious barrier to pupils' achievement in terms of teachers' knowledge and understanding. Additionally, an earlier report (Ofsted 2011), teachers' subject knowledge was found to be at least satisfactory and in the large majority of the schools, the teachers' knowledge and understanding of the National Curriculum science requirements were good or outstanding. The supports available to, and used by, teachers who were aware of the limitations of their knowledge and their conscientious planning were also acknowledged (Ofsted 2013). Here we begin to appreciate the importance of teachers' pedagogic knowledge. Parker and Heywood (2000) also suggest that knowing the subject does not necessarily translate into effective teaching of that subject. Findings from a research study on secondary science teacher trainees (Kind 2009) offer further insights. The study reported somewhat counter-intuitively that the trainees were found to teach more successful lessons outside their specialism, particularly in the early stages. This was enabled by using a richer range of subject matter knowledge sources, including, crucially, advice from experienced colleagues and practicing unfamiliar experiments and seeking advice from technicians. Additionally, in the Ofsted report on primary teachers' subject knowledge

(Ofsted 2009 p. 7) it was reported that where lessons were judged to be good were sometimes so because of teachers' strong general teaching skills more than made up for any weaknesses in their knowledge of the subject they were teaching. Furthermore, studies have shown that integrating science can compensate for primary teachers' lack of confidence in science teaching. (Gresnigt et al 2014)

However, Pollard (2008) states that though an association between sound subject knowledge and effective teaching may be unproven, recognising in particular the myriad of factors that play a part in effective teaching and learning, he expresses the crucial role substantive knowledge plays in teachers being able to explain and scaffold children's knowledge and understanding. He argues that there does, in fact, seem to be something of a consensus that teachers with sound subject knowledge can do this more effectively, citing several research studies in science education. Furthermore, Ofsted (2013, 2009) reported that teachers' lack of subject knowledge meant some teachers did not spot and tackle errors or misconceptions in pupils' work. Occasional inaccuracies in terms of technical explanation were also noted. However, it was noted that these did not necessarily impede learning. The role of substantive or content knowledge is complex but it is clear that applying good pedagogy and valuing the role of the processes or syntactic knowledge of science can contribute significantly to effective teaching and learning in science.

Pedagogic content knowledge

A theme underpinning this book had been the recognition of the importance of teaching that supports conceptual understanding and children constructing their own ideas rather than rote memorising in science. As teacher educators it is impossible to 'teach' all the required substantive and syntactic knowledge as well develop our students' skills and expertise in teaching science in the primary classroom. It is in supporting student teachers in acquiring content knowledge in science that the tension between subject knowledge and conceptual understanding manifests itself most acutely. Parker and Heywood (2000 p.89) suggest that it concerns not simply knowing something (for example that the seasons are caused by the tilt of the earth' s axis), but having a coherent, causal explanation which makes sense to the teacher such that they feel skilled in teaching the concept to children.

Shulman introduced the idea of pedagogical content knowledge (PCK) as 'a special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding' (Shulman 1987: 8). It is the ways of representing and formulating the subject that make it comprehensible to others. Shulman (1987) described it as 'taking what he or she (the teacher) understands and making it ready for effective instruction' (p.14). Asoko (2002) recognises the need for teachers to be confident enough in their own knowledge of science to identify those ideas which they considered appropriate for their class, the level at which these would be discussed and ways to exploit opportunities to introduce and apply them (p. 161). These are all aspects of PCK.

PCK was valued in the 2008 Teacher Standard Q14 'Those recommended for the award of QTS should have a secure knowledge and understanding of their subjects/curriculum areas and related pedagogy to enable them to teach effectively across the age and ability range for which they are trained'. (TDA 2008, p. 7) This reflected an appreciation for the role subject specific pedagogy played. In the latest Teachers' Standards for England (Department for Education 2013b) there is again an emphasis on secure knowledge including being able to address misunderstandings. In relation to the earlier discussion, Pollard (2008) suggested that substantive subject knowledge is needed for this.

The purpose of the discussion here is to relieve fears of the often assumed central role of substantive subject knowledge to teach science effectively. Syntactic knowledge of the processes of science, and pedagogic content knowledge have equally important roles in effective teaching and learning in primary science. Additionally, it is important to recognise the role that knowledge of the curriculum requirements has. We will now look at the substantive and syntactic content of the National Curriculum for England.

Overview of the 2014 National Curriculum for England

According to the Department for Education (2013a) a high-quality science education provides the foundations for understanding the world through the specific disciplines of biology, chemistry and physics. Figure 4.1 shows the content covered for each school year from Year 1 to Year 6. It is clear that apart from working scientifically, the content area ‘Animals, including humans’ is the only one that is covered across all 6 years, additionally ‘living things and their habitats’ and ‘plants’ are strongly represented. In fact, a simple tally of the different content areas shows that over half of the content areas relate to biology (15 of 28), with areas related to physics being slightly more represented than chemistry, 8 of 28 and 5 of 28 respectively. While we welcome the focus on plants, animals and habitats, in particular the inclusion of evolution, it is a concern that children’s understanding of chemical and physical processes are not being given as much attention in these crucial early stages.

[Insert Figure 4.1]

Figure 4.1 – Overview of content areas in the 2014 National Curriculum for England

Interestingly, Chiu et al (2007) suggested that it might be wise for science curriculum frameworks, textbooks, and science teachers to emphasize a minimum number of core concepts and to deal with them in greater depth (p. 387) and a slimmed down curriculum was a stated aim of the revised curriculum (Department for Education 2012). Also, the US is making moves in this direction (McGraw Hill (2014), see the recommended further reading for more on this). The idea of a slimmed-down curriculum focussing on core concepts is something that has clear merit when thinking of the creative classroom. Rather than considering a long list of specific facts and criterion, the focus should shift to some general principles and underlying concepts.

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Activity box 4.1

Thinking about one of the disciplines of science: biology, chemistry or physics, consider how you would describe it to someone who has never heard of it before.

Biology is… Chemistry is… Physics is…

Now having done this, create a concept map for your chosen disciple. A concept map is a diagram that depicts suggested relationships between concepts, allowing you to organise and structure your knowledge and understanding. It is more demanding than a spider diagram as concepts maps show the connection between ideas. As an example, let's consider light within physics, rather than just linking 'light→ shadows', it is necessary to state your understanding of how these are related for example 'shadows→ **are formed when an object blocks→** light, a second connection could then be made to show further understanding 'light→ **travels in→** straight lines'. Use the questions below to develop your ideas for your concept map:

- Which three words come to mind first when you think of this subject?
- What subject specific language would you use to describe this subject?
- What physical resources would you use to exemplify this subject in the classroom?
- What examples of it can you see around you?

- What connections does it have to other areas of science?

It would be useful to repeat this for the other areas of science too.

[end box]

It is important to step back from the details of the curriculum and try to recognise the core concepts which underpin each discipline and the core processes which drive the development of science. However, there is not space in this book to offer a comprehensive and worthwhile discussion of all the core concepts and indeed development of such understanding takes time. Moreover the National Research Council in the US (2007) noted that one of the best ways for students to learn the core concepts of science is to learn successively more sophisticated ways of thinking about these ideas over multiple years, as evident through progression. However, to exemplify what this might look like in practice, progression in materials is described here.

[start box]

Case example 4.1

Chemistry is all about atoms and molecules. It is fascinating that various combinations of these make up everything, both in the living and non-living world, the natural and the man-made. Single atoms, the smallest particle of matter that retains the properties of a given element, make up precious metals like gold (Au) and platinum (Pt), liquids like mercury (Hg) and gases like helium (He) and krypton (Kr). Simple molecules are made up of two or more atoms joined together. Everyday examples of simple molecules are carbon dioxide, CO_2; hydrogen gas, H_2; water, H_2O; salt (sodium chloride) NaCl. The idea that unimaginable combinations of the 98 naturally occurring elements give rise to all matter is impressive and this identifies one of the fundamental concepts: that all matter is made up of the elements. Furthermore, matter is anything that has occupies space and has mass; this includes all that we can see and, most of the time, what we can’t see. Chemistry is all about the study of the composition, structure, properties and changes of matter. In primary science, children encounter chemistry, the study of matter, through materials.

Progression in materials

On close inspection of the statutory content for materials in the 2014 National Curriculum for England (Department for Education 2013a), it is clear that there are two key areas to consider. The first one is investigating materials based on their properties, with implicit links to the following skills of working scientifically, observation, identification and classification. Progression is evident from year 1 to 5. See Figure 4.2 for more details. It is important that subject specific language is encouraged as the children progress in their observations and descriptions. They should also be encouraged to group materials in a variety of different ways. Initially children will classify and sort into groups based on obvious properties, for example colour and size. To progress this you could get children to rank them from smallest to largest, or darkest to lightest. They should then be encouraged to classify based on other properties such as texture or use. The teacher's choice of materials for sorting is important here as well as the classroom environment. A wide range of familiar materials should be provided. Additionally, time should be allowed for free exploration of the materials, with the teacher encouraging use of all the children's senses as appropriate, for example the sound the objects make. Additionally magnifying glasses and teacher questions should further promote observations. As children progress they should also be encouraged to classify based on similarities as well as differences. Finally, children observing and classifying based on chemical properties, such as magnetism, or conductivity (a material's ability to allow electric current to pass through it) show an appreciation for the internal make-up of the material and thus begins their understanding that all things are made up of atoms and molecules which give rise to different properties and characteristics of materials.

[insert figure 4.2]

Figure 4.2 Progression in grouping materials based on their properties from Year 1 to Year 5 (adapted from Department for Education 2013a)

[end box]

Progression in working scientifically

It is expected that the content areas of science are taught through the processes of working scientifically (Department for Education 2013). One of the key characteristics of teacher knowledge in science is knowing how to progress and develop children's ability to work scientifically through the primary phase. Figure 4.3 gives an overview of the various elements of progression in the key areas of working scientifically. These generally reflect the requirements of the 2014 National Curriculum for England (Department for Education 2013) but level of independence and explanations have been added to provide a fuller picture of progression when children are working scientifically.

[Insert Fig 4.3]

Figure 4.3 – Overview of progression in working scientifically

Conclusion

In this chapter we have explored the importance of teacher knowledge for effective teaching and learning in science, emphasising the importance of substantive or content knowledge in allowing teachers to offer explanations, scaffold learning, as well as recognise and challenge misconceptions or naïve ideas. However, other areas of teacher knowledge are equally valuable, in particular the role of syntactic knowledge, that of working scientifically, as well as teachers beliefs about science. Moreover, evidence shows that teachers teach good science lessons by drawing on their general teaching skills or pedagogic knowledge. A case is made for a specific kind of pedagogic knowledge in science, that of pedagogical content knowledge, which brings together pedagogic and content knowledge to enable effective learning experiences in science. Teachers should therefore strive to develop their own conceptual understanding of science, as well as develop their general teaching skills.

The value of a slimmed down curriculum is noted, and we encourage you as teachers to step back from the curriculum and recognise the key elements of progression in the various curriculum areas. Case example 4.1 provided, as an example, an overview of progression in materials and their properties in primary school. This showed how experiences in primary school link to developing core concepts, which children will further develop in secondary school and beyond. The central role of scientific enquiry and working scientifically is again highlighted in this chapter alongside concepts of progression across the primary age phase.

Further reading:

Kind, V. (2009) Pedagogical content knowledge in science education: perspectives and potential for progress, *Studies in Science Education*, 45(2) p. 169-204

In this paper, the author put forwards an argument for Pedagogical content knowledge (PCK) having a higher profile in teacher education. It offers useful perspectives for both the trainee and the experienced teacher.

ASE (2014) Subject knowledge [Online] Available at:

http://www.ase.org.uk/resources/scitutors/subject-knowledge/

This is an excellent overview of the different areas of learning within primary science, though they are currently grouped as per the 1999 National Curriculum, the ideas presented are relevant and highly useful.

Dunne, M. and Howard, D. (2012) Tricky Topics and How to Teach Them in Dunne, M. and Peacock, A. (Eds.) *Primary Science A guide to Teaching Practice*, London: Sage p. 125-136

This chapter offers some practical advice on using analogies, metaphors, similes and models to support children's conceptual development in science and some of the issues with them. Consideration is also give for how children develop their own ideas.

McGraw-Hill Education (2014) New Generation Science Standards – White papers [Online] Available at: https://www.mheonline.com/ngss/view/9

The New Generation Science Standards (NGSS) framework has been collaboratively developed in the US and acts as the foundation for science education standards, with consideration for practices, cross cutting concepts and disciplinary core ideas. This offers a perspective on reducing the content and considering the big ideas and underlying concepts and processes in science. In the white papers there are a number of useful discussions. Particularly relevant to this chapter are the ones entitled 'Twelve Core Ideas' and 'Learning Progressions: What Are They, and Why Are They Important?'.

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