Chapter 3: Pedagogical approaches and the teaching of science

Chapter aims:

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

- Examine dimensions of teaching that enable effective learning about the nature of science
- Explore a range of approaches to scientific enquiry in the primary classroom
- Develop strategies for enquiry based science education

Introduction

Teachers are continually striving to raise standards as well as provide children with a holistic education that develops the whole child and promotes their well-being. The real pressures that teachers are under means that some may argue that there is little space outside of the traditional Arts subjects for creativity. Fortunately, Ofsted's 2010 report '*Learning: creative approaches that raise standards'* states that 'In schools with good teaching, there is not a conflict between the National Curriculum, national standards in core subjects and creative approaches to learning. (p 5)

In relation to science and the other STEM (science, technology, engineering and mathematics) subjects, the report noted the commitments of these schools to promoting investigation, invention and evaluation. They also reported the use of practitioners, both in and out of the classroom, to extend pupils' opportunities for creative learning. (pg 5) Opportunities for creative science outside the class room are explored in depth in Chapter 11. Other contributing factors were the use of approaches traditionally used in creative subjects being incorporated into science and mathematics. (pg 5) Sadly, in Ofsted's most recent report on schools successful in science (Ofsted 2013) there is no reference to creativity and the previous one (Ofsted 2011) contains only one reference to being creative and it refers to being creative with a budget!

Therefore, this book (and this chapter in particular) aims to empower teachers to embrace creative approaches and know that this will not be to the detriment of meeting internal or external performance targets. Instead with the right planning and confidence in their understanding of the core concepts underpinning science, teachers can deliver creative lesson with engaged children, who are taking ownership of their own learning and developing as active, informed citizens.

What are creative approaches to science?

There is no simple answer to this. Creativity can mean, as has been discussed in chapter 1, different things to different people and at different times depending on the context. This chapter will make a case for some key ingredients to successful teaching and learning in science. By combining elements of these with creative contexts, as explored in Chapters 8-13 (part 2 of this book), effective and creative learning in the primary science classroom can happen.

National curricula and accompanying guidance are excellent sources for ideas and exemplars on how to approach teaching particular subject areas. The 2014 National Curriculum for England (Department for Education 2013) identifies a number of approaches to teaching and learning including direct teaching, drama and discussion across the range of subject areas. In science, it suggests using a variety of approaches. Scotland's Curriculum for Excellence (Education Scotland 2013) offers guidance on a number of key approaches including first-hand experience outdoors, active learning and co-operative and collaborative learning across all subjects. Northern Ireland’s curriculum (CCEA 2007) states that teachers should make use of a wide range of teaching methods, balancing whole class, group and individual activities, to engage children in effective learning. Wales’ curriculum (ACCAC 2003) offers an exemplar on using the outdoors as an approach to effective science teaching. The Irish National Curriculum Teacher Guidelines (NCCA/DES 1997) offers clear direction for how to approach teaching the different strand areas of science and identifies relevant and appropriate methods.

Underlying all this is a common understanding and valuing of the importance of a variety of teaching and learning approaches, particularly in the context of increasing pupil diversity in our classrooms. No one approach is best and certainly when considering the range of learners and their needs a varied approach to teaching and learning is seen as best practice.

Nature of science

The most recent Ofsted reports on schools successful in science (2013, 2011, 2008) clearly recognise that scientific enquiry is at the heart of effective science teaching and learning. Most recently, it was observed that science teaching was most effective when teachers’ set out to sustain pupils’ natural curiosity, so that they were eager to learn the subject content as well as develop the necessary investigative skills (Ofsted 2013). Instances where science lessons were more practical and focussed on the development of the skills of scientific enquiry (Ofsted 2010) and where emphasis was placed on children designing and carrying out investigations for themselves (Ofsted 2008) were also noted. However, each report also recognises the need for further engagement with scientific enquiry. Education Scotland (2012) also report that while there is some evidence of high quality scientific enquiry, there is scope for children to be engaged further in such fruitful investigative work as this is not a consistent enough feature of learning in the sciences across primary school. This is particularly interesting given that Scotland has a longer history of teacher assessment in science and studies (Murphy 2005) have indicated that teaching investigative science was considerably constrained by preparation for national tests. This suggests that other factors play a part in teacher's desire and ability to teach through scientific enquiry.

Underpinning effective scientific enquiry is the need for a common understanding of and appreciation for the nature of science. This is reflected explicitly in the 2014 National Curriculum for England (Department for Education 2013) through 'Working scientifically' which specifies the understanding of the nature, processes and methods of science. A similar focus is implicit and explicit in other national curricula. These combine the key elements of working and thinking scientifically and promote understanding of the nature of science.

The nature of science, in particular scientific methods, will be explored in more depth in Chapter 6 but for now a brief consideration is required. Osbourne et al. (2003) in their research identified nine elements that should underpin ideas about science and the nature of science;

1. Scientific methods and critical testing
2. Science and certainty
3. Diversity of scientific thinking
4. Hypothesis and prediction
5. Historical development of scientific knowledge
6. Creativity
7. Science and questioning
8. Analysis and interpretation of data
9. Cooperation and collaboration in the development of scientific knowledge

See Osbourne et al. (2003) for an explanation of each of these elements.

While there is a common understanding that engaging in scientific enquiry will help develop ideas about the nature of science, Schwarz *et al.* (2004) state that research does not generally support the idea that engaging in scientific enquiry alone will enhance conceptions of the nature of science. Further research was carried out by Bartholomew et al. (2004) and they reported five dimensions of practice which impact of teachers' success with teaching about the nature of science. It was most successful where teachers were confident that they have a sufficient understanding of the nature of science, saw their role as facilitators of learning, promoted open and dialogic discourse in the classroom, valued knowledge and reasoning outcomes and learning activities were authentic and owned by the students. These dimensions, as shall be discussed in more depth in this chapter, strengthen a creative approach to science teaching and learning and foster understanding of the nature of science.

Inquiry-based science education

Investigations and enquiry lie at the heart of science. Though science is a practical subject by its very nature, research evidence clearly shows that a lot of practical work makes little difference to students' understanding of scientific ideas. Many studies have found no significant difference in understanding between students taught a range of topics with and without hands-on practical work. Some of the studies suggest the reasons may lie in the way practical work is used. (Millar 2010 p133) Traditionally, students of science experienced a didactic approach to this, whereby the teacher had control over the various aspects of the investigation including the question to be investigated, how it would be investigated, the expected outcome and how results would be recorded and communicated. This is defined as a transmissive, deductive approach to learning. In this the teacher has a clear knowledge outcome which the students are expected to meet through a singular pre-determined route.

This was certainly the case when we studied science in secondary school and for part of our university degree courses. It wasn't until we had the opportunity to undertake research projects that we really felt we were actually doing science.

There is value to transmissive approach however and in the primary classroom it would be best described as an illustrative approach or closed investigation whereby the question is defined by the teacher and the variables identified, the teacher tells the children what to do and there is one expected answer. In an illustrative approach the aim is to enable the children to experience a particular phenomenon or concept. It is about clarifying or exemplifying a particular scientific idea. It is particularly useful when a shared understanding among the children is desired. This may be appropriate as an enquiry in itself, such as a closed investigation, or before children start investigating their own questions and ideas or equally as effective after to consolidate understanding. It may also be used to teach children how to use particular equipment or tools. Figure 3.1 shows the stages in scientific enquiry and an illustrative approach or closed investigation would typically see the teacher control steps 1-5.

Insert Figure 3.1]

Figure 3.1: The stages of scientific enquiry (from Ward et al. 2008 p. 60)

[start box]

Time for reflection 3.1

Remember the five dimensions of practice developed by Bartholomew *et al.* (2004 p 664), where teachers had success in teaching about the nature of science? Review the scale below in Figure 3.2 and reflect on each dimension. Consider which end of the scale for each dimension of practice an illustrative approach or closed investigation supports.

[insert figure 3.2]

Figure 3.2 The Five Dimensions of Practice (Bartholomew *et al.* 2004 p 664) which impact on the success of teaching about the nature of science

Reflect on your experience of teaching science or from your experiences of being taught science either in university, college, secondary or primary school. Which dimensions and to what degree were they evident in your experiences of science?

Finally, consider how each of these dimensions might encourage creativity.

[end box]

A contrasting approach, which is defined by its inductive approach to developing scientific ideas, is inquiry-based science education (IBSE). Wolk (2008) writes that inquiry-based teaching 'transforms the aims of school from short term memorisation of facts into disciplined questioning and investigating' (pg. 117), which as we know are core elements of working scientifically. Inquiry-based learning gets students asking questions and investigating possible answers, using a variety of skills to collect reliable and accurate data, analyse secondary sources, draw conclusions, reason and debate. (Wellcome Trust 2012) IBSE sees a shift in the teacher's role to one of facilitator and centres the learning around the child. IBSE has proved its efficiency at both primary and secondary levels in increasing children's and students' interest and attainment levels while at the same time stimulating teacher motivation. (Rocard *et al.* 2007) Furthermore, Rocard et al. (2007) report 'IBSE is effective with all kinds of students from the weakest to the most able and is fully compatible with the ambition of excellence. Moreover IBSE is beneficial to promoting girls' interest and participation in science activities' p2.

The evidence is such that the European Commission has shown its support for IBSE through its FP7 funding (2007-2013). This has resulted in a significant number of large-scale Europe-wide projects investigating, developing and disseminating relevant research, practice and professional development around IBSE. These include ESTABLISH, FIBONACCI, PRIMAS, PROFILES, Pathway, INQUIRE and Pri-Sci-Net (Europa 2007). However, Peacock (2012) raises the question to what extent, if any, IBSE has affected the curriculum, teaching methods and professional development in England. His answer suggests little. Instead he recognises the positive directions of Wales, Northern Ireland and Scotland towards more creative approaches to science. Particularly in the case of the Northern Ireland curriculum, he notes the positive impact of teacher independence and freedom in terms of assessment methods on creative approaches to science, including IBSE. However, despite a more open curriculum, Education Scotland (2012) note that at times, practical work in all sectors is still too prescriptive and teacher-led thereby not allowing the development of learners' creativity and enquiry skills.

There are many different degrees to IBSE and a range of interpretations and practice. On one end you have guided enquiry and on the other you have fully open ended, child-led investigations or free exploration, where the children identify the question, how to go about doing it and their solution to the problem based on their question and evidence gathered.

Process oriented guided inquiry learning

Process oriented guided inquiry learning (POGIL) is, as the term suggests, a guided approach to enquiry. It originated in college chemistry departments in America (pogil.org) in 1994 and has gained widespread popularity since across a range of disciplines. It is defined as a learning cycle of exploration, concept invention and application to guide the students' to construct new knowledge. POGIL activities focus on core concepts and encourage a deep understanding of the curriculum content while developing higher-order thinking and process skills. The resources used supply students with data or information followed by leading questions designed to guide them toward formulation of their own valid conclusions and conceptual understanding. Thus making it guided enquiry.

Martin (2011) discusses a number of constructivist approaches to primary science including POGIL and states that POGIL is reported as the most effective for elementary (primary) children.

Problem-based learning

Problem based learning (PBL) is another such 'enquiry-based' teaching methodology and has its origins in the medical field. It is attributed to Howard S. Barrows and Robyn M. Tamblyn at McMaster University, Ontario, Canada. Like other methodologies it has evolved and taken different forms. However, the underlying principle is consistent, that PBL is any learning environment in which the problem drives the learning. And in this vein, it has been around a lot longer than you or me. From the Stone Age people have developed skills and knowledge in the face of problems. However, in its purest state as a teaching methodology, PBL is small group, self-directed, self-assessed learning (Woods No date). PBL requires students to identify and develop new knowledge, understanding and skills before they can solve the problem. Additionally, they should come to that realisation, the gap in their knowledge, themselves rather than being made aware of it by the teacher. Furthermore, the students having identified these knowledge gaps, then go about finding and making sense of these new ideas and apply them to the problem. In this way the teacher takes on the role of facilitator throughout the process. This is where the primary school teacher has a much easier job adapting to such an approach compared to the university teacher (the authors included!), who is used to being in the position of 'fount of all knowledge'. Here the role of the teacher is to ask questions (not answer them) and support discussion by challenging assumptions. Facilitators should use different questions types when facilitating, including informational, application and problem-solving ones (Walsh 2005), which promote both lower and higher order thinking.

A problem-based investigation naturally demands problem-solving and the National Advisory Committee on Creative and Cultural Education (NACCCE) has long since recognised the importance of developing this skill in younger children 'Problem-solving is now a key skill in education. Developing young peoples' abilities to solve problems is fundamental to preparing them for an independent life and a somewhat uncertain future. Creative education can contribute directly to problem-solving abilities in all disciplines and fields of work.' (NACCCE 1999 p 37) This NACCCE report also stated that more opportunities should be given to young people to sense and define problems for themselves, as well as identifying solutions to given problems.

PBL supports both a constructivist and social constructivist approach to learning, as students work together to solve the problem. Through PBL students are starting from their learning. Their own ideas, experiences and knowledge are examined in the context of the problem and misconceptions are challenged and new learning connected to existing ideas. It is important that problems or scenarios are relevant, this is particularly the case with children. They need to be able to relate to the problem or scenario, this encourages them and will allow them to make progress with the problem.

Problems can be set up as 'real' experiences. There is a wonderful example of this in Ashbridge and Joesphidou (2012). It is a cross-curricular scheme of work for infants. Whilst on a walk in the school grounds, the children come across a bear, with a parachute on, stuck in a tree. This leads to lots of questioning and a range of learning opportunities across the curriculum, including science, as the children find out where the bear has come from, who he is and how he will get home. Such an approach is to be recommended when working with younger children. With older children, written scenarios with pictures and/or objects would also work well.

Case example

Scenario: The children are out in the playground when one of them discovers a small tooth (this is set up by the teacher). The children don't know where it came from. They are at the age when they are losing their baby teeth and are beginning to grow their adult teeth so it is relevant to them. There are also a few schools pets and they might offer that it could belong to one of them. There is some scope for some whole class discussion at this stage so initial excitement and motivation can be shared. Then it would be important to divide the children into small groups (no more than 5) to work on the problem. Next follows a 7 step approach to this problem, as suggested by Walsh (2005).

Step 1: Identify the problem

As facilitator, the teacher should encourage questioning around the problem amongst the group. Who does the tooth belong to? How did it get here? Why did the tooth come out? They should encourage talk and discussion amongst the children, not teacher directed talk.

Step 2: Explore pre-existing knowledge

The children should discuss and share their existing knowledge. What do they know about teeth? Why do humans have different kinds of teeth? What do different teeth look like? What animals do they know that have teeth? What are they like? At this stage, the teacher should allow children to share their experiences and ideas about the problem and encourage some critical thinking around the ideas being expressed.

Step 3: Generate hypotheses and possible ways to investigate these

At this stage, children should be encouraged to discuss possible solutions to the problem and how they are going to approach solving it. The teacher needs to ensure all ideas are being heard and considered and that the group have a clear plan of action.

Step 4: Identify learning issues

These are questions that can't be answered by the existing knowledge within the group. These might be: Has anyone lost a tooth recently and not found it? What are the shapes of different human teeth? Why do we have different kinds of teeth? Why do we look after our teeth by brushing regularly? What pets are in the school? What type of teeth do they have? What diets do the different pets have and what kind of teeth would they need for this? Why might an animal's tooth fall out? How do animals look after their teeth?

Step 5: Self study

As this stage, children should be encouraged to do some primary and/or secondary research to help solve the problem. Primary research could involve doing an observational drawing of the tooth and doing a comparison to a child's tooth, identifying similarities and differences or this could again be done by consulting secondary sources. Primary research could also involve collecting data around the diets of the school pets or this could be done through secondary research using the internet or information books. Other sources of information could be the local vet. It is important that a clear time frame is set for this stage so that children know how much time they have and how best to use this time to tackle the identified learning issues. During this stage, the teacher should conference with individuals and groups to ensure they are focussed on their work and addressing issues that will help solve the original problem.

Step 6: Re-evaluation and application of new knowledge to the problem

During this stage, the children should share all the new knowledge and understanding they have gained from their self-study. As well as encouraging sharing, the teacher should also encourage children to ask each other questions, explain concepts to each other and identify and understand the key concepts that will help to solve the problem. The children apply the knowledge gained to the original problem and offer a solution.

Step 7: Assessment and reflection on learning

In this final stage, the children should reflect on the skills and processes they used and how well they worked together as a group. They should evaluate their learning and identify ways to improve next time.

End of case example

Good PBL problems don't have one clear solution. Instead, given the children's experiences, prior learning and information, or resources available, the children may come up with any number of different solutions, there is no right answer! The tooth could be a rabbit's tooth if it hasn't had enough hard things to chew on; the tooth could be a cat's tooth, particularly if the cat is over 10 years old. Poor diet can also lead to gum disease and a cat losing teeth due to the build-up of plaque from canned or dry food. Older hamsters are prone to teeth that may break easily. Some vets also think that a hamster's teeth may break more easily if the diet is low in calcium. It could be a part of a tooth from a fight between animals. The possibilities are many. If you are thinking, ‘my school doesn’t have any pets’ then be creative, what way could you rework the problem so that the children are still developing their scientific enquiry skills and engaging with similar content?

As an extension to this, you could get your local vet to come in and talk about dental care for pets. As highlighted earlier, Ofsted’s 2010 report praised the use of practitioners, both in and out of the classroom, to extend pupils’ opportunities for creative learning. They also are probably the person to ask to get hold of some animal teeth!

The case example links to the following objectives of the 2014 National Curriculum for England (Department for Education 2013), under the content area ‘Animals, including humans’. As can be seen, this problem can be used from year 1 to year 4.

[insert figure 3.3]

Figure 3.3: Links to the 2014 National Curriculum for England (Department for Education 2013) for the Case Example

[start box]

Activity 3.1: Consider which of the working scientifically objectives for Year 1 and 2 and/or Year 3 and 4 could be developed by the case example.

Year 1 and 2 – Working scientifically (Department for Education 2013 p. 147)

- asking simple questions and recognising that they can be answered in different ways
- observing closely, using simple equipment
- performing simple tests
- identifying and classifying
- using their observations and ideas to suggest answers to questions

- gathering and recording data to help in answering questions.

Year 3 and 4 (Department for Education 2013 p. 155)

- asking relevant questions and using different types of scientific enquiries to answer them
- setting up simple practical enquiries, comparative and fair tests
- making systematic and careful observations and, where appropriate, taking accurate measurements using standard units, using a range of equipment, including thermometers and data loggers
- gathering, recording, classifying and presenting data in a variety of ways to help in answering questions
- recording findings using simple scientific language, drawings, labelled diagrams, keys, bar charts, and tables
- reporting on findings from enquiries, including oral and written explanations, displays or presentations of results and conclusions
- using results to draw simple conclusions, make predictions for new values, suggest improvements and raise further questions
- identifying differences, similarities or changes related to simple scientific ideas and processes
- using straightforward scientific evidence to answer questions or to support their findings.

Now let's think back to the five dimensions of practice identified by Bartholomew et al. (2004 pp 664). Would a teacher adopting this kind of problem-based approach to science have to have a sufficient knowledge and understanding of the nature of science? What would they see as their role; dispenser of knowledge or facilitator of learning? Would the teacher's use of discourse be closed and authoritative or open and dialogic? Would the teacher see the learning benefits of both knowledge gains and skills? Who would have ownership of such an activity? How confident would you feel to adopt such an approach to your science teaching and learning?

Now compose a checklist of the attributes needed to adopt this approach.

[End box]

Conclusion

According to the Council for Curriculum, Examinations and Assessment in Northern Ireland (CCEA 2007) children should be able to use creative approaches to be imaginative and inventive, to explore possibilities and take risks in their learning. Some of the ways they suggest that children do this is by experimenting with questions and ideas in a playful way; seeking out questions to explore and problems to solve; challenging the routine method, accepting that there is not always a 'right' answer; learning from and building on own and others' experiences; using all the senses to stimulate and contribute to ideas; making ideas real by experimenting with different designs, actions and outcomes; and valuing other people's ideas to stimulate their own thinking. By adopting an enquiry based approach to teaching and learning in science there is more opportunity and scope for children to be creative in all of the above ways.

At the heart of good practice in science education is investigation. Hopefully a case has been made for adopting an open, child-led enquiry based approach but Rocard *et al.* (2007) note that 'IBSE and traditional deductive approaches are not mutually exclusive and they should be combined in any science classroom to accommodate different mindsets and age-group preferences' (p. 2). Indeed, whether it is teacher or child-led, open or closed, primary or secondary data collection the key elements that are required are discussion, questioning, both teacher and children's questions, starting from children's ideas and experiences and opportunity for evaluation and reflection. These are the consistent elements of teaching and learning in schools which are successful in primary science in England and they are simply good practice.

Further reading

Dunlop, L., Compton, K., Clarke, L. and McKelvey-Martin, V. (2013) Child-led enquiry in primary science, *Education 3-13: International Journal of Primary, Elementary and Early Years Education.* Available at: http://dx.doi.org/10.1080/03004279.2013.822013

In this research paper, the authors describe and evaluate the application of a child-led approach to scientific enquiry to children aged 8–11. It offers useful insights into the experience of both the teachers and children engaged with scientific enquiry.

Wellcome Trust (2011) Perspectives on Education: Inquiry-based learning [Online] Available at: http://www.wellcome.ac.uk/stellent/groups/corporatesite/@msh_peda/documents/web_document/wtvm055190.pdf

This article presents four perspectives on enquiry based teaching; a secondary teacher's perspective, a policy perspective, an international perspective and a research perspective. It addresses the need for informed debate to consider what enquiry based learning means in practice and what role it has in inspiring science education.

Primary Science Teaching Trust (2013) Focused Assessment of Science Enquiry [Online] Available at: http://www.pstt.org.uk/resources/curriculum-materials/focused-assessment-of-science-enquiry-.aspx

Assessment is a key driver of learning and this website provides guidance on how to assess during enquiry work. See also Chapter 5 for more on how to assess skills and content knowledge.

References

ACCAC (Qualifications, Curriculum and Assessment Authority for Wales) (2003) Developing the Curriculum Cymreig. Cardiff: ACCAC Publications. Available at: http://wales.gov.uk/docs/dcells/publications/090902curriculumcymreigen.pdf

Ashbridge, J. and Joesphidou, J. (2012).Who am I? How can we learn to value ourselves and others through thematic work supporting the development of children's knowledge and understanding of the world in the Foundation Stage? In Rowley, C. and Cooper, H. (Eds.) *Cross Curricular Approaches to Teaching and Learning*. London: Sage, pp. 17-33

Bartholomew, H., Osborne, J. and Ratcliffe, M. (2004) Teaching Students ''Ideas-About-Science'': Five Dimensions of Effective Practice. *Science Education* Vol. 88 (5) pp 654-682

CCEA (2007) The Northern Ireland Curriculum Primary. Council for the Curriculum, Examinations and Assessment [Online] Available at: http://www.nicurriculum.org.uk/docs/key_stages_1_and_2/northern_ireland_curriculum_primary.pdf

Department for Education (2013) The National Curriculum in England. [Online] Available at:

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/260481/PRIMARY_national_curriculum_11-9-13_2.pdf

Education Scotland (2012) The Sciences 3-18. Available at:

http://www.educationscotland.gov.uk/Images/Science3to18v4_tcm4-731895.pdf September 2012

Education Scotland (2013)

http://www.educationscotland.gov.uk/learningteachingandassessment/

Europa (2007) http://ec.europa.eu/research/science-society/document_library/pdf_06/fp7-science-education-contracts-2007-2010_en.pdf

Martin, D.J. (2011) *Elementary Science Methods: A Constructivist Approach*. 6th Ed. Stamford: CENGAGE Learning Custom Publishing

Millar, R. (2010) Practical Work in Osborne, J. and Dillin, J. (Eds.) *Good practice in science teaching. What research has to say*. 2nd Ed. Maidenhead: Open University Press

Murphy, C. (2005) Primary science in the UK: a scoping study. Wellcome Trust. [Online] Available at:

http://www.wellcome.ac.uk/stellent/groups/corporatesite/@msh_peda/documents/web_document/wtx026636.pdf

NACCCE (1999) All Our Futures: Creativity, Culture and Education. National Advisory Committee on Creative and Cultural Education [Online] Available at:

http://sirkenrobinson.com/pdf/allourfutures.pdf

NCCA/DES National Council for Curriculum and Assessment/Department of Education and Science (1997) Science: Social, Environmental and Scientific Education Teacher Guidelines Dublin: The Stationery Office

Osborne, J. F., Ratcliffe, M., Collins, S., Millar, R., & Duschl, R. (2003). What 'ideas-about-science'should be taught in school science? A Delphi Study of the 'Expert' Community. *Journal of Research in Science Teaching*, 40(7), 692–720

Ofsted (2008) Success in Science. [Online] Available at: http://www.ofsted.gov.uk/resources/success-science June 2008

Ofsted (2010) Learning: creative approaches that raise standards. [Online] Available at: http://www.ofsted.gov.uk/node/2405 January 2010

Ofsted (2011) Successful Science. [Online] Available at: http://www.ofsted.gov.uk/resources/successful-science January 2011

Ofsted (2013) Maintaining Curiosity: A survey into science education in schools [Online] Available at: http://www.ofsted.gov.uk/resources/maintaining-curiosity-survey-science-education-schools

Peacock, A. (2012) Learning from elsewhere: An International perspective in the development of primary science in Dunne, M. and Peacock, A. (Eds.) Primary Science A guide to Teaching Practice. London: Sage

Rocard, M., Csermely, P., Jorde, D., Lenzen, D., Walberg-Henriksson, H., and Hemmo, V. (2007) *Science Education Now: A renewed pedagogy for the future of Europe*. Luxembourg: Office for Official Publications of the European Communities

Schwartz, R. S., Lederman, N. G. and Crawford, B. A. (2004) Developing views of nature of science in an authentic context: An explicit approach to bridging the gap between nature of science and scientific inquiry. *Science Education*. Vol. 88 (4) p. 610-645

Walsh, A. (2005) The Tutor in Problem Based Learning: A Novice's Guide. Hamilton: Programme for Faculty Development. [Online] Available at: http://www.fhs.mcmaster.ca/facdev/documents/tutorPBL.pdf

Ward, H., Roden, J., Hewlett, C. and Foreman, J. (2008) Teaching Science in the Primary Classroom. A Practical Guide. 2nd Ed. London: Sage

Wellcome Trust (2012) Inquiry-based learning - what is its role in an inspiring science education? [Online] Available at: http://www.wellcome.ac.uk/News/2012/News/WTVM054002.htm

Wolk, S. (2008) School as Inquiry. *Phi Delta Kappan* October 2008 [Online] Available at: http://www.pdkmembers.org/members_online/publications/Archive/pdf/k0810wol.pdf

Woods, D. (No date) Problem-based learning [Online] Available at: http://chemeng.mcmaster.ca/problem-based-learning {Accessed 16 January 2014}