What makes it science?

Primary teacher practices that support learning about science

DAYLE ANDERSON

KEY POINTS

- Authentic scientific inquiry involves examining the natural physical world, suggesting and comparing explanations based on evidence, and critique and debate of scientific claims.

- Student participation in authentic scientific inquiry provides opportunity to consider the nature of scientific knowledge and how it is developed.

Teachers can create opportunities to learn about science by:
  - making it explicit when students are engaging in science
  - facilitating and structuring students’ participation in scientific practices such as practical investigation, debate, and critique using evidence
  - making scientific behaviours, thinking and values explicit, for instance, through discussion, co-construction of success criteria, or using examples of expert practice.
The New Zealand Curriculum (NZC) identifies an understanding of science that supports informed citizenship as a major goal for the Science learning area. The Nature of Science strand, which explores how science itself works, is the overarching and compulsory strand in Science for Years 1–10. New Zealand primary schools vary in their choice of approach to science, but many employ generic inquiry approaches, most commonly aligned to information literacy processes, to address a range of learning areas, including Science. Experiences at primary level are formative for students in terms of their appreciation of science as a discipline. Key reports suggest that many New Zealand primary students’ experience of science is largely information based. This article draws on sociocultural learning theory and a multiple case study of science teaching in New Zealand upper-primary classrooms to propose that primary science educational experiences that reflect the discipline of science provide a range of opportunities for students to understand how science works, as is expected by NZC. Literature and findings from the study are used to suggest ways that primary teachers can support learning about the nature of science as part of their science programme.

Primary science in New Zealand: What science do students experience?

The aims and objectives of the Science learning area of NZC signal that, to participate as “critical, informed, and responsible citizens in a society in which science plays a significant role’, students should explore not only how the natural physical world works but also how “science itself works” (Ministry of Education, 2007, p. 17). A recent examination of primary science in New Zealand (Education Review Office, 2012) found that, as yet, these goals do not appear to extensively guide New Zealand primary teacher practice. The report identified that information-based science programmes were more common than those that actively involved students in practical investigation, discussion, and thinking. These findings are supported by national monitoring studies indicating that increasing proportions of primary students say that they do not do science often at school, do not enjoy the science they experience, and have little opportunity to do practical investigation in science (Crooks, Smith, & Flockton, 2008; Educational Assessment Research Unit & New Zealand Council for Educational Research, 2013). International studies also shed light on the New Zealand primary student experience of science. Analysis of the 2011 Trends in Mathematics and Science Study showed that New Zealand Year 5 teachers gave less emphasis to conducting experiments and investigations in science than in other OECD countries. Six percent of instructional time was spent on science compared to the 10 percent international average. New Zealand Year 5 students were less likely to enjoy and engage with the science they were doing than students from many other countries (Chamberlain & Caygill, 2012).

In New Zealand, Science forms part of a cluster of learning areas most commonly integrated in primary schools within a generic approach which involves students developing and answering their own questions in a given context. Students then apply the school’s inquiry cycle, usually aligned to information literacy approaches, in finding the answers to their questions (Boyd & Hipkins, 2012). The prevalence of these approaches may be a factor in students reporting that they do little science at school; the ERO review of primary science found that, in many schools, science learning was lost in an integrated approach (2012).
One of the expected outcomes of New Zealand science education is that students are able to critique scientific claims and use knowledge developed by science to usefully inform their decisions as citizens. This outcome suggests students should be learning to recognise the values and practices that underpin knowledge generation in science. The above studies suggest that students commonly experience science at primary school in New Zealand as an information-based subject. If students only experience science as information gleaned from books and the internet, it may be difficult for them to see science as a process of contestable knowledge generation; they are more likely to see it as a set of uncontestable facts to be accepted and understood. To be critical and informed users of scientific knowledge, rather than passive acceptors, students need to appreciate how such knowledge comes to be (Duschl, 2008). This goal is evident in the aims and objectives of the Science learning area of NZC, but as is evident above, is currently not being widely addressed in primary classrooms.

Ally Bull (citing Perkins, 2009) suggests that one way teachers could support students to address the Nature of Science strand of NZC and learn more about how science works is to involve them in a “junior version of the whole game of science” (Bull, 2011, p. 1). By this she means that students could be engaged, in a suitably scaffolded and supported way, in science as scientists do it, using scientific forms of inquiry. Learning by doing underlies sociocultural theories where learning is seen as increasing participation in a community of practice (Lave & Wenger, 1991). What would be involved in setting up more scientific communities of practice in our primary classrooms? To answer this question, we first need to consider the nature of scientific inquiry and the processes involved in knowledge generation within the discipline of science.

How science works: The practices and values involved in the generation of scientific knowledge

Scientific inquiry or investigation underpins knowledge generation in the discipline of science. In some ways, scientific processes follow the general inquiry cycle often employed by schools, i.e., asking questions, gathering then synthesising information, and deciding on its applications and implications. However, as Ford and Forman (2006) describe, what makes an inquiry scientific is that the questions are asked about the natural physical world, and the “information” is data gathered from or about that world, which is then analysed and interpreted to develop theories about how the world works.

The theories and explanations that result from data gathering and analysis are a human construct and are discussed, critiqued, and evaluated by scientists, along with the quality of the evidence, that is, the analysis and data-gathering processes through which they were developed. The requirement for sound evidence is paramount (Roberts & Gott, 2006). Theories and explanations are accepted or rejected by the science community through informal and formal discussions and presentations at the personal and institutional level, at conferences, and via the publication of peer-reviewed scientific articles in academic journals. Previously accepted explanations are sometimes revised or rejected as new evidence is gathered or existing evidence reinterpreted. Ultimately, however, any theory or explanation has to account for the evidence present in the real world: “the ultimate arbiter in [science] community debates is the behaviour of nature” (Ford & Forman, 2006, p. 4).

Ford and Forman (2006) summarise the two roles that scientists assume in generating scientific knowledge as “creators” and “critiquers” of scientific claims. They describe how scientists often accommodate both roles simultaneously. For example, when creating claims, that is, when they are gathering and interpreting data, scientists are concurrently aware of the “critiquer” role and therefore aim to produce sound evidence using rigorous, defendable and reproducible methods.

Learning through participation in authentic science investigation and communities of practice

Developing more scientific communities of practice in primary classrooms means then that students need to be engaged in investigating in practical ways the natural physical world around them. If they are to participate fully in scientific practices they should also be involved in contesting and critiquing the claims of others. These types of experiences are echoed in the aims and primary level achievement objectives of the Science learning area of NZC. They suggest that students should have opportunity to explore, observe, investigate, and gather data about the world around them, make claims and suggest explanations based on evidence, and consider explanations offered by others. Since scientific inquiries or investigations are carried out in many and varied contexts, there are many ways of gathering and interpreting data in science. Consequently, NZC suggests that students should experience a range of approaches to scientific investigation: “classifying and identifying, pattern seeking, exploring, investigating models, fair testing, making things, or developing systems” (http://nzcurriculum.tki.org.nz/The-New-Zealand-Curriculum/Learning-areas/Science/Science-curriculum-achievement-aims-and-objectives).
Working with different ways of representing science ideas, and considering how the scientific ideas they are developing apply to their daily lives, further builds their ability to use science effectively as citizens.

In his sociocultural theories of learning, Wenger (1998) identifies that within communities of practice there are often cultural brokers who introduce ideas from one community into another. In the classroom, teachers could be seen to have this role, introducing aspects of expert communities of practice, like science, into the learning community of the classroom. Another sociocultural theorist, Rogoff (2003), identifies some ways in which we as adults support children to develop the values and practices of our cultural communities. Her ideas about guided participation, together with ideas drawn from apprenticeship (Lave & Wenger, 1991), and enculturation (Aikenhead, 1996; Hennessey, 1993) may provide ways for teachers to help students learn about the culture that is science.

These theories and understandings about the way people learn within communities of practice provided the impetus for the study that forms the focus of the remainder of this article. It was part of a more comprehensive study of three generalist primary teachers as they taught a unit of science to their senior primary classes (Anderson, 2012). The aim of the section of the study that is described here was an exploratory one: to examine the teachers’ practice during science lessons for the opportunities that it afforded for students to learn about science.

The study

The examples of teacher practice described in the following sections are derived from analysis, using the sociocultural theories described earlier, of three case studies. Each case involved a New Zealand generalist teacher implementing a unit of science with a class of Year 7 and 8 students (Anderson, 2012). The teachers selected for the study were those in charge of science in schools that were well regarded by members of the science education community, which meant that the teachers taught science regularly and usually included practical investigation as part of their science programme. Data collected included audio-recordings of science lessons, notes from observation of teaching, and transcripts of student and teacher interviews.

The teachers’ focus and context for science learning varied. One class was studying the rocky shore; a major goal for this teacher was for students to understand the concept of interdependence. A day trip part-way through the unit was organised where students explored the rocky shore, focusing on observing the species present in different zones. In the second class, the focus of the observed science unit was the development of an individual student science investigation for presentation at the school science fair. The context and focus of their investigation was selected, with teacher guidance, by the student. This teacher’s formal learning goals concerned the students being able to conduct a scientific fair test. A fair-test investigation is one in which all but one variable are controlled and the effect of changing this single variable is noted on an observed outcome. The students carried out a number of fair tests in class under the guidance of their teacher while concurrently developing their own fair test, which they carried out at home, but wrote up at school. In the third class, the context was fitness, in a science-focused inquiry unit that was integrated with English, mathematics, health, and physical education. This was the only example in the study of an inquiry teaching approach, but all three teachers included practical scientific investigations as part of science. The formal learning goals set by this teacher included both nature of science and conceptual outcomes. Students were involved in a number of practical scientific investigations related to the circulatory system and fitness, as well as information gathering and processing activities to answer the questions they had developed as part of the general inquiry process.

None of the teachers identified sociocultural theories as specifically underpinning their practice, although the third teacher espoused a participatory approach to science learning: “I want them to actually feel like they themselves are scientists.” However, all three demonstrated sociocultural practices to varying degrees. Although it was not a prerequisite for participation in the study, all three teachers stated in interviews that they wanted students to learn about science itself and believed that students learned this through practical work. The ways in which they supported their students to learn about science are presented here and linked with sociocultural theories of learning.

Teacher practices that provided opportunities to learn about science

1. Engaging students in practical scientific investigation

A key finding from the study was that engaging students in practical scientific inquiry afforded many further opportunities for students to learn about science. Once students were engaged in doing science other opportunities arose for teachers to promote scientific ways of behaving and thinking.

Enculturation involves opportunities to develop vocabulary, discourse, values and behaviours specific to
the culture (Aikenhead, 1996; Hennessey, 1993). In the study, involving students in practical scientific investigation appeared critical in providing opportunities to enculturate students into other scientific behaviours and values. Opportunities were most commonly observed in student-led investigations. Engaging in the messy business of planning a real-life investigation forced students to deal with problems and dilemmas faced by real scientists. These situations were opportunities for teachers to highlight behaviours and values important to science.

Once students were engaged in scientific investigation, the three teachers seemed readily able to highlight scientific ways of behaving and thinking. Quite often this was because initial behaviours adopted by students were not scientific. Seeing what they recognised as unscientific behaviours prompted the teachers in the study to emphasise more scientific ways of working. The scientific behaviours and values they highlighted included:

- recognising the need for careful observation
- differentiating between observation and inference
- developing validity through repetition and reproducibility
- requiring accuracy and orderliness in making and recording observations
- controlling conditions so that the effects of a single variable can be examined
- considering sample size and other statistical features in correlation-type investigations
- being creative in designing methods and thinking of possible explanations
- being collegial and building on other people’s ideas
- being sceptical and respecting sound evidence
- persevering and being rigorous

Students’ experience of different types of science investigation varied in the observed classes. In one class there was an opportunity for extended exploration and observation of the living world during the field trip to the rocky shore; in another, fair testing was the only valuable and supported form of scientific investigation. In the third, as part of their general inquiry about fitness and the circulatory system, students were involved in making and recording detailed observations of sheep hearts and lungs, measuring their own lung capacity, making models of the circulatory system, and analysing and interpreting class data sets related to fitness, as well as designing and carrying out their own scientific inquiries about fitness of different groups of students in the school.

2. Defining and naming scientific practice

Participating in a community involves understanding the nature of its enterprise (Wenger, 1998). The teachers in this study each made it clear that the enterprise being undertaken was science. The third teacher often referred to her students as “scientists”, which gave her opportunity to highlight expected scientific practices and behaviours: “I want you to think of yourself as a scientist and scientists have really great, creative thinking ideas, but they also have a little bit of order and rigour to what they do”. Two of the teachers created a very real sense of joint enterprise in science through frequent use of “we” and “our” and by welcoming and valuing student input. They made scientific practices and values explicit, often through co-construction with students. For example:

| Teacher: | Why do scientists need to be sure tricky observers? Why do they need to use their eyes? |
| Student 1: | They need to look carefully or they might miss something. |
| Teacher: | So we’re looking for precision and you might lose data. Fantastic. Give me another reason why scientists have to be really good observers. |
| Student 2: | Because they need evidence that they’ve done that. |
| Teacher: | Right, evidence. Great, fantastic. |
| Student 3: | This is a bit random but, like, to give someone who’s reading an observation to get a picture in their head of what it looks like. |
| Teacher: | Great. So they need to be quite precise so that others can follow their thoughts. |

In another class, scientific practices were formalised after discussion as written learning intentions and success criteria. For example, in helping groups to shape questions that could be investigated scientifically, one teacher and her class developed the following learning intentions:

We are learning to develop:

- A question which is open ended (why, when, what, where, who or how)
- A question that is specific and can only be answered by observing, testing, measuring of data and experimentation
- A question that is focused on one aspect (For example instead of writing “Does mould grow on bread?” Try “How does light affect the reproduction of bread mould on white bread?”)

Simple reflective questions such as “How have we behaved like scientists today?” also helped clarify and make explicit the nature of scientific enterprise.

3. Structuring and supporting participation in scientific practices

In apprenticeship situations novices are not expected to begin with the mature practice of experts; they begin with simpler tasks in a staged or stepped manner (Lave & Wenger, 1991). Teachers in the study commonly and usefully managed students’ science investigations in stages like this, for example, first immersing them in multiple experiences of the context under investigation before expecting them to identify their own question or idea to investigate. In two instances in student-led investigations,
teachers focused on the nature and development of a testable question before allowing students to proceed to the planning stage of an investigation.

When talking about how children learn a culture, Rogoff (2003) describes how adults structure children’s direct participation in cultural activities by adjusting the level and nature of prompts and assistance provided, reducing support as children participate in an activity with growing competence. An example observed in the present study was the way in which the third teacher introduced fitness investigations. The broad nature of the investigation was set by the teacher and students made choices within that. The teacher also provided questions to guide their planning: “What exercise will the students do and for how long? What other observations might you need to take and record? How will you record your data?”

Drawing on students’ cultural experiences can assist with enculturation into science as they help students engage with the new culture using aspects familiar from their own culture (Lee & Fradd, 1998). Teachers in the present study used contexts and examples familiar to students to help with enculturation into science. For example, one teacher introduced the identification strategies students might use to guide their planning: “What exercise will the students do and for how long? What other observations might you need to take and record? How will you record your data?”

In mature communities of practice, experts are present to coach and model expected practices and values (Lave & Wenger, 1991). Schoenfeld (1998) describes how teachers can think aloud as they work through a problem and reflect with the students on the strategies used and directions taken. Barab and Duffy (2000) suggest that teachers coach and model problem solving by asking questions that students should be asking themselves.

In the present study, examples of such modelling supported students in developing scientific processes and ways of thinking. In the following example the teacher posed possible questions about sample selection:

**You need to decide which four students you want to test. Are they going to be four Year Eights, two boys, two girls? Are they going to be four Year 8 girls? Are you going to take all Year 5 students or Year 5 and Year 6? Are you going to take just 11 year olds?**

**Teachers in the study also highlighted and shared examples of student scientific thinking:**

**Teacher:** I’m going to ask you to say that louder and I’m going to ask everyone else to listen to you because I really like the way you’re thinking… Why do you think I’m so pleased with the way you’re thinking there?

**Student:** ’Cos I’m thinking about keeping everything the same.

**Teacher:** Great. Just have a check, have another look at your method and see if you can answer your own question there.

Expert models of scientific reports and representations such as annotated diagrams and models were readily accessible for teachers to use with students. Teachers supported students to analyse these examples and facilitated their use of these forms of scientific communication.

**What else could teachers do to support learning about science?**

The practices described above are those that were observed during the study. There are other practices implied from the sociocultural literature that teachers could employ in helping students understand how science works.

**Fostering evidence based debate and critique**

Students in the study most often participated in the scientific practices of observation and gathering data. There were fewer opportunities to interpret data and develop explanations and hardly any to critique methods or use evidence in debating their own and others’ explanations. For example, students preparing for the science fair carried out practical investigations at home. The teacher talked individually with students to support them to make the procedures they used rigorous and fair. The students could also have discussed the development of their methodology with other students, defending and amending it in response to their critique, creating more opportunities to learn about how science is done.

Students in the third class often collaborated in groups to investigate similar or related questions as scientists do. These groups could additionally have been supported to prepare for and engage in conference-like opportunities, again as real scientists do, where they could compare and critique methods, or contest and add to one another’s thinking, using evidence, in developing and comparing explanations. Participating in debating scientific ideas and methods would add to students’ experience of how science knowledge comes to be accepted.

Scientific ideas gathered from the internet and books were nearly always uncritically accepted as fact by both...
teachers and students. Teachers could develop more critical scientific thinking among their students by raising questions about the evidence and investigation that may have produced these ideas when discussing scientific reports and claims. Only once in the study was a teacher observed supporting such thinking. She asked students: “How do you think they know that?” “What evidence would they need?” and “How could we test that idea?” Developing students’ willingness and ability to engage in scientific debate and critique would be a useful contribution toward their development as scientifically literate citizens. Capabilities in science useful for citizenship involve such critical thinking, and it has been observed supporting such thinking. She asked students: “How do you think they know that?” “What evidence would they need?” and “How could we test that idea?”

Using science stories

Rogoff (2003) describes how children’s participation in a culture can be structured through cultural practices such as storytelling. Telling the stories of science is advocated by Barker as a way of learning about science (2001, 2002). Bell (2005) describes how teachers and students share anecdotes as a way of linking prior learning to the current science focus. The teachers in the current study also shared anecdotes to help children understand scientific concepts, but not about science itself. For instance, one teacher described his childhood experiences of flooding in Holland to develop students’ understanding of the nature of spring tides. Stories about science and scientists were not used by any of these teachers to develop understanding about science, but they form an approach that could be easily adopted by primary teachers. Stories about New Zealand science and scientists are available on the Science Learning Hub (www.sciencelearn.org.nz) and in the Connected journal sent to primary schools.

Using roles and developing scientific discourse

Offering children opportunities to take on a specified role is another way that adults help children participate in cultural practices (Rogoff, 2003). Roles were not used by teachers in this study but are a potentially useful approach for use in scientific inquiry in primary schools. Scientists’ roles as creators and critics of scientific claims, described earlier (Ford & Forman, 2006), could be defined and adopted by students as they participate in scientific practices. Hipkins (2012) elaborates on the dynamic interrelationship of these roles and describes how one class of primary school students took them on as they participated in a scientific inquiry about growing tomato plants.

Role taking like this would provide opportunities to practise the kind of talk in which scientists engage: debate and argument using evidence. Little opportunity to develop and practice these forms of scientific discourse was observed in the study. Keogh, Naylor and Downing (2003) found that these discourse skills can be developed through use concept cartoons, in which cartoon children are depicted as putting forward different explanations for a phenomenon (www.conceptcartoons.com), and also through use of puppets.

Summary and implications for professional development

The practices described above all provide opportunities for students to learn about science. The teachers in this study were all generalists, with no particular experience or background in science, except for personal interest in the subject. This suggests many of the practices described could be readily enacted by other teachers who want their students to learn about science.

In summary, teachers wanting to foster learning about science could develop scientific communities of practice as part of their science programme by:

- engaging students in practical investigation of the world around them and labelling this as science
- structuring and supporting student participation in investigation and critique by simplifying tasks or adjusting the level of support required
- enculturating students into scientific language, behaviours, and values through use of familiar contexts and examples
- using student examples and teacher modelling of expert practice to highlight scientific behaviours and thinking
- providing opportunities for students to develop and critique scientific investigation methods and explanations
- using stories about real scientists
- identifying the roles of that scientists play in their work and providing opportunities for students to assume them
- providing opportunities for students to practise debating and arguing using evidence

The findings from this study suggest that a more participatory experience of science is beneficial for students. Such an approach may also be beneficial in teacher professional development. As described earlier, while expert examples of scientific text such as reports and explanations were readily available and used by the teachers in this study, expert examples of the use of relevant scientific practices were not. Teachers had to rely on their own knowledge of the practice of science. Their modelling of scientific thinking and behaviour came from their own experience and understanding of what was scientific. The teachers’ appreciation of the range
of approaches that occur in scientific investigation also varied. Building teachers’ capacity with different ways of investigating in science would form a useful component of future primary science professional development.

One avenue for such professional development could be through increasing and improving the nature of partnerships between schools and the scientific community, which has been suggested as a way of improving New Zealand students’ experience of science (Office of the Prime Minister’s Science Advisory Committee, 2011). Teachers may be more confident in using and identifying scientific practices if they have been involved in scientific investigations themselves or have some experience of the work of scientists. Recent reports provide examples of successful primary school/science partnerships (Bolstad & Bull, 2013; Anderson, 2013). Working with experts may support both teachers and students by building teachers’ confidence in their role as cultural brokers. Teachers who are clear about the practices and values that characterise science will be more able to support students to identify just what it is that makes it science.

Further reading

- Descriptions of the capabilities in science for citizenship and resources for teachers that support their development are available at http://scienceonline.tki.org.nz/Science-Capabilities-for-citizenship
- Descriptions of the Nature of Science, including different approaches to investigation and supporting activities, can be found at http://scienceonline.tki.org.nz/Nature-of-science
- Connected promotes scientific, technological, and mathematical literacy so that students can engage in a critical and informed manner with real-life issues. The focus of the Connected 2013 series is on the Nature of Science strand and the science capability. Gather and interpret data: http://literacyonline.tki.org.nz/Literacy-Online/Teacher-needs/Instructional-Series/Connected

References


Dayle Anderson is a senior lecturer in primary science and mathematics education in the Faculty of Education at Victoria University of Wellington. She has experience working as a scientist and more recently as a primary teacher and deputy principal. In addition to her research and work in initial teacher education, Dayle is involved in primary teacher professional development in science and primary science resource development.

Email: Dayle.Anderson@vuw.ac.nz