Scientific enquiry and engaging primary-aged children in science lessons Part 2: why teach science via enquiry?

- Amanda McCrory

Abstract
The first part of this paper, published in the summer 2017 issue, JES 13, discussed and reflected on the concept of scientific enquiry in primary schools, including the possible barriers to provision of the primary science curriculum via enquiry. The second part of this paper firstly discusses the positives of teaching scientific concepts via enquiry, before presenting two case studies centred around children in Year 5 (age 9-10 years) and Year 6 (age 10-11 years) learning science via enquiry. The case studies specifically focus on the nature of science using authentic, meaningful learning opportunities and cross-curricular aims.

Keywords: Controversial issues, engagement, enquiry, observation, Ofsted, PCK (pedagogical content knowledge), nature of science, questioning, process skills, scientific concepts, socio-scientific issues, working scientifically.

Practical work in science lessons – why teach via enquiry?

Engagement and motivation…

Amanda Spielman, the current Chief Inspector of Ofsted, recently questioned the usefulness of practical science experiments when addressing the audience at the 2018 ASE Annual Conference (2018). Her concern lies with the outcomes of a survey published in John Holman's Gatsby report (2017) on 'Good Practical Science', which argues that secondary school teachers rate motivation as the most important factor in teaching science practically. Granted, her speech in the main focused on enquiry in secondary schools; however, the parallels to teaching science via enquiry in primary schools are clear. Spielman argues that we should be uncomfortable with the idea of practical science being mainly about motivation. The important word here is *mainly;* it is no secret that declining student engagement in both secondary and primary science has been a source of angst for scientists and science educators for some time (Ofsted, 2011) – no wonder then that motivation and engagement is high on the agenda. Good science schoolteachers know that motivation is key to engaging children in learning science, so that teachers can then actually teach! Quite frankly, as any teacher knows, it is very hard to teach a child anything when disengaged; therefore, motivation and a positive attitude to science is an important first step to engaging with learning science.

Evidence from the field of neuroscience supports the argument that the first stage in learning is motivation (Collins, 2015); persistence is a required state for most learning – children need to practise, repeat, try again and practise. In addition, exploration and investigation increase creativity and brain plasticity, which help children to become open to new ideas and be more creative in their own ideas (Collins, 2015): all strong arguments for teaching science via enquiry. Therefore, is this argument simply about 'motivation' and 'science taught practically', or perhaps a fundamental misunderstanding by some, including class teachers, regarding the role of scientific enquiry to enhance scientific knowledge and understanding and the pivotal role teachers play in this?

The link between being curious and creative, and scientific endeavour – the importance of children making sense of the world around them via exploration

Maintaining curiosity is an important aspect of science education; scientific enquiry is *'crucial in developing and sustaining curiosity'* (Smith, 2016: 6). As we know, facilitating and promoting curiosity in science education is integral to the primary science curriculum (Ofsted, 2013); being curious and creative is vital to scientific endeavour:

'If you're doing an experiment on cells, and you want to find out why those cells keep dying, you have a problem. It really takes a level of creative thought to solve that problem' (Robert deHaan, cell biologist; cited by Cutraro, 2012).

Spielman (2018) also noted that children need knowledge and understanding before they can create and test hypotheses; it would have been fruitful for her to elaborate on this further, because young children's ideas develop from interaction with the physical world around them – learning is cyclical, not linear. In early years and primary science, children make observations and hypotheses all the time and this starts at a very young age: *'Babies formulate theories, make and test predictions, seek explanations, do experiments and revise what they know in light of new evidence'* (Gopnik *et al*, 2001: 161). Toddlers build on their early experiences and become intrigued by finding out what things can do and how things can be changed. All this early experience leads to pre-school children with the attitudes, dispositions and skills to explore and investigate independently (Brunton & Thornton, 2010).

Children's alternative ideas or misconceptions

As children move into the early years foundation stage (EYFS) and then Key Stage 1 (age 5-7), these ideas can sometimes conflict with the recognised conceptual ideas of science as stated in the curriculum. Scientific enquiry therefore enables teachers to gauge an understanding of children's alternative ideas or misconceptions, so that teachers can provide opportunities to reconstruct children's scientific understanding (Allen, 2014). The importance of using alternative ideas as a starting point to develop children's scientific ideas, knowledge and understanding is clearly recognised (Harlen & Qualter, 2014).

Active processing includes relating new experiences and learning to previous experiences and real life events and this is an important part of the brain-based approach to learning, which includes situated learning, authentic contexts, the importance of prior learning and engagement (Collins, 2015). This is closely related to 'mental processing' as described by constructionist theorists (Piaget, 1929; Bruner, 1966; Vygotsky, 1978): the notion that all new learning builds upon a foundation of what has gone before with the relating of new information to old being just as important.

Conceptual understanding and the role of enquiry

Therefore, curiosity and imagination should stimulate questions, predictions and hypotheses; it is then the teacher's role to enable children to explore ways to investigate and test out their ideas by making observations, gathering data, presenting their findings and then explaining what they have found out scientifically. This can only be achieved by teaching children how to analyse their data with an important learning aim of teaching children concepts that are new to them in science or, indeed, consolidating their understanding of conceptual science. Spielman (2018) also highlights this point. Giving children time to then evaluate what they have done often creates new questions and ideas to investigate further. Working scientifically is therefore *'crucial to facilitate conceptual understanding'* for all children (Smith, 2016: 6). It promotes inclusion as children work collaboratively, socially constructing their understanding of science; this enables the teacher to not only meet the needs of all children but also to provide opportunities to challenge them. Collins (2015) argues that complex learning is enhanced by challenge – scientific enquiry provides opportunities for teachers to facilitate this.

The nature of science

As I argued in Part 1 of this article (McCrory, 2017), there is now an increased focus on children understanding the nature of science; teachers need to be clear about what this is and how to teach it. For primary science teachers, this involves understanding that:

- there is not one scientific method that fits all, but many methodologies to pursuing knowledge in science; scientists are creative, and a one-size-fits-all scientific method can only be restrictive;
- scientific knowledge is tentative; although often supported by a wealth of data from repeated trials, it is not considered the final word – findings are tested and challenged. *This is an important part of the nature of science,* which can sometimes be neglected;
- scientific theories are underpinned by evidence (gathered via observation and experimentation); theories are not simply a guess, or ideas that have not been validated;
- observations and inferences play different roles in the development of scientific knowledge; and
- human error is inevitable – scientists are humans and make mistakes; pupils need to understand that critically examining mistakes or unexpected results is an important part of the process of enquiry.

***The teacher's role and pedagogical content knowledge (PCK)* (Shulman, 1986)**

Unsurprisingly, it is the role of the teacher that is therefore crucial to delivering high quality science provision. It is a fundamental misunderstanding of teaching pedagogy in primary science to suggest that the teacher plays little or no role when children are working scientifically, or indeed that exploration or enquiry is simply about children having fun! On the contrary, the teacher plays a pivotal role when teaching scientific enquiry, to teach the skills involved as well as the scientific concepts. This is an *'active process [by the teacher] which requires an organised approach'* (Smith, 2016: 7).

Hattie and Yates's (2013) work on visible learning demonstrates how critical, and quantifiably so, a teacher's pedagogical content knowledge is to pupil success in learning. Pedagogical Content Knowledge (PCK) (Shulman, 1986) underpins effective teaching because it combines:

- multi-faceted knowledge (child development, learning theories, teaching strategies including explanations and demonstrations, which make abstract principles concrete for children to understand; inclusion and differentiation – understanding barriers to learning and how to overcome them) that the teacher has of ***how to teach*** a subject, so that children progress in their knowledge, understanding and skills (which informs the cycle of planning, teaching, marking and assessment); with

- a deep knowledge of the curriculum subject content (the national curriculum, the nature of science, key concepts within science subject knowledge, scientific enquiry skills, and scientific misconceptions or children's alternative ideas).

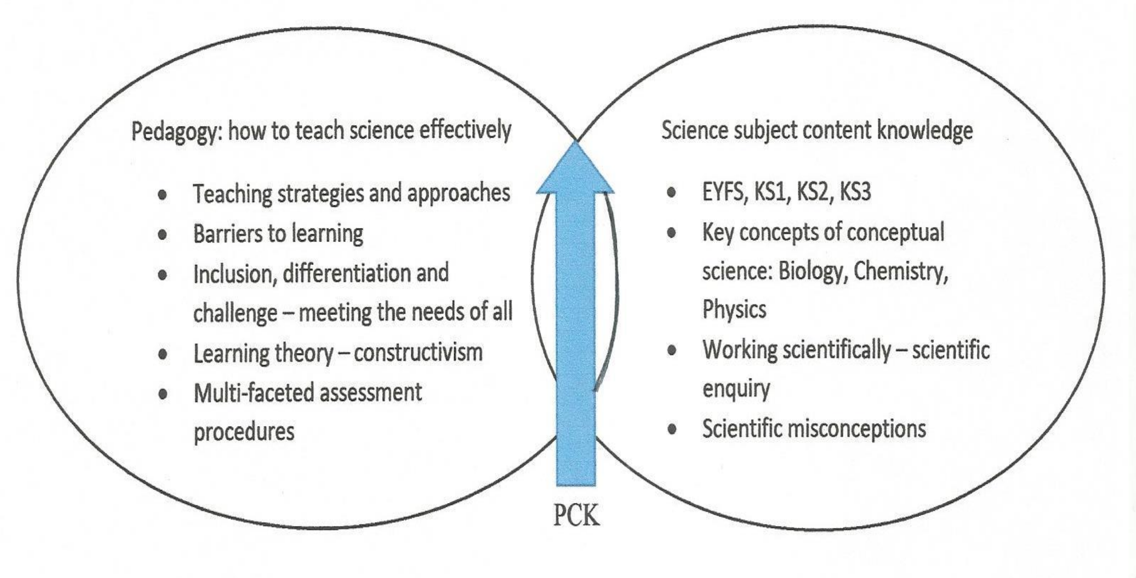


Figure 1: PCK (Pedagogical Content Knowledge) for teaching science in primary schools (McCrory & Worthington, 2018).

Case studies

The case studies included here demonstrate cross-curricular ways to teach children science concepts whilst working scientifically, with a particular focus on the nature of science and authenticity in learning about science concepts.

Case Study One: Year 5 children (age 9-10 years) learning about the nature of science via working scientifically

When learning about Earth and Space in Key Stage 2 (age 7-11), non-statutory guidance suggests that pupils should find out about how ideas about the solar system have developed over time, by understanding why the geocentric model of the solar system was replaced by the heliocentric model through considering the work of Ptolemy, Copernicus and Galileo. Figure 2 was presented to a class of Year 5 children as a stimulus to use their enquiry skills to understand more about this. The pupils were also asked to consider what scientific evidence was used to support the claims of each model. The outcomes of one child's work is demonstrated in Figure 3.

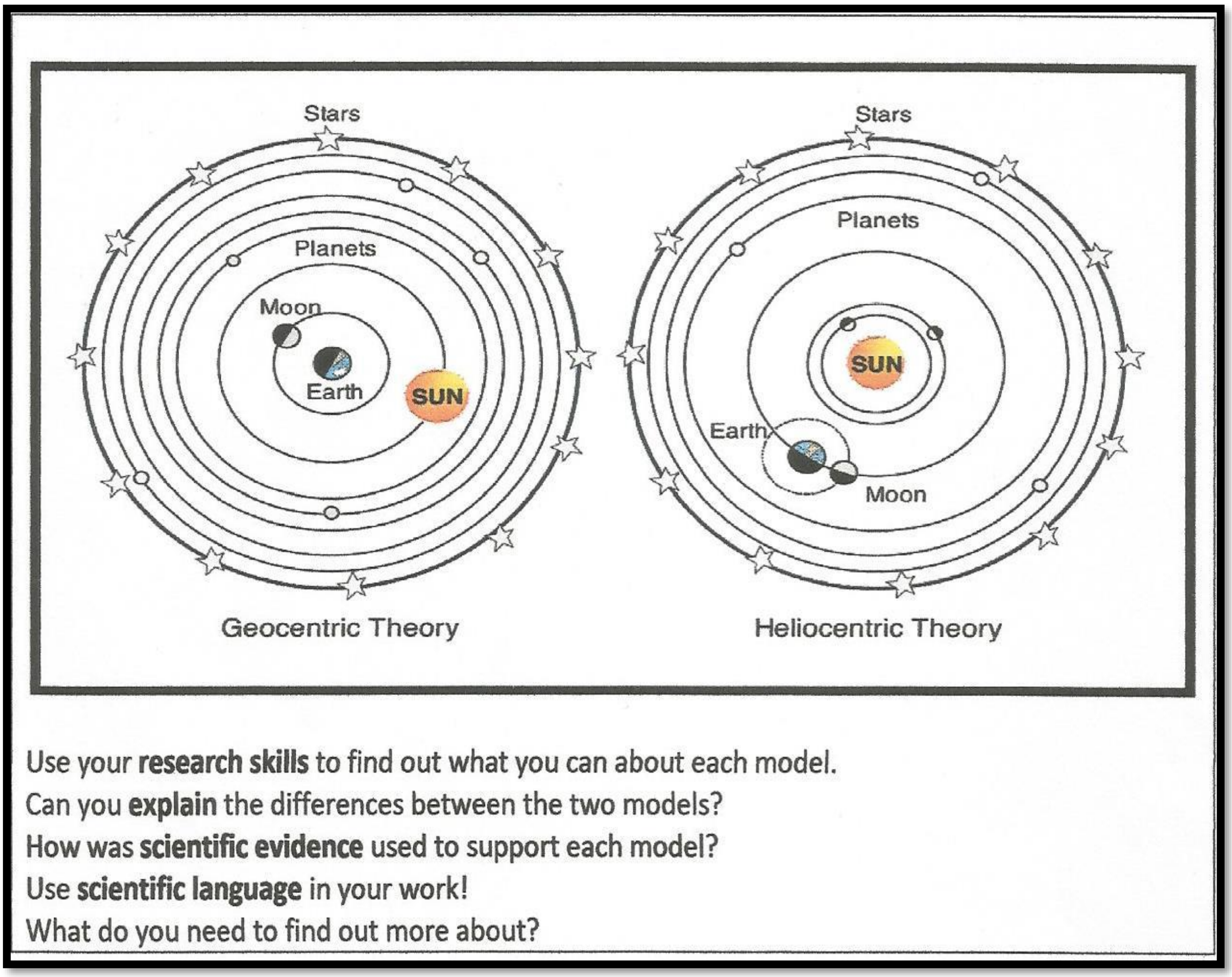


Figure 2: The stimulus given to Year 5 children to research and investigate the geocentric and heliocentric models (McCrory & Worthington, 2018).

What was the role of the teacher here?

The teacher orientates the children by almost providing success criteria (although not referred to as such) that are clear for the children to understand (Nottingham & Nottingham, 2017). It can be argued that there is shared understanding between the teacher and the children (this does not simply happen by itself but is facilitated, over time, by the expectations of the class teacher); the phrases *research skills, scientific evidence, explain* and *scientific language* are highlighted but not explained, indicating that the teacher is building on what he knows the children already know (Hattie & Yates, 2013). The outcomes of the lesson, as exemplified by one child's work in Figure 3, support this assessment. It can be clearly seen that the child has highlighted the scientific vocabulary used and included everything required of the task. What is not clear is whether or not the teacher has prompted the child to do this. I have no doubt that some children would need this prompt; however, it might very well be that what was once an explicit expectation directed by the teacher has now become implicit for the child in question.

The teacher has chosen resources that he thinks the children can access based on his knowledge of the children (PCK, Shulman, 1986). When introducing this, the teacher did not simply give the children the diagram and tell them to get on with the research. On the contrary, he was careful to ask the children to explain their initial understanding of the difference between the two models by asking the following questions:

1. We have been learning about the Earth, Moon and Sun. Let's recap what we know about these.
2. We have also been thinking about how scientific knowledge changes over time because of evidence. What are these two models demonstrating?
3. Can you see any similarities?
4. Can you see any differences?

The teacher encourages the children to recap on what they have learned so far, so that they can make connections between what they know and what they are about to analyse and learn (Hattie & Yates, 2013). The aim here for the teacher is to facilitate the children learning for themselves, to encourage independence and resilience. In terms of working scientifically, this lesson gives the children an opportunity to identify scientific evidence that has been used to support or refute ideas in science (DfE, 2013), whilst using their process skills to answer questions so they can deepen their understanding of the two models. Through activities such as this, children's thinking, reasoning and questioning skills are nurtured (ASE, 2017).

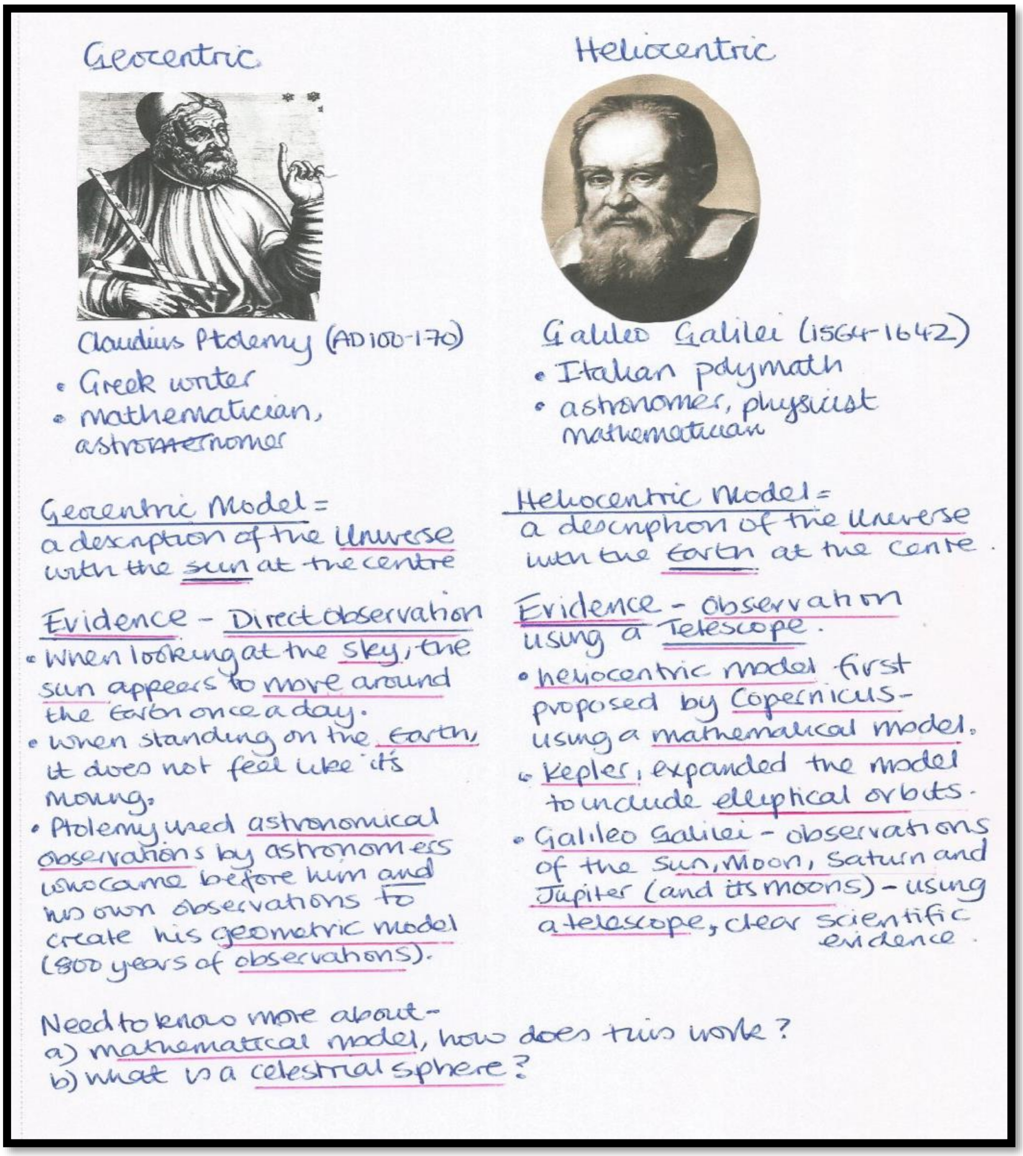


Figure 3: An example of a Year 5 child's response to the challenge in Figure 2 (McCrory & Worthington, 2018).

Reflections

- It is clear that the teacher has taken a cross-curricular approach to teaching science, with links to English and history. The child has found out about the scientists who created the models and provided some short biographical information – the child has communicated the results of his/her enquiry effectively, demonstrating that s/he has not simply copied information from the Internet or an information book.
- The child has identified the different types of observation (direct, and the use of a telescope) used as evidence to inform the models. Interestingly, the child gives examples of direct observation that s/he can relate to. What is not clear in this example is how the child has evaluated the evidence for each model (although s/he does note that the use of the telescope is clear scientific evidence) and, therefore, does not indicate clearly if s/he understands why the heliocentric replaced the geocentric model. Therefore, a next step from this lesson would be for the child to explain this clearly.

Case Study Two – using controversial issues to engage children in learning science

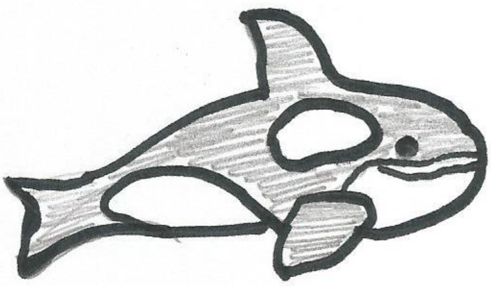
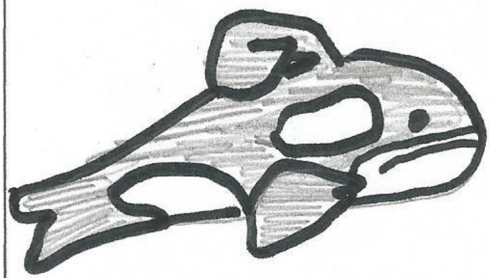
Controversial issues in contemporary life are issues about which there might very well be social disagreement (different individuals and groups interpreting and understanding in differing ways), competition or conflict, but are not easy to define (Sadler *et al*, 2016; Woolley, 2010). It is crucial to understand that a *'controversial issue must involve value judgements, so that the issue cannot be simply settled by facts, evidence or experiment alone'* (Wellington, 1986: 3). Socio-scientific issues typically include a controversial aspect; they involve values and require *ethical reasoning* (Levinson & Reiss, 2003).

As argued earlier, pupil motivation is key to learning; engagement in contemporary issues (socio-scientific issues) is one way to stimulate interest in science (Sadler, 2011; Claire & Holden, 2007). If the social and ethical aspects of science were included more fully in school science, then many pupils may be encouraged to study science longer, as the humanistic side of science appeals to many pupils, particularly girls (Sadler *et al,* 2016). As we know, when taught well, children start to develop a love for science in the primary school, which can only happen if primary-aged children experience inspiring science that *'builds their understanding of the value and place of science in their lives'* (Wellcome Trust, 2013: 4).

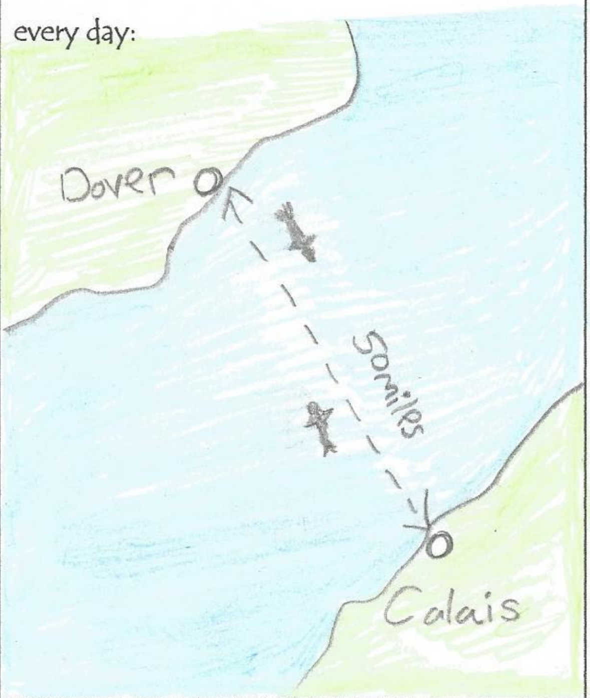
Guidance for the National Curriculum also states that the social and economic implications of science are taught most appropriately within the wider school curriculum: clearly a recognition of the strength of primary teaching – taking a cross-curricular approach to teaching and learning. It also actively encourages creativity: *'teachers will wish to use different contexts to maximise their pupils' engagement with and motivation to study science'* (DfE, 2013: 3), which Wyse and Dowson (2009) argue *'is a right not a privilege'.*

This gives primary schools the freedom to deliver the curriculum in ways that they see best, as long as the statutory requirements are adhered to and children are given both the opportunities and time to develop their enquiry skills and conceptual understanding (ASE, 2017). The following example is the outcome of a project undertaken by two children in a Year 6 (age 10-11) class. The project is authentic and driven by the children's interests; in this case, the children were galvanised by the media story of a trainer at SeaWorld in Orlando who was killed by Tilikum, a killer whale kept in captivity. The report produced incorporated aims from computing, English, geography, maths, PSHE and science.

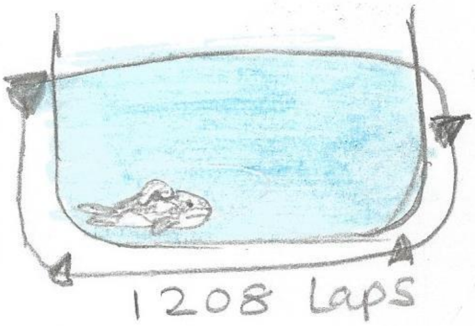
Start of Figure 4, which incorporates the following children's work plus the table.

It is rare for an orca in the wild to have a collapsed dorsal fin, if this is the case, the reason is because the fin has been injured or damaged. In the wild, orca dorsal fins look like this: 	In captivity, orcas spend most of their time on the surface of the water – because of gravity, a lack of support from the water, and being fed an unnatural diet, orca dorsal fins look like this: 
Orcas live longer in the wild! In the wild, average life span for male orcas is 30 (max 50-60 years) ; female 46 (max 80-90 years).	In captivity, the average life span for male orcas is 17 and 27 for females.

In the wild, orcas can swim up to 100 miles every day:



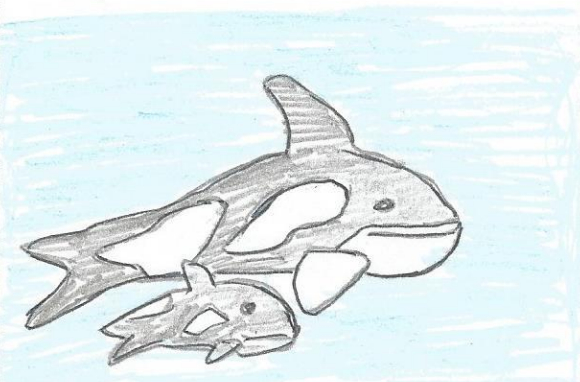
In captivity, orcas are trapped in a tank, they would need to swim 1,208 laps around the tank every day to equal what they would swim in the wild.



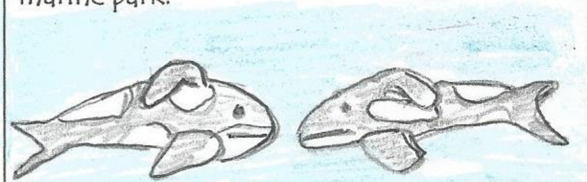
In the wild, there has only every been one reliable report of an orca harming a human.

In captivity, orcas have attacked and killed 3 humans since 1991 and injured many others because of the stress of being derpived a natural life.

In the wild, orcas are highly social animals, living in pods from 2 – 15, calves are raised by the pod . In some pods, calves stay with their mothers for life.



In captivity, orcas are forced to live with orcas from other pods, are moved between facilties for breeding and to perform. Tilikum, was snatched from his mother when he was just 2 years old – taken form his family, he was kept ina holding tank for almost a year before being transferred to a marine park.



Is it right to keep killer whales in captivity?
We think that it is very wrong to keep killer whales in captivity because …

‘They are kept from their natural habitat, their dorsal fins collapse’
‘They are kept away from their families, this is awful – this makes them very unhappy’
‘They don’t live as long’
‘They become stressed and aggressive by being trapped’
‘Isn’t it wicked to keep them in such a small space when they are used to swimming for miles in oceans, they gnaw on the iron bars and concrete from being so stressed – this shows how much they want to escape, so would we if we were trapped and taken away from our family’
‘They are fed an unnatural diet – they are unable to hunt or obtain water from their prey’
‘Being in captivity is the same as being in prison but they have done nothing wrong’
‘They are not for our entertainment’

Figure 4: An example of how to incorporate controversial issues in teaching science – is it right to keep killer whales in captivity? Paired work by two Year 6 children using scientific enquiry skills, ICT, reasoning based on scientific evidence and moral considerations. In addition, the children have demonstrated their scientific knowledge and understanding of science via representations: in this case, habitats, animal behaviour and diet, which is all communicated in a clear and engaging way to support their arguments alongside mathematical reasoning.

Final considerations and discussion

This article deliberately focuses on including two examples of working scientifically that are research-based and which require children to evaluate evidence as exemplars of how scientific enquiry does not always need to focus on ‘fair testing’ or ‘experiments’, although both of these quite rightly have a place in primary science education. Both examples focus on the *nature of science* and are provided to give teachers ideas of what can be achieved by teaching science via enquiry and in a cross-curricular fashion. In particular, when considering using socio-scientific issues to engage children in learning science, it is important for teachers and the children taking part to understand the nature of the controversy – why, and in what way, is this topic controversial and how does it relate to science (Oulton, Dillon & Grace, 2004)?

Debate and discussion are key aspects of lessons based in controversial or socio-scientific issues and ground rules need to be agreed for group work and debates (an important aspect of this is using scientific evidence to justify arguments, as well as being able to identify evidence that is irrelevant); as with any form of discussion and debate, children need to be aware of the learning objective and their steps to success to meet the learning outcomes.

As one would expect, teachers should consider the cognitive capabilities of the children whom they are teaching in relation to the learning of the conceptual science. Pupils should be encouraged to express their own views in a safe environment, where they know that their ***views are valued.*** Children should be taught to appreciate the process, to take part in debate and discussion using scientific evidence (from a variety of sources) and language to support or refute arguments (engaging in the nature of science).

Teaching strategies are varied and can include: group work or paired work, role play such as 'decision alley' or theatre, ICT, debates, producing information posters, PowerPoint presentations, assemblies and research activities (which incorporate a whole range of scientific enquiry skills); this also provides a wealth of cross-curricular links integral to primary education and beyond. Using a variety of teaching strategies also serves to ensure that children do not become bored with the work that they are undertaking, allowing them to be creative and express themselves in many different ways (Wyse & Dowson, 2009).

Teachers should provide opportunities for children to consider the local, national or global implications of the issue and, where appropriate, build on the interests of the child (Duschl *et al*, 2007) – children may be made aware of controversial or socio-scientific issues via the media, movies, television and books and these can be a great starting point. However, teachers should provide children with opportunities to consider authentic controversial or socio-scientific issues that come from the children themselves, as in Figure 4, but which also enable the children to improve or consolidate their conceptual understanding of science concepts (Sadler *et al*, 2016; Spielman, 2018).

Another way to achieve this is through field trips, which typically have a favourable impact not only on enhancing the children's learning, but also by further capturing their attention, therefore adding to the authenticity of what the children are learning. Evagarou (2008) found that a field trip – in this case a visit to a local pig farm by children aged 10-11 – had a positive impact on the students' motivation in engaging with socio-scientific issues and furthering their understanding of the underlying scientific concepts. It provided an opportunity for meaningful learning.

There is now much more support for primary classroom practitioners in using these pedagogical approaches in their classroom; for example, the overarching aim of the PARRISE project (www.parrise.eu) is to share and improve best practices by integrating the pedagogical approaches discussed here – inquiry-based science education (IBSE) and learning based on controversial and socio-scientific issues. The researchers call their innovative approach 'Socio-Scientific Inquiry-Based Learning' (SSIBL), which scaffolds pedagogy so that teachers can build confidence together as they develop the skills needed to teach science in this way. The Primary Science Teaching Trust (PSTT) and the Association of Science Education (ASE) both provide primary teachers with teaching resources and opportunities for continuing professional development (CPD) to teach scientific concepts via scientific enquiry (ASE, 2017).

In conclusion
We can therefore surmise that delivering the science curriculum through working scientifically enables the early years and primary classroom teacher to:

- actively engage children in their learning via constructivism (Skamp & Preston, 2015);
- gauge an understanding of children's ideas about the world (Allen, 2014) and plan learning opportunities to build on these, as well as reconstruct knowledge and understanding;
- facilitate progress in conceptual knowledge and understanding of science via multiple teaching pedagogies (Shulman, 1986);
- challenge and include all children (Collins, 2015);
- encourage children to be curious and creative, because science is a never-ending journey of discovery by the curious (Ofsted, 2013);
- promote science as enjoyable in order to maintain a positive attitude to science. Motivation plays an important role in this (CBI, 2014);
- help children to understand the nature of science by examining evidence and using this to evaluate science concepts and ideas, as well as examine issues based in science that are important to them, thus promoting scientific literacy. Children need to understand that scientists build on the foundations provided by the scientists who came before them and that concepts in science are underpinned by evidence that can be built upon, refuted and/or replaced (McCrory & Worthington, 2018); and
- model how scientists work in the real world by engaging children with scientific methods. The idea that scientists work in isolation must be challenged as it is simply inaccurate – in today's world, scientists are collaborative and children need to understand this if we want them to understand that science is a human endeavour to which anyone from any walk of life can contribute and be successful (McCrory & Worthington, 2018).

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