Chapter 6 Working scientifically

Chapter aims

This chapter aims to:

- Help you understand the steps that a scientific investigation should go through
- Provide the framework onto which you can place creative approaches, designs, reporting and communication of the findings

In the new science programme of study in the 2014 National Curriculum for England (DfE, 2013) the term 'scientific inquiry' has been replaced with 'working scientifically'. However, the skills that are described, with only the omission of 'fair testing' and a greater emphasis on classification, have remained broadly similar. Children, across the primary years are still encouraged to ask questions, make observations, test, and record and to make suggestions based on results. However, the phrase 'working scientifically' does have much wider implications. The methods of observation, the type of testing, even the way we present our data can all involve some degree of creativity and invention.

In the last chapter you were asked you to list adjectives that you felt best-described science. If you were asked to do the same again, but this time the phrase was 'science methods' do you think terms like 'enthusiasm', 'excitement' and 'delight' might have appeared on your list? On a chapter dealing with science methods it should not be unusual to talk about excitement and enthusiasm these are after all key features of primary science.

It has almost become clichéd now in the literature, but fostering children's 'sense of wonder' and enthusiasm must be one of the key aims of not only science education, but education generally. While this is recognised as essential (who would disagree after all?) enthusiasm and excitement do at some point need to be appropriately focussed if we are to effectively utilise it. Joseph Cornell's (1989) 'Flow Learning' approach is a good starting point for science sessions. Here early activities embrace and utilise the children's excitement and enthusiasm, but through staged activities begin to focus more their attention.

In science education it is important that we do not make the mistake of assuming that interest is somehow innately present in all science topics. The design of experiments and activities needs to take that into account. Sometimes simple observation and recording may fail to inspire or even maintain children's attention because they do not engage child's imagination. If we are not very careful, we not only fail to channel and focus enthusiasm; we may very well extinguish it.

Key Stage 1 of the 2014 National Curriculum for England (DfE 2013) provides both the guidance (content) and requirements (outcomes) for science and places the child at the centre of the process. Indeed in Year 1 they should:

"be encouraged to be curious and ask questions about what they notice. They should be helped to develop their understanding of scientific ideas by using different types of scientific enquiry to answer their own questions, including observing changes over a period of time, noticing patterns, grouping and classifying things, carrying out simple comparative tests, and finding things out using secondary"

In an activity based on observation children can make connections and have ideas that can be imaginative and creative. They will not always be right but should we at this early stage encourage children to 'chase' predetermined right answers? Being given the answer isn't even how science works, so why should we teach it that way? It really doesn't matter if they're explanations are incorrect; exploring the question is the key scientific process here, not the result. After all, suggested answers can always be tested and that's good science.

Children should be involved in the exploration both in the sense of hands-on and mind-on. In other words being engaged in problem solving, designing experiments and drawing conclusions. If possible you can go with them on the adventure. Don't feel that you need to know the answers, be a fellow explorer, it really doesn't matter, if you all come up with something that's not quite right, that is the nature of science.

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Time for reflection 2.1

"But the reason I call myself by my childhood name is to remind myself that a scientist must also be absolutely like a child. If he sees a thing, he must say that he sees it, whether it was what he thought he was going to see or not. See first, think later, then test. But always see first. Otherwise you will only see what you were expecting." Douglas Adams, So Long, and Thanks for All the Fish

Think carefully about the sentiment of this Douglas Adams quote and reflect on how, beyond challenging its gender specificity, it may influence your approach to teaching science to young children.

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The myth of scientific method

From the outside looking in science often seems to be full of difficult terminology, technical equipment and befuddling analysis, numerical results (that may be significant, or not, whatever that means) and produces inexplicable graphical displays that no one, other than scientists, can seemingly understand.

Well, actually, some of that is true! However, in reality science, at a basic level, is a simple and particular way of looking for answers to questions that we may have about the world around us. As method it doesn't always provide clear answers, perhaps because on occasion our questions are not very clear, but it is unarguably successful in progressing our understanding of the world around us.

Occasionally science is seen as a single entity and references about scientific method may imply that there is some universal format that needs to be followed for something to 'be science'. This of course is actually a common misconception as science is practiced in all sorts of ways and in all sorts of places. Not all science involves experiments and of course it can be practiced in all sorts of different environments. It does in fact have a range of different methodological approaches that can be both practical and theoretical and these in turn may be pragmatic, inventive and in some cases, even accidental! The National Curriculum identifies key features of scientific enquiry namely;

"observing over time; pattern seeking; identifying, classifying and grouping; comparative and fair testing (controlled investigations); and researching using secondary sources" 2014 National Curriculum for England (DfE 2013)

It suggests that answers should be arrived at through collecting, analysing and presenting data. Often the results are presented in similar ways but the ways in which the results are arrived at can therefore be exceptionally varied. This is good news for those who wish to bring creativity to the practice of science because it does afford plenty of opportunities to do just that. In fact, another common misconception in science is that it discourages creativity, in that it is a linear process going through a number of well defined and clearly prescribed steps. In fact the best science is often founded on creative thinking and creative approaches to problem solving. Far from stifling creativeness, science actually encourages it.

Having said that there are wide ranges of methods and that science does not have to be a linear process for clarity this chapter will consider certain characteristics of science based inquiry that are perhaps useful at the primary school level and that are also suggested in the 2014 National Curriculum for England (DfE 2013) guidelines. However, any practice in science needs to creative and that often involves the development of new methods and approaches. It is at the heart of good science investigations and practice and it is a point that we make no apology about returning to several times.

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Time for reflection 2.2

"When I think of innovation and I think of creativity, I don't necessarily think of thousands of scientists getting together to create a gigantic space program. I think of the individual scientists. The people who have this "ah-ha" moment, this "eureka" moment that allows them to see farther, to make that incredible breakthrough, to open up whole new worlds that were never seen before."

Dr. Michio Kaku: Theoretical Physicist and Author

http://curiosity.discovery.com/question/creativity-role-in-science

Consider this quotation. To what extent are the children in your class involved in the creative process of science? Are they involved in designing experiments to answer questions? Do they have the opportunity to test their ideas? To what degree do you explore with them?

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Observation

Trying to understand the world we observe around us is perhaps the basis for all human inquiry and not simply science, so as such it's a pretty good place to start. Simple observation is the basis of much of science and it shouldn't be underestimated as an investigative tool in itself. After all, Charles Darwin formulated the theory of natural selection on work that was essentially observational. It may seem like a long way from Darwin to the National Curriculum, yet scientific observation appropriately is a key feature in the first section of Key Stage 1. It is also a significant advantage to us as teachers that it is something that children do all the time.

Of course the problem with observation as a method is that there is far more to it than a cursory glance over things. Observing requires not only very careful looking, but also some degree of thoughtful or rather intellectual engagement.

In terms of observation there are a number of tricks of the trade. One of these is to promote what could be called ‘attentive watching’ meaning looking with some form of purpose, as opposed to simply observing something. Of course, imaginative engagements in observation (shapes of clouds, patterns on water surfaces) are an excellent way of initially engaging children. Once they have begun to observe however, their observations may need to be focussed and the simplest way of achieving this is through simple questions. Observing with a question to answer can be much more focussed than general observation.

With the later we rarely notice detail.

Before going on, read Activity 2.1 as this a practical example of promoting active observation.

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Activity 2.1

Collect together a variety of about 30 everyday objects. Don’t choose anything too large, as you need to be able to easily carry them all. Chose some objects that are brightly coloured (such as a red ball, a bright marker pen) and others are simply wooden (a peg, a wooden spoon, pencil).

In a wildlife, or wooded area, certainly beyond the sight of children (or even colleagues) pace out about 30 metres along a path, marking both the start point and the end point. Walk back along the path that you have marked out and randomly place each object somewhere along it. Don't place them too far from the path, as they need to be clearly visible (you'll need to find them all to collect at the end of the activity!) Also, try to place some of the objects above ground, on the branches of shrubs or trees. Once all the items have been secreted the activity is ready to begin.

Line up the children and (your colleagues) and tell them that along the path there are a number of items that should not be there (you need to stress that they are everyday items). Ask them to walk quietly along the path and count the number that they see. At the end of the path, ask the children how many they counted. The number is normally pretty low (normally well below half) and your colleagues may not have spotted many more! Make a note of what has been seen, and ask them to walk back and count again, only this time looking really carefully, and also looking up into the branches. When they've completed the path for the second time, ask them how many this time? They will have improved an awful lot, but in all the time we've done this activity with children and trainee teachers, they have never spotted them all. Of course it is the wooden objects that are the hardest to find. The brightly coloured objects are seen almost straight away. This last point of course can provide some interesting discussions with older groups about camouflage in nature and its use in avoiding predators. However, with all groups it introduces the idea of close and purposeful observation.

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Asking the right questions

From observations, science comes to ask questions, either about ourselves or about the wider environment. Of course asking questions is not unique to science, as sociologists, philosophers, theologians and all sorts of non-science methods of inquiry also ask questions and seek to understand more about the nature of the world around us. Given that, what makes science different? Well, the primary difference is that science has a peculiar approach to providing answers to questions that relies on producing evidence normally, but not always, through experimentation. We do ask questions of course but we often set out to find answers in science by using a peculiar method known as ‘hypothesis testing’. A hypothesis tends to take the form of an initial guess at an outcome, or explanation, so just to make things even more complicated, they sometimes aren’t even questions, but may take the form of a statement of a possible explanation. It is this explanation that we then set out to test.

A hypothesis therefore will lead to some form of testing and more often than not in science this is through experimentation. It is very important to understand the idea of a hypothesis, because it allows us to ask appropriate questions even before we start to design experiments.

The easiest way of thinking about a hypothesis is that by and large they can be answered by three responses, namely, ‘yes’, ‘no’ and ‘perhaps’ and results should not be dependant on personal preference or relate to phenomena that cannot be measured.

For example, the question “How many leaves are there on that tree” is not really a hypothesis, as it will lead, if you could be bothered to count them, to a definitive number – say 12,345. Answers like this should promote the response, ‘so what?’

A different question might be ‘Are the leaves broader on the south facing side of the tree than the north facing side?’ This is better, for this allows us to test that statement and to perhaps suggest why, or why there is not, a difference. It also fits with our simple test, in that the answer is likely to be ‘yes’, ‘no’ or ‘perhaps’. If the result shows a difference and this result still promotes the response, ‘so what?’ we can now talk about why there is a difference and explore further some ideas for why this appears to be the case.

This is a really key idea in the methodology of science as investigation of one hypothesis will invariably lead on to others. Simple questions have definitive answers and are often full stops in investigations. A key issue here is to let the children develop their own hypotheses and then to help them test them. It is required at Key Stage 1, but more importantly it empowers the child to see that all explanations have validity at this stage. Their explanations at this stage can be as imaginative and as creative as they like as such engagement will facilitate their direct involvement in the next stage, namely that of experimental designs and hands on experiments.

Designing good simple tests and experiments

Having spent some time thinking about the nature of questions, we are now in a position to start to think about designing experiments. Now without labouring the point and also stating the obvious, it is very important to design an experiment that actually goes at least some way to attempting to provide evidence to support, or not to support the hypothesis. You'd be surprised by how many people lose focus at this point; perhaps in part because, as you should be aware now, not all experiments provide direct and irrefutable evidence, they are normally a small part of a much longer process.

Generally, experimental design needs to consider all of the factors that are not in the experimenter's control that may influence the result. We call these factors 'variables'. So, if you were designing an experiment to measure the acceleration of two toy cars travelling down a slope that was to be set at different angles, what other variables may influence the toy cars acceleration? These might include the type of tyres, the efficiency of any bearings on the axels, the relative masses of the two cars, in fact there are quite a few. Even perhaps the different shape of the cars might produce variable drag. This last one probably wouldn't be much of an influence, but is probably worth thinking about, just in case. Good experimental design identifies as many 'potential' variables as possible and then tries to eradicate them, or at least reduce their influence as much as possible. Thinking about other influencing variables can be quite creative in its own right. All sorts of suggestions may be forthcoming. Again, it can empower children to offer ideas and to get involved in a design process and help to develop their confidence where there are no 'right' and 'wrongs' only ideas.

A good deal of this reduction may be achieved by standardising the equipment used, so for example, you might use the same type of toy car on both slopes. The idea in this experiment would be to make sure, as far as reasonably possible, that only the changing angle of slope of the surface influences both cars descent.

When carrying out an experiment it is always worth remembering that any variable that the experimenter controls or changes (in the previous example it might be the different angles that the slope is set at) is known as the ‘independent variable’ A good experiment normally only involves one independent variable. The variable that we are looking at to record any change to as we alter the independent variable is called the ‘dependant variable’. It really is important for teachers to understand this, as it is a very simple way (despite the confusing language) to make experiments really robust. A good experiment is one where only the changes made to the independent variable (the one that is controlled/altered by the experimenter) could result in changes to the dependant variable.

Living with error, looking for precision and accuracy

Once you have understood the idea of variables, the next stage is quite straight-forward. In some cases we cannot keep the dependant variable as the sole influence on the experiment, other factors, however careful we may be, might influence the outcome. In fact sometimes we can only reduce the influence of other factors as no matter how hard we try it is sometimes simply not practically possible to do so. This provides us with so called ‘sources of error’ in our experimental design. We try as hard as we can to make the independent variable the sole influence on changes to the dependant variable, but sometimes those sources of error may still be there influencing the results. At this point of course, we just have to live with it and accept that there may be some error in our results, but that is not a problem, because we have a way around this. An important characteristic of experimental science is ‘replication’. This word has a number of different meanings in science, but in this instance it simply means doing the experiment several times over. This produces a number, or a set, of results. If there is variation between the results for the same experiment it will be due to sources error. Children should not be concerned about this, as it will inevitably happen, they need to know that sometimes it is just part of doing an experiment.

Perhaps the simplest way of dealing with these variations is look initially at the results and see if there is anything glaringly obvious errors that can be easily sorted out.

If not, then we can begin to think about ways of living with experimental error. One of the most usual ways is to repeat the experiment a few times. This provides a number of results, or what is referred to as a ‘set’ of data. From the data set derived from repeating the experiment, you should be able to calculate a simple mean. Of course this brings us on to data presentation and simple analyses. However, before we move on to the next stage, it may be valuable to clarify a couple of terms that are often used erroneously in relation to experiments, namely ‘accuracy’ and ‘precision’.

To explain these terms let’s start with a question. If you were a footballer and had several shots at goal during a match, would prefer your shots to be accurate or would you prefer them to be precise?

You would most probably go for accurate, because accuracy is a measure of how close you come to an aimed at value, in this case the goal. An accurate range of shots would be on target to go into the goal-mouth, but may be spread around rather than clustered in one area of the goal. You'd certainly give the goal-keeper something to do.

A precise range of shots would indeed be closely clustered together. In fact a precise range of shots would hit exactly the same spot each time. The problem of course, is that the location of that same spot the shots hit may be the corner flag! Hitting the corner flag over and over again when you are aiming at the goal, is very precise shooting, but not very accurate. Hitting the ball somewhere different in the goal (top right, bottom left and so on) is accurate, but not necessarily precise.

Data and its creative presentation

One of the interesting things about science is that it often seems to convert everything to numbers. The speed of something becomes a number, the taste of something can be (with some thought) be converted to a number, even colours (and the brilliance and depth) can be described by assigning numerical values. It can be quite good fun to come up with 'taste' or 'colour' scales. Of course most numerical values are based on an S.I. units of measurement and these are adopted everywhere. Again, there is nothing wrong with children getting used to measuring in units by designing their own (for example distance by hand widths, volume by Smarties) but sooner or later the appropriate unit will need to be introduced. It is worth remembering which unit we use for certain measurement, as there are often mistakes made over this. Probably the most common is the unit used for the weight of an object. In conversation we will often say that something weighs so many kilograms, when actually the S.I. unit is Newtons, as weight is measured as a force the kilogram is a measure of mass.

Graphs are a pictorial presentation of the collected data and they do afford an excellent opportunity for creative design. There are plenty of inventive ways to present data from traditional charts and graphs, to three dimensional structures constructed from art materials, to 'living graphs' involving the children as the unts. Of course with any graphical presentation the key components of graphical presentation should really be observed, namely a clear title as to what it shows, that the axes are clearly labelled and that the S.I. Units (or children's units) are given and that in all cases the independent variable (remember, the one that the experimenter controls) is plotted on the x axis and that the dependant variable (the thing that the experimenter is looking for change in) is always plotted in the y axis. Just getting making that clear and consistent will be truly advantageous as the children move through science at school.

Drawing conclusions

The reason we do experiments is to provide evidence to help answer, or at least elucidate a hypothesis that we normally set up before we start. We can take any data the experiment has provided us with and we can present it in a way that allows us to clearly see what has happened. Very often when we do this of course we find very little has actually happened! The important thing at this point of course is not to immediately think that the experiment has not worked. It usually has worked and you

have provided some intriguing data, it just sometimes means that it’s worked in a way that you weren’t expecting.
This is a really important point, if you have reduced error as much as you can and you are assured that it would only be the changes in the independent variable potentially causing change in the dependant variable, then your data is valid. If you have found nothing happens, then that may be a really important finding. In science negative results are always more important than positive. It is a really important feature of science that we rule things out rather than rule things in. It is a perennial problem trying to convince enthusiastic children of this however.

Of course part of the process of looking at the results is that it can encourage further questioning not only of the process, but also of course, of the experimental design and this too is a really valuable focus for discussion. “How could we have done this experiment in a different way?” is the sort of question that relies of creative thinking and eventually, action. The process allows children to see that science is actually a continuous process of design, experiment, results, conclusions, redesign.

Back to the National Curriculum

In September 2013 the UK Government published the new science programmes of study for Key Stage 1 and 2 to be introduced in England in 2014. It is a 32 page document and if you are a primary school teacher or are training to be one, you should be familiar with it. A simple frequency analysis of the document is quite illuminating. As one would expect the words ‘science/scientific’ are quite frequent, occurring 103 times. Following a science based approach, the word ‘question’ occurs 52 times which is the same for the words ‘observe/observing’. It can be assumed here that questioning and observing are then key features of science in Key Stage 1 and 2. Recording observations is referred to less with the words ‘record/recording’ occurring 25 times in total. The word ‘data’ occurs 19 times, ‘conclusion/s’ 6 times, ‘presenting/presentation’ only 5, ‘creative’ 3 times (but in relation to creative uses of materials). Curiously, the word ‘experiment’ occurs only once. Words such as ‘imagination’, ‘inspire’, ‘wonder’, ‘outside’ perhaps not surprisingly do not appear in the document.

This simple word count, without context, is only provided to show at least how important the initial stages of observation, recording and questioning is in relation to the National Curriculum. One further aspect that it more positive in the context of this chapter is the following from the Science Programme of Study: key stages 1 and 2:

“teachers will wish to use different contexts to maximise their pupils’ engagement with and motivation to study science”

Investigation in a variety of contexts in primary science provides the best opportunity for children to develop scientific thinking and skills. It will be the teacher who will now need to identify these contexts. The opportunity is now there to be inventive and creative with science methods. Hopefully you will take it.

Further reading

Feasey, R. (2005) *Creative Science: Achieving the WOW Factor with 5-11 Year Olds*

This is an interesting book that while predating the present changes to the primary curriculum provides some original ideas and approaches. David Fulton Publishers. Abingdon. Oxon.

Winston, A. (2014) *Quilt Lab: The Creative Side of Science*. C & T Publishing

A short book about how to use making quilts to teach about science and maths. It provides some intriguing ideas

Ofsted (2003) Expecting the unexpected: developing creativity in primary and secondary schools. London: Office For Standards in Education.

Always worth knowing what Ofsted think about creativity.

Johnston, J. (2007) 'Creative Science?', Teaching, Thinking and Creativity No. 22 Available at http://www.bishopg.ac.uk/docs/Profiles/Johnston_TTC22_pg42_47_Can_children_be_creative.pdf

This paper reviews what is meant by creativity and it's implications for primary science teaching

Leedy, L. (2006) *The Great Graph Contest.* Holiday House

A small book for younger children about graphs.

Whitehead Nagda A. and Bickel, C. (2002) *Tiger Math: Learning to Graph from a Baby Tiger*. Square Fish

Popular children's introduction to drawing graphs.

Roden, J., Ward, H. and Ritchie, H. (2007) Primary Science: Extending Knowledge in Practice. Learning Matters. Exeter

Good guide for new teachers but Part 1 in particular is useful in relation to science inquiry.

Finally the Understanding Science Website is an excellent resource. Available at http://undsci.berkeley.edu/

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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