# **Doing what we do better than we’ve ever done it: Simple ideas for Enriching the Science Curriculum**

\*Draft only\* : article for comment only

by Dr. Joe Ireland.

Abstract:

This article explores ways to enrich the primary science syllabus by using practical suggestions and clear explanations of the Scientific Process Skills, such as remembering, writing, sorting and listening. But there are many more scientific process skills that add volumes to the primary science curriculum, such as questioning, observing, explaining, predicting, theorising, communicating, experimenting and much, much more. Science is a pedagogically rich subject area that has a lot to contribute to the early childhood curriculum, even moreso when the wide array of scientific ‘ways of behaving’ are enlisted to the cause.

This article is written to the early childhood teacher looking for ideas to enrich their science curriculum. Science process skills, such as remembering, writing, sorting and listening are an important part of any science curriculum. However, too often these few skills are all the science a class has! There are many important science skills that greatly add to the learning outcomes of the school curriculum, such as questioning, observing, explaining, predicting, theorising, communicating, experimenting and much, much more. These process skills are a part of what it means to be “Working Scientifically”. Science education has moved on quite a bit since these ‘process skills’ were the whole focus of what it meant to teach science, but they still play an important and vital contemporary role in science *and* in the science classroom today (Carin and Bass, 2001).

The Queensland science curriculum hosts an entire page of verbs associated with working scientifically (QSA, 1998, see appendix B). By getting to know the skills that practicing scientists use, and seeing how they can be meaningfully employed in the primary science classroom, teachers can enrich and expand the repertoire of activities that make up ‘working scientifically’. More importantly, they can help students become better creators and users of scientific knowledge in the classroom and their communities.

As you read the article, I would ask you to consider these science process skills and look for ways you can explicitly include them in your teaching. You may be surprised at how much good learning you already encourage is considered ‘Working Scientifically’.

For example, consider the following scenario;

The teacher sets up a table and rolls a sealed tube forward along the table. To her feigned surprise the tube rolls back towards her. After the laughter subsides, the teacher asks: “Why did the tube do that? Can anyone think of a reason?”

## Questioning

In science, there is probably no skill more important, nor attitude more helpful, than to encourage your students to be askers of questions. Most science begins with a question. Even those great discoveries that came about by accident did so only because someone eventually asked “What’s happening here?”

Modern science education owes much to the constructivist philosophy; that learning best occurs when students are guided to construct their own understanding, and not being ‘given’ the right answers by teachers (Fleer & Hardy, 2001). What this can mean, among other things, is that students are always better motivated, and often learn more, when they are researching their own questions (Abruscato, 2001). Questions form a major, even key roll in real science, and have an important roll in school science (Harwood, 2004). Many modern curricular techniques are based on the teacher choosing and initiating interest in a topic, and then helping the children develop their own questions and ways of finding answers to those questions. Teachers could design an entire unit of work around questions the students have brought up. (For example, see French, 2004 or Skamp, 1998). One useful idea that is never likely to grow old is to bring a unique object to class and have the children write all the questions they can about it. Then you can discuss ways to find answers to the questions, or choose one to work on for a unit of work.

Sometimes, however, a student might propose a question which is untestable - perhaps it is beyond the scope of classroom equipment and talent (“Can we smash an atom in class?”) In this case, you can always visit those that do have the funding, or have a fundraiser yourself. (However… while we all know primary schools are under funded in terms of science equipment anyway, most magnetrons are outside the budget of many nations…) However, you might be surprised at the cost effective and creative experiments you and the children can generate (except perhaps when smashing atoms).

The best science questions are ones that we can look to find the answer to, maybe through research or an experiment of some kind. Indeed, whether an idea is testable is one measure of whether it is considered scientific (Popper, 1972, and is one protest against the Intelligent Design theory). Science questions might be “What foods do lobsters eat?” “How do ants know when it’s daytime?” “Why does it rain?” Or even “Why is dirt brown?” In our example, the teacher can encourage students to ask questions about the roller: “Why does it return?”, “Does its outside colour make a difference?”, “What happens if you shake it?”, “Does the way or direction it is rolled it effect it?”, and, of course, “Why did the roller return?“

It may seem a superfluous comment to encourage question asking when young students are so naturally curious, but sometimes we all need a reminder (and sometime, it’s been so discouraged in them that they just aren’t inclined to try any more). When you are faced with questions you cannot answer, please avoid “It just is”. Perhaps better answers might be “We can find out!”, or, “I don’t know, yet.” Can I also suggest; “how do you think you can find an answer to that question for yourself?” Indeed, if there is one thing teachers can do to enrich their primary science curriculum it would be to encourage students to ask more questions and think of ways to find, and test, their own answers.

Questions lead us in certain directions to look for answers, and learning to ask questions, and finding ways to answer them, is possibly the very essence of science itself. In the words of Dr Who (the Science fiction TV character, not the president of China) “Answers are easy, it’s asking the right questions that’s the trick.”

## Observing

We are constantly observing the world through our senses of sight, taste, touch, smell and hearing (although, since taste and smell are both chemical reception, why not combine them into one sense? This give us the chance to add balance – without which it is more difficult to tell which way is up, or when we are changing speed and direction. Roller coasters would be a whole lot less fun without balance! Why has it never been counted as a sense? – tradition.) Not only can students see the roller, they can pick it up and feel its curved edges, shake it and listen to the sound, and a whole lot more. Carefully observing, and with equal care recording your observations, is an important skill in science.

However, science has a special purpose for observation; it is used *only* to say **what** you experienced, and not **why** it may have occurred. Knowing the distinction here is a difficult skill for children and adults alike. It requires suspending your explanation of what is happening: just say exactly **what** you saw/ heard/ felt etc, and not give any reason **why** things might behave as they do. For instance, you enter a room and smell a rose, but that doesn’t mean there *is* a rose near by, only that you smelt one. There could be many reasons why you smelt a rose: rose oil, perfume, hallucinations again etc. Understanding the difference between observing and explaining an observation is a challenging task!

Developing observation through senses is a great learning activity, and one that children are arguably engaged in every day. To enhance the experience, for example, teachers may set up a ‘senses centre’ with various activities for students to hear unique sounds, blindfolds to help feel unique objects (and ‘see’ them with their imaginations), and essential oils to smell unique smells. Indeed, whenever children pick up an object to explore its size, colour and shape they are observing (and perhaps that’s why everything ends up in a toddler’s mouth: taste, touch and smell all at once!)

Developing the skills to *report* observations is also an important skill in life and science. Students could perhaps record and share their observations using pictures to show whether the day feels hot or cold, create collages to express textures, or use magazine cuts-outs to demonstrate what certain smells remind them of.

In our example; the teacher rolled a cylindrical tube in one direction along a table and it rolled unexpectedly back. What was observed? The roller returned. Observations do not contain explanations, such as the floor is on a slope and it made the tube roll, or the tube was scared and wanted to be back in your hand. Say *what*, not *why*. The task of explaining why is the job of the next science skill.

You may be wondering why it is so important that students understand the skill of saying *what* they experienced, and not what it might mean or *why* it is so. This is because students and teachers often confuse ideas or explanations with sensory experience. They think they see a spider, so they decide it **was** a spider. But sensory illusions also help to illustrate that what we sense, and how we make sense of what we sense, are very different things. By making our observations separate from our explanations we realise our ideas are theories that can be tested.

## Explaining

(AKA ‘theorising’ or ‘Inference’)

Explanations are attempts to give reasons for the observations. All explanations have some merit, thought the most meritorious could be said to be based on their observations and not entirely on prior or intuitive beliefs[[1]](#footnote-1). Explaining helps the children explore the world with their minds as well as their senses, and is a key skill in science that might lead to the creation of theories. To encourage creative explaining, you could encourage a brain storming of ideas and explanations whenever children bring you a question, or try a think / pair / share activity to get the explaining juices flowing (Candler, 1995).

In our example, students now make suggestions as to why the roller behaves as it does. Perhaps it doesn’t like you. Perhaps there is a little mouse inside running along. Maybe it has something to do with magnets. Children are very creative in their explanations, and creativity is one of the most important attributes of great scientists (and ‘more important than knowledge’ in a quote attributed to Albert Einstein).

To further illustrate the difference between observing and inferring, for instance, a teacher walks into a room and there is a puddle of water between two children and one is holding an empty cup. One might understandably assume that they spilt the water, but this would be inferring, not observing. The observation is that there are two kids, a cup, and a puddle. But one would be wise to suspend judgement until sufficient evidence is gathered. It may turn out they found the puddle and the conscientious pair decided to try and pick it up with an empty cup?

Once they have an explanation (sometimes called a ‘theory’), your students might like to test it, and so we move on to the next science skill.

## Predicting

This science skill is all about using our ideas or explanations of the world to predict what will happen. We can thus test our predictions to see if our explanations are supported by evidence. This is a very important way to know if we’ve come up with the best science ideas possible. One classic prediction experiment has students deciding whether things dropped into water will sink or float (followed by also explaining why they thought so.) Perhaps the children have a theory that popcorn actually pops simply because they are shaken around a lot. Is there a way to set up an experiment to test a prediction using that theory? Predicting is an important way to help children think out their consequences and the way the world works.

In our example, based on the explanation that “The tube’s rolling is caused by magnets” your students might predict that, “The roller is attracted to your ring / belt buckle, so if you roll it towards me it will keep rolling!” Observation often pops right back in about now, as the predictions are tested as accurately and fairly as possible. You’ll find that with all these aspects of working scientifically, they often interrelate and need not follow a strict linear progression.

Predictions are a powerful way to teach. Instead of using science demonstrations to prove science ideas things next time, perhaps you can stop just before you complete it and ask students what they think will happen. Encourage them to give explanations as to why they think a certain event will occur. Then you can complete the demonstration and have them assess it in terms of their ideas. This is the basis of the Predict- Observe- Explain teaching technique of Mitchell & Mitchell (1992).

While predicting, it is vital to remind students that it is not important whether they ‘get it right’, but whether they learn something or not. After all, what is science; creating and testing ideas or learning to agree with an expert? For instance, when doing an experiment have the children predict what they think will happen. When the results are not what some children expected, point out that the goal of science is to *learn things*. Ask for hands up who learnt something (all the children whose result was not what they expected, for one), and then give a big clap to the children who learnt something because learning is what science is all about.

Returning to our demonstration, eventually you’re going to have let the children open it up. But even when they do, seeing what is inside isn’t enough to understand how it works. Students will still need to use their imagination, creativity and past experience to understand how the roller operates when the cylinder is all closed up. In short, they need to create an explanation, or a theory, of what makes the roller return.

## Theorising

After testing their prediction, students should be encouraged to express what they think this tells them about how the world works. Their explanations may be called a theory. Theories are like stories; explanations or models that attempt to make sense of the complex way the world operates. Theories often involve things that aren’t directly observable, such as atoms or forces. Each theory implies certain predictions about the world can be made; thus we test our predictions, not our theories (since, for one reason, theories involve things that cannot be directly observed.)

Researchers such as Sandoval (2005) have been arguing for some time that science should be taught as models or theories to be tested (especially ones generated by the students themselves), and not as impersonal concepts to be demonstrated as correct. A powerful way to teach can be to have student’s gather their own evidence to support or refute the explanations given in textbooks or from the teacher. (As opposed to the current practice of giving students the theories and explanations, and then the tests that supposedly ‘prove’ them true). Doing this can help students come to know the nature of science better, especially if you talk openly about the processes (Abd-El-Khalick and Lederman, 2000.)

If, however, students do become stuck or seem to be re-enforcing the wrong ideas, you still can choose to present the accepted scientific explanation as a theory or model for the students to *test*, as opposed to the answer they’re *supposed* to be getting. For example, ‘one theory that scientists often use to explain this situation is… what do you think’ (Abell, Smith & Volkmann, 2004). They may disagree with the theory, but the hope is that they will at least understand it. This brings them into conversation with scientific ideas, rather than subjugation.

The important point here is that scientific knowledge need not be taken for granted. Students can and should explore scientific claims and concepts for themselves, and not simply absorb them from a text book or believe them because the teacher says so (ie, Spencer, 1864). The failure to do so may be one factor that leads to disaffected learners of science who fail to see its usefulness in their everyday life, as opposed to becoming scientifically literate individuals who use their critical thinking skills to make valuable contributions to a knowledge driven society (Carin and Bass, 2001). Students in any science class can become ‘scientifically literate’.

Creating and testing theories is what science is all about, and it’s something students can do too. Set up some batteries, bulbs and wires, and after students manage to light them, challenge them to create, and test, a theory as to what is happening in the wires (ie, Abell, Smith and Volkman, 2004). Challenge students to explain the relationship between the length and period of a pendulum (eg, Carin and Bass, 2001). Teaching science as theories to be explored, rather than as concepts to be memorised, is a powerful way to enrich the primary science curriculum.

## Communicating

Once students have learnt something new they have the opportunity to explain it to others. Scientists do this all the time. Students can use many different means to express their ideas. They can draw them, act them out, move their hands like the wind, imitate animal sounds with their voice, write a story about Derry the Drip and a day in the life of the water cycle. There is a large scope for creativity, and for using the arts in science, to express scientific ideas (Meador, 2003). Learning to communicate ideas clearly and informatively is a useful skill in life, and communicating ideas to others is a powerful way of helping students consolidate and monitor their own learning. Science communication traditionally, and for good reasons, also plays an important part in the summative assessment of students learning in science. (And an even larger part in the decorating of school classrooms worldwide!)

So science communicating is a great opportunity for cross-curricular activities in art, music, and language. Science reports need not be boring monologues, or even structured presentations. Drawing pictures, writing songs, putting on plays for parents, and making models are all highly valid and highly motivating means of helping children communicate their learning in science. How will you get them to discuss their shared ideas of what makes the roller return?

## Experimenting

Everything we have been discussing so far forms a major part of what it means to do when we are ‘experimenting’: questioning, observing, generating explanations, testing hypothesis, forming theories, communicating our results and questioning again (but not necessarily in that order). ‘Experiments’ are not the only way to do science (Lederman, 2004), but they are a very common way (for good reasons). Of course, experiments can be much more complicated things with independent variables, null hypotheses and random distributions. But there are lots of theories that you can experiment on right in your school that deal directly with the needs and experiences of the children. If someone has a theory that the moon only comes out at night (and many people do in my experience), take several days (same time every day for at least three weeks) and see if you can spot the moon during the day. Try experimenting on the theory that plants need predominantly red light for photosynthesis by growing plants in different conditions. Experiment on the theory that sedimentary rocks ‘drink’ because they are porous by comparing their density to igneous rocks (or observing them under a microscope). Test your ideas about how the world works, about the differences between boys and girls, even about ways to teach science better; the list goes on and on and on.

Important in experimenting (and often overlooked) is the notion of a “**fair test**”. For example, is it fair to test the theory that boys are stronger then girls with grade 2 girls V’s the grade 7 boys? Or just to be political, is it fair to test intelligence using tests designed in one group or culture in another culture that values different kinds of excellence? You see, a fair experiment will do things such as try to make all other conditions equal *except* the one(s) you wish to test. Consider: Is it a fair test for microbes when the agar plates from location 1 are kept in a different incubator to the agar plates from location 2? Can you be sure what you are testing, locations, or incubators…? While it may be impossible to be completely ‘fair’, it is something scientists, and good science students, understandably go to great lengths to try to be.

Another important point in experimenting is that of **multiple trials**, or that single examples are rarely enough to establish a knowledge claim in science. For example, imagine you and your class are trying to see which is will run a maze faster, white or black mice. How many trails does it take before you can say for sure which kind of mouse is faster? 10? 100? You decide. However, the idea is that in science that there is never enough evidence to prove a theory irrefutable beyond all doubt forever, since for one reason it is impossible to experiment on every single instance of a phenomenon (see ‘Underdetermination’, Kosso, 1992). Still, at some point we must decide that our results are reasonably sufficient to make a claim.

For this reason, all scientific ideas are up for review at any time, should the scientific community form consensus that a better theory has come along, or new evidence has cast doubt on the effectiveness of an older theory. This is a fundamental attribute of the nature of science (QSA, 1998.), and has been called the **tentative** nature of scientific knowledge (Also, ‘reversionary’ or ‘subject to change’, Lederman, 2004), though others prefer the term ‘open minded’ for philosophical reasons (Harding and Hare, 2000). Tentativeness can be a part of science teaching when students are taught that all scientific knowledge is up for review, but is currently accepted for very good reasons; reasons which are often very evidence based. Because of this, even you and your students can contribute to what science knows (with lots of hard work and careful experiments!), and certainly challenge the many inappropriate claims made in the name of science everyday.

I find it useful to discriminate between **tests** and experiments in my work, though for most practical reasons it is an unnecessary distinction. Tests are things that don’t need to have a theory or prediction at all. Whenever you start a sentence with: ‘Let’s see what happens when …’ you are doing a science test. Children, adults and even animals do these kinds of tests all the time, seeing what will happen when they do certain things. Try stacking blocks in a certain way. Hang some birdseed sticks in the garden and see what kinds of birds (and bugs) they attract. Swing a cat by it’s tail (Ok, don’t do that). Find out what things make shadows and the kinds of shadows that they make. Free- range testing is important in science and science education, and can lead to scientific experiments later on.

Testing can also mean using science skills and materials to learn something about specific objects and people (ie, testing for cancer, performing a scratch test in geology). The point I wish to emphasise here is unless you are investigating a theory, it will be confusing to call your activity ‘experimenting’.

Also, **demonstrations** are diverse from experiments in that they involve making a point rather than testing an idea (usually by the teacher in front of the class, but it also includes most practical activities in science classes). While these demonstrations are important for science education and certainly do have their place, sadly, this seems to be most common way (and sometimes only) way that science is taught (Fleer & Hardy, 2001). To expand of this, since experiments are used to test predictions (derived from theories) most science ‘experiments’ in schools aren’t experiments at all, but are demonstrations or ‘proofs’, even in high school (Goodrum, Hackling and Rennie, 2001).

Teaching predominantly in this way fails to challenge students intellectually, and makes the point of school science seem to be the generating of various simple effects (as opposed to creating and testing ideas, e.g. Schauble et al, cited in Sandoval 2005). This can give students the unfortunate impression that science and working scientifically have little to contribute to the decisions in everyday life. But they can, as Chinn and Malhotra (2002) state;

“All citizens need to be able to reason well about complex evidence such as evidence relating to health and medical decisions, evidence relating to social policies upon which citizens vote, or evidence relating to the best way to promote employee motivation and satisfaction. Learning an oversimplified version of scientific reasoning will not help on such real-world tasks.” (p 213)

It is important to note that not all sciences progress using this “Experimental method”, and that this is also certainly not the only valid way to do science. For instance, Lederman (2004) cites 3 general levels of scientific inquiry; Descriptive (closely observing a situation, common to anatomy and taxonomy for instance), Correlational (comparing information for patterns, common to sociology for instance), and Experimental (discussed here a creating and testing ideas about the world). Each of these ways of working scientifically make use of many of the process skills discussed so far (observing, inferring and communicating, for instance).

Learning the mental disciple of experimental science is of great value to students in schools, and helps them to become critical consumers of scientific claims in the community, and that’s an important part of what it means to be scientifically literate (Goodrum, Hackling and Rennie, 2001).

## Enriching the Primary Science Curriculum

The beginning of this article included the conundrum of the returning roller, and Appendix A contains instructions and explanations of how the roller rolls. As we saw, this activity can be used to illustrate all kinds of aspects of working scientifically (such as observing, questioning, experimenting, explaining, predicting, theorising and communicating). Science itself is also much more than the process skills discussed here, but these process skills still play an important roll in the science inquiry classroom today (Carin and Bass, 2001).

There are also many other science process skills that are part of school and community science. The Australian Queensland science syllabus (QSA, 1998.) has many suggestions (See Appendix B) and divides them into three main strands: Investigating, Understanding, and Communicating. You might be able to use this as a suggestion to help you get science working in your classroom, and it may surprise you how many ideas that make up ‘working scientifically’ can be applied to other school subjects.

Please note that science, and especially school science, does not *have* to progress in the manner described above. What I have presented here is not a teaching approach, as the science process skills are used when they are needed in any teaching approach to make our ideas in science the best they can be. There are also many more activities beside the ‘returning roller’ that can help children learn how to work scientifically. Almost any demonstration where children can explore their own explanations of a phenomenon can help learn how to be creators and users of scientific knowledge. Everything from alka seltzer rockets, to flick flaks, to even a balloon inverted into the neck of a soft drink bottle can be used to teach working scientifically skills when student explanations and investigations are explored before teacher driven descriptions.

In conclusion, one of the most important ideas I wish to share is that science is all about creating knowledge, for students and for scientists. When students are encouraged create and test their own ideas, rather than being handed the ‘right’ answer all the time children will develop greater levels of scientific literacy and enjoy science more. Science is a great opportunity to help students learn how to learn, and to create understandings for themselves based on the processes of science; such as creating and testing theories, observing and explaining observations, and communicating conclusions with their peers.

The intent of this article has been to enrich the options for teaching science in primary schools through an examination of ideas on the process skills of science, and to make practical suggestions for including them in school. It has also been to point to other places to look for more information, and to admittedly share a small part of the enthusiasm I feel for science in schools. Science provides daily opportunities to enrich the primary school curriculum. Keep teaching, keep learning, and keep enjoying science!

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We welcome responses and feedbackto this article. Especially other people’s successes, frustrations and stories with the ‘returning roller’. Please visit me at [www.DrJoe.com.au](http://www.DrJoe.com.au)

Thankyou for reading my article – Dr Joe.

# Appendix: The Science Inquiry Skills section from the natural curriclulum

**Science Inquiry Skills**

Science inquiry involves identifying and posing questions; planning, conducting and reflecting on investigations; processing, analysing and interpreting evidence; and communicating findings. This strand is concerned with evaluating claims, investigating ideas, solving problems, drawing valid conclusions and developing evidence based arguments.

Science investigations are activities in which ideas, predictions or hypotheses are tested and conclusions are drawn in response to a question or problem. Investigations can involve a range of activities, including experimental testing, field work, locating and using information sources, conducting surveys, and using modelling and simulations. The choice of the approach taken will depend on the context and subject of the investigation.

In science investigations, collection and analysis of data and evidence play a major role. This can involve collecting or extracting information and reorganising data in the form of tables, graphs, flow charts, diagrams, prose, keys, spreadsheets and databases.

The content in the **Science Inquiry Skills** strand is described in two year bands. There are five substrands of **Science Inquiry Skills**. These are:

**Questioning and predicting**: Identifying and constructing questions, proposing hypotheses and suggesting possible outcomes.

**Planning and conducting**: Making decisions regarding how to investigate or solve a problem and carrying out an investigation, including the collection of data.

**Processing and analysing data and information**: Representing data in meaningful and useful ways; identifying trends, patterns and relationships in data, and using this evidence to justify conclusions.

**Evaluating**: Considering the quality of available evidence and the merit or significance of a claim, proposition or conclusion with reference to that evidence.

**Communicating**: Conveying information or ideas to others through appropriate representations, text types and modes.

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1. though all explanations are, to some extent. [↑](#footnote-ref-1)