CHAPTER 1
WHAT IS SCIENCE?

Mitch O'Toole

KEY IDEAS

1. Science provides learners with knowledge of their surroundings that can help them develop productive and fruitful meanings.
2. Science is powerful but scientific ideas change.
3. Science should be taught in ways that recognise the sources of its power and that acknowledge the limits of present understanding.

KEY TERMS

models   narrative

What does science mean to us?

> '[S]uddenly I find myself momentarily alone before one new corner of nature's pattern of beauty and true majesty revealed.'

People structure their lives on stories. Here are a few that touch on this thing that we call 'science'.

STORY 1

I once taught in a school in Sydney's outer western suburbs. The families who trusted the school with their children were mainstream Anglo-Australians. The school had just appointed a chaplain and her teaching role included aspects of personal development. One recess she approached me as the Science coordinator and said:

> 'Mitch, something funny just happened in class', to which I replied, 'Funny ha-ha, or funny peculiar?'
>
> 'I'm not sure, maybe a bit of both.'
>
> I asked, 'What happened?'
>
> 'I was talking about puberty with Year 7 and I mentioned testosterone. One of the girls down the front asked, "What's that?" and before I could answer, one of the kids up the back called out "Isn't that a pasta dish?" No one laughed.' (think: *minestrone*)

STORY 2

The Second World War ended in 1945 with the unconditional surrender of Imperial Japan following the detonation of atomic bombs over two cities. Enrico Fermi was an Italian physicist who fled Fascist Italy and achieved the world's first sustainable nuclear chain reaction on a pile of graphite blocks in a squash court at the University of Chicago in 1942. When asked about the nuclear bomb that his work had made possible, Fermi is reported as replying, 'Don't bother me with your conscientious scruples, after all, the thing is superb physics.'

Jungk, R. (1958). *Brighter than a thousand suns: A personal history of the atomic scientists.* (J. Cleugh, Trans.). (p. 202). New York: Harcourt Brace.

STORY 3

Richard P. Feynman was a young US physicist who managed the computer room at Los Alamos, where atomic bomb was developed. While accepting the Nobel Prize for physics for other work, he said:

> The work I have done has, already, been adequately rewarded and recognized. Imagination reaches out repeatedly trying to achieve some higher level of understanding, until suddenly I find myself momentarily alone before one new corner of nature's pattern of beauty and true majesty revealed. That was my reward.

Nobel acceptance speech (Physics 1965). Retrieved 11 March 2012 from <www.nobelprize.org/nobel_prizes/physics/laureates/1965/feynman-speech.html>

QUESTIONS

1 What has been your experience in studying science?
2 What does science mean to you?
3 Are all scientific discoveries of value to the world?

What do the introductory stories tell us about science?

The introductory stories tell us the following ideas about science:

- Society thinks that science is important; after all, we make all young people study it in school but we don't make them all study Chinese or needlework. Powerful people apparently believe that learning science at school will help future citizens make informed choices about local and global issues and will prepare them for jobs that need knowledge and skills that come from people 'doing' science.
- People who 'do' science have changed the world. Atomic bombs, mobile phones and the internet are just the tip of the iceberg. More ideas have been developed and the way we do things has changed faster in the last two centuries than in the previous thousand years. Most of these changes have involved people doing science. No one knows what life will be like in the middle of the 21st century.
- Scientists are people who are driven by curiosity, notions of beauty and the pleasure of discovery, and our understanding keeps changing as they expose unfamiliar aspects of the world around us.
- What learners learn from the science presented in science classrooms depends on what they already know, because people can only understand new things in terms of how they already think. The meanings learners make, or fail to make, may not be what their teachers expect.

This first chapter will touch on a number of themes that will surface in much more detail later in the book. It will also provide a taste of the history of science and of different ideas about science and how it works, with references to take you further. If any of us are going to teach science well, we need to know what it is and where it came from.

Where did the science we teach today come from?

Where does science knowledge come from, and how can knowing what happened in the past help us to understand the strengths and limitations of what we teach? Perhaps the most surprising thing is that while we see the changes in the science curriculum we are not always aware of how the understanding of science changes.

Curriculum change is predictable. In other key learning areas as people learn more about their subjects, the new knowledge and expectations lead to changes in what school teachers teach. They may change how teachers teach their subjects, but not the perspective they teach it from. Science teaching is different; the content we teach evolves over time. We teach about things that keep changing. A contemporary account of the lead-up to the Boer War will probably be understood differently now from when it was written, but it is still a useful document. A science text from the 1890s would be of almost no use in the 21st century other than from a historical perspective.

To extend the historical example: Australians streamed to Africa at the beginning of the twentieth century to fight in the Boer War. The label given to the conflict changes over time, opinions may shift regarding the causes and impact of the events, and the episode may move in and out of the school curriculum. However, the events themselves are static: gold was discovered in the Transvaal, the Jamison raid happened, Cecil Rhodes was involved, the war moved from set-piece battles to remarkably nasty guerilla warfare, many people died and the British ended up in charge. Changing views of the importance of the event will affect its role in the school curriculum at different times, in different places. We change what we teach about what we know. This is not surprising.

→ For ideas about how you can help students explore how science changes, see 'Science changes' on page 17.

What happens to science is stranger. The subject itself and our understanding of it both change.

The explanations of geologic change in a 1940s textbook are not accepted now. We simply don't use the same terminology, and the meanings of those words that we do still use have changed in most confusing ways. Our knowledge of the structure of DNA and the role of genes has undergone many reviews as improvements and advances have been made in the technology available to scientists. Confocal bioimaging microscopes allow scientists to view living cells engaged in processes such as cell division and protein synthesis, and the image seen is converted into animations for further analysis. We can now make observations that were unavailable before. These observations lead to new knowledge and deeper scientific understanding.

New science understanding has resulted from the rapid interplay between research, technology and application across all areas of science. Such changes surface in contemporary recognition of 'Science as a Human Endeavour' in the Australian Curriculum: Science (ACS).

> Through science, humans seek to improve their understanding and explanations of the natural world. Science involves the construction of explanations based on evidence and science knowledge can be changed as new evidence becomes available. Science influences society by posing, and responding to, social and ethical questions, and scientific research is itself influenced by the needs and priorities of society. This strand (*Science as a Human Endeavour*) highlights the development of science as a unique way of knowing and doing, and the role of science in contemporary decision making and problem solving. It acknowledges that in making decisions about science practices and applications, ethical and social implications must be taken into account. This strand also recognises that science advances through the contributions of many different people from different cultures and that there are many rewarding science-based career paths. (ACARA, 2015, p. 8)

Using stories to explain the history of our understanding of science

Comments such as the quote above from the ACS encourage teachers to tell stories about science. This is probably a good idea, as **narrative** is recognised as one of the elements of significance in quality teaching. Stories help learners to make connections to their own lives, to see what matters and to hear about real people who have contributed to our understanding of science.

narrative
A story or an account of a series of events.

Does it matter if the stories are true? Let us look at one of the pivotal personalities in the history of science.

Stories about Galileo

A lot of people tell stories about Galileo Galilei (1564–1642) and his work still causes problems for secondary school learners (Ford, 2003; Galili, 2016; Poole, 1995). He stands at the beginning of modern science and, for many, provides a model of what a scientist should be. His relationships with Tycho Brahe and Johannes Kepler provide episodes for teacher story-telling. He had rocky relations with organised religion, and his trial and recantation make some people see him as a martyr for science.

However, it is the story of Galileo and the Leaning Tower of Pisa that seem to recur most often. Long before, Aristotle (384–322 BCE) taught that things fall because of something about them, and they fall faster the closer they get to the ground. Galileo suspected that things fall because of something about the ground. If Aristotle was right, different things would fall at different speeds, because they were different. If Galileo was right, different things would fall at the same speed because they were falling to the same ground. The extract below recounts the only illustration of Galileo's theory that was included in an Australian secondary school resource (Brice, 1987), and a similar version can be found in a more recent children's book (Macdonald & Rui, 2009).

Brice illustrates Galileo dropping a rock and a feather from what looks like a timber balustrade and the rock is already leaving the feather behind!

Figure 1.1 Galileo Galilei was an important and controversial figure at the dawn of modern science.

> Galileo began his work on the study of movement. Using the Leaning Tower of the city he was able to show that Aristotle was wrong in saying that 'bodies of different weights fall at different speeds'. Galileo proved that substances of any weight fell at the same rate. They also accelerated and slowed down uniformly. This was proved to be the same on the moon when two of the American astronauts in the Apollo program copied Galileo's experiment. It was easier to prove on the moon where the pull of gravity was so much less than on Earth. The astronauts did not need a high tower. They just dropped a feather and a piece of rock at the same time and it was clearly seen that they landed together. (Brice, 1987, pp. 19, 20)

This is one of the simpler examples, although it is also one of the more confused. At the time that Brice's book was written it had been known for thirty years that Galileo never did any such thing. The inaccuracy had been known for more than fifty years when the children's book appeared. In any event, it is the absence of air on the moon that allows the falling body demonstration to be carried out so convincingly, not the lower force of gravity. Furthermore, astronaut David Scott dropped a hammer and a feather, not a feather and a rock. You should not try the demonstration yourself, even from a third-storey window; you'll find yourself agreeing with what Galileo did say about the demonstration (although not about the theory):

> he (Galileo) said in one of his juvenile works that he had tested the matter on many occasions from a high tower and that in his experience a lump of lead would very soon leave a lump of wood behind (Butterfield, 1957, p. 81)

Resistance to change in astronomical ideas has been far from consistent. Copernicus was a lay canon who only finalised his work at the insistence of Pope Clement VII, and Galileo went public because he expected support from Cardinal Robert Bellarmine (1542–1621, canonised 1930). Copernicus' work caused him no inconvenience during his life as his work *de Revolutionibus* was only placed on the Index of prohibited books in 1616, more than 70 years after his death.

Bellarmine contacted Galileo privately that year (1616) to warn him that the banning of Copernicus' *de Revolutionibus* changed the conditions under which Galileo would now work. Galileo agreed neither to teach nor to defend the ideas of long-dead Copernicus as physically real. Bellarmine had sat on the panel of judges that ordered Giordano Bruno to be burnt at the stake in 1600 for heresy, and so his warning, and subsequent public announcement that it did not represent any sort of reprimand, bore much weight for Galileo. Bruno believed that the universe was God and in a multitude of worlds, all circling suns that we see as stars in the night sky. His pantheism got him executed, but the latter teachings have caused many to confuse his fate with that of Copernicus and Galileo. Galileo eventually did run foul of the Inquisition when he wrote *Dialogue Concerning the Two Chief World Systems* (published 1632, more than a decade after Bellarmine's warning). The book sets out the argument between the Copernican and Aristotelian systems as a discussion between two people, and the Aristotelian wins. Galileo had the book approved by four official censors, but he had put all the current Pope's favourite arguments in the mouth of a character he called 'Simplicio'—*simpleton* or *fool*. The Pope did not move to punish Galileo but he was much less inclined to defend Galileo when old enemies denounced him. Galileo was brought before the Inquisition in 1633, recanted, and was placed under house arrest in his country villa. While there, he wrote *On Two New Sciences*, which contained the results of the work on dynamics that Newton put with Kepler's astronomy to form the basis of modern science.

Galileo's interaction with religious authority casts light on the complexity of interplay between personality and power when **models** in science are changing. By the 1630s there were at least four different models of the universe in circulation: Ptolemy (earth-centred with lots of little circles), Copernicus (sun-centred with lots of little circles), Brahe (outer planets orbiting the Sun, which orbited the Earth with the inner planets) and Kepler (sun-centred with elliptical orbits). Practising astronomers and navigators had already abandoned the two earlier models in favour of either Brahe or Kepler. Kepler was more useful but the controversies put Catholics in the uncomfortable position of using Brahe to explain the universe while they used tables based on Kepler's arithmetic.

models Sets of theories that become so widely accepted by scientists that they become pictures of that part of the universe on which particular scientists work. If a model lasts long enough, it can become a lens through which scientists see the universe. Such models define what can be noticed and described and what is beneath notice because the model suggests that it cannot exist.

This story shows that narrative is an element of significance in quality teaching (Ladwig & Gore, 2003) that recognises that the human interest of stories such as this can broaden the appeal of science beyond those learners who are already interested. However, we need to be careful that they are not gossip that grows in the telling. We need to organise the historical material that we use so that it helps learners develop an accurate understanding of what science has been, what it is now, and where it is likely to be going (Brush & Segal, 2015). Science has changed and keeps changing, so must the way we teach it.

→ For ideas about how you can use narratives to enhance students' understanding of science, see 'Using narratives' on page 18.

What makes science different from other ways of knowing?

The Australian Curriculum for Science recognises that science is a 'human endeavour' marked by characteristic intellectual change. So, it is probably wise to think about some of the ways that this might happen. The five approaches to the nature of science outlined in Table 1.1 fall into different positions on the philosophical continuum between *realism* and *conventionalism* (Binns & Bell, 2015).

Table 1.1 Ways of understanding change in science

Label	Source	Description	Source of change
Inductivism	Francis Bacon in 1620	Scientists should collect facts and look for patterns that suggest generalisations. More facts mean new generalisations.	Intellectual development among scientists: More facts.
Logical positivism	Vienna, 1920s Rudolf Carnap from 1935	The only statements that have meaning are those that can be proved by logic or public experience. Hypothetico-deductive steps whereby scientists derive hypotheses inductively and then develop tests for their hypotheses by a process of logical deduction.	Intellectual development among scientists: Better experiments.
Falsification	Karl Popper 1934	Ideas in science cannot be proved to be true; scientists should spend time trying to show that their theories are false. Support for any theory must rest on past experience, which is induction. Popper is often mentioned approvingly by practising scientists.	Intellectual development among scientists: Crucial tests that defeat theories.
Cycles of revolution	Thomas Kuhn 1970	Normal science (routine research work) produces revolutionary science (paradigm change). When paradigms stop posing puzzles, crisis lasts until there is a new paradigm. Rival paradigms are incommensurable: communication is impossible. Paradigm shift is cyclical and essentially non-rational. Practising scientists are often unhappy about Kuhn, as he appears to trivialise their daily work.	Prestige and power among scientists and social support for their work: Ebb and flow of promotion and funding patterns.
Socio-intellectual interaction	Emerged from arguments about Kuhn 1980s and 1990s	Interaction of social causes and intellectual reasons in response to problems that need solving. Made more complex as bureaucrats use funding to push science in utilitarian and multidisciplinary directions.	Model development is supported by social context: Prestige and funding patterns expose fruitfulness of model.

The place of science in learners' worlds

Young children have sometimes been compared to blotting paper. They soak up experiences at an astounding rate and appear able to pay meaningful attention to multiple tasks. Many young children are profoundly interested in the world around them. Anybody who spends time with them will hear many questions like: 'Why does the wind blow?', 'Do koalas float?', 'Why is the sky blue?', 'Where does the rain come from?', 'Where does the sun go at night?', and often they will come in quick succession. Many of these questions fall within the search for an understanding that we call 'science', and they provide those of us who teach it with a great place to start and a wonderful opportunity for development. People at the cutting edge of science talk about it as play, driven by curiosity and formed by creative interaction between themselves and problems that interest them. Sounds childlike, doesn't it? If we feel that we need it, comments like Feynman's give us permission to encourage the maintenance of wonder in our classes (Egan, Cant, & Judson, 2014) and should remove any embarrassment over fun in our science classes.

However, something happens when young children become young school learners. For many, their almost insatiable curiosity about the world around them becomes dulled, and 'science' becomes something older people do to make facts for younger people to learn. It becomes an exercise in memory rather than an exciting opportunity to solve important problems. The consequences become clear as older learners avoid school science when it is no longer compulsory to study it. Teachers of younger learners recall confusion and boredom in their own junior secondary classes and consequently neglect science in their programs. The difficulty compounds.

Think about it 1.1: Your experiences

Did you pursue science when it was no longer compulsory? Why/why not? Think about the following factors:

- Teaching quality
- Subject matter
- Personal preferences and goals
- Other circumstances (e.g. advice from school guidance counsellor)

These factors may have something to do with the fact that science has traditionally been presented as complicated and challenging. Some teachers may describe some older learners as having 'no head for physics', while teachers of younger learners ask how they can teach science without specialist knowledge and specialist spaces. Many people think that science is a collection of things that we now know for certain and that the teacher's job is to make sure that learners know enough of these facts and figures to go on to the next level of their education. Understanding our world is easier and the people who study it are more approachable than these responses suggest, but such attitudes can make learners less confident in their studies of science. Less confident learners can rapidly become less interested, and less interested learners are more easily confused.

Words like 'testosterone' are only the beginning of learner confusion. Learners often 'zone out' when what is happening makes little sense to them. 'Making sense' means connecting science with what learners already know and with people who seem within reach. This is sometimes called 'significance' and is one of the fundamentals of quality teaching (Ladwig & Gore, 2003). However, learners do not live in isolation. Their experiences are framed by their families, cultures and subcultures. Their cultural knowledge and the extent to which school knowledge is connected to their lives will influence how they react to science (Waldrip, Timothy, & Wilikai, 2007).

Table 1.2 What sorts of things might increase the significance of school science?

Question	Movement label	Origins and key ideas
What's what and how is it connected?	Science, Technology, Society (and, more recently, Environment) [STS(E)]	Based on earlier 'science for all' and 'science for citizens' movements. Recognises interactions between scientists, industrialists and politicians; and is critical of the impact of those interactions on ordinary people. Environmental concerns incorporated over past decade or so.
How does science work and how has it changed?	History and Nature of Science [HNS]	The concept of the 'nature of science' grew from disputes about the philosophy of science in the mid-twentieth century. Critical view of the responsibility of scientists and the importance of defensible ideas about where the science we teach came from.
What's the use and what's it doing to us?	Applications of Science	Recognises both the industrial power of applied science and the environmental impact of those applications. Leans towards Environmental Education if impact is considered more important than power and towards Vocational Education if power is considered more important than impact.
What's happening now?	Modern Science	Science changed rapidly from mid-twentieth century and programs for schools had trouble keeping up. Treatments of contemporary science recognise the power of incidental motivation: exciting stuff might carry learners through less interesting work.
Do we need school?	Informal Science	Museums in developed countries and travelling public health exhibitions in less developed ones both broadened attention beyond school. Both draw on the incidental motivation provided by excursions and visiting speakers/exhibitions.

→ For ideas about how you can help students understand the link between scientists and 'everyone else', see 'The relevance of science' on page 17.

Modern societies depend on science and technology and so powerful people become concerned when enrolments in science courses fall. More learners may remain in science courses if we increase the significance of science for them, rather than stressing its difficulty. Learners may see how science matters if we can connect what we teach more closely to what they know and value and expose the two-way relationship between the people who do science and everyone else. Table 1.2 provides some information about methods that have been suggested to make science matter more to learners. The questions and the movements arising from each clearly interact, but each was more or less important at different times in different places. The different movements provide a range of insights and resources for 21st-century teachers of science. These movements are visible in contemporary developments in science curriculum.

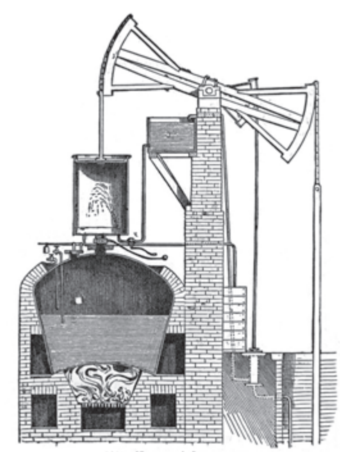
How does science interact with technology?

Science and technology are commonly linked in people's minds but even a brief look at the historical evidence shows that the relationship between the two is complex. Science is sometimes described as the 'knowing' and technology as the 'knowing how'. Contributions from these distinct fields flow in both directions as attempts to answer 'what' questions often produce ideas with implications for problems of 'how', and new ways of doing things often act as a spur in the search for better explanations. Severing the link between the two may impoverish both, as each feed off the other.

This mutuality is shown by the following brief sketch of pumping water, in which (S) marks a scientist and (T) a technologist. This early modern example is presented because the science itself is fairly accessible.

Lifting water has been a human problem since the beginning of agriculture and it became crucial when mining moved underground. The muscles of men or animals drove early force pumps that lifted water from diggings and allowed miners to follow valuable mineral veins. The economic imperative that drove the improvement of the pumps led to the eventual development of the turbines that move nuclear submarines.

Figure 1.2 Thomas Newcomen designed this engine driven by air pressure and, two generations later, James Watt improved it to produce the first true steam engine.



Near the end of the sixteenth century, an Italian plumber (T) brought a problem to Galileo (S) in Florence. The plumber could only lift water ten metres with the pumps he was using to drain cellars. Galileo could not explain why this should be. He reportedly remarked that 'Nature apparently abhors a vacuum less than Aristotle supposed'. Galileo's student, Torricelli (S: 1608–1647), invented the barometer as he worked on this thing his teacher could not explain, why the pumps only lifted water so far. A Frenchman Pascal (S: 1623–1662) later confirmed the existence of air pressure. Savery (T: 1650–1715), a French religious refugee working in London, used condensing water to make a partial vacuum that drew water up a tube.

In 1712 an Englishman Thomas Newcomen (T) devised a more useful way of raising water with fire. Newcomen's 'atmospheric engine' consisted of a cast-iron cylinder with a heavy piston inside. A boiler produced steam that went into the bottom of the cylinder through a pipe. The piston was connected to a balance beam, the other weighted end of which was connected to a rod that, in turn, was connected to a pump. The top of the cylinder was open to the air and another pipe delivered cold water to the top of the cylinder, just beneath the piston at the top of its stroke. The weighted end of the beam pulled the piston up the cylinder, drawing in steam through the lower pipe. The upper pipe delivered a shot of cold water at the top of the stroke. The steam below the piston condensed, forming a partial vacuum, and the atmospheric pressure forced the piston down the cylinder and lifted the weighted end of the beam to drive the pump. When the piston reached the bottom of the cylinder, the weighted end of the balance beam pulled it up the cylinder again and the engine went through another cycle. The engine was not very efficient, but it would pump water automatically providing that the boiler below supplied steam and the tank above supplied cold water to condense it.

James Watt (T: 1736–1819) was a Scottish instrument-maker. He applied the work of Black (S: 1728–1799) on latent heat to improve a scale model of Newcomen's atmospheric engine that he had been asked to repair. Black had recognised that change of state required energy that did not cause a rise in temperature. Watt recognised that the heating and cooling of Newcomen's cylinder during each cycle was using a great deal of energy. Watt produced the first true steam engine in 1769. He sealed the upper end of the cylinder and used steam to drive the piston in both directions. This required him to increase the pressure throughout the system, which increased the danger of explosion, but it also produced a much more efficient and potentially more versatile engine.

Figure 1.3 Hollow-cast cannon blew up more often than solid-cast weapons that had been bored out by a steam-driven drill.

Photograph: Gjyn O'Toole

In 1774, Wilkinson (T) used a steam engine to bore out a cannon that had been cast solid. This greatly increased the safety of the weapon as hollow-cast cannon had a nasty habit of exploding. It also laid the foundation of the machine tool industry and generated observations that focused the attention of the scientific community on heat. Rumford (S/T: 1753–1814), Carnot (S: 1796–1832), Joule (S: 1818–1889) and Kelvin (S: 1824–1907) developed the three laws of thermodynamics in response to the puzzles emerging from the foundries. Parsons (T: 1854–1931) designed the first successful steam turbines in the 1880s, which has led to the production of the linear engines we find at the heart of power stations and nuclear submarines today.

→ For ideas about how you can explore the concept of technology in the science classroom, see 'Science and technology' on page 19.

The interaction between science and technology is more complex than it first appears. Our modern world is a product of this interaction between the competing demands of the internal community that defines science and the external community that supports or restrains it.

What the students already know or what they think they know

No matter where they get the information, students do not come to science classes as blank canvases. You only have to visit dinosaur exhibitions and listen to three- and four-year-olds citing names, habitats and eating preferences of the dinosaurs to realise that our younger students come to school with knowledge and experience across a range of scientific concepts. Figures 1.4, 1.5, 1.6 and 1.7 show just what students in Years 3–6 already know about science.

Figure 1.4 A Year 3 student's representation of science

This young student has already recognised that chemicals come in a range of colours. The picture also demonstrates a simplistic idea about different types of equipment used in science and how they are used together during experiments. The bubbles show that the concept of chemical reactions and the products of chemical reactions are already known to the student.

Figure 1.5 A Year 4 student's representation of science

Figure 1.5 highlights an understanding of the variety of concepts that is covered in science. The student has already begun to understand classification. The student has also made links between the different stages in life cycles and the relationship between the Earth, Sun and Moon.

Figure 1.6 A Year 5 student's representation of science

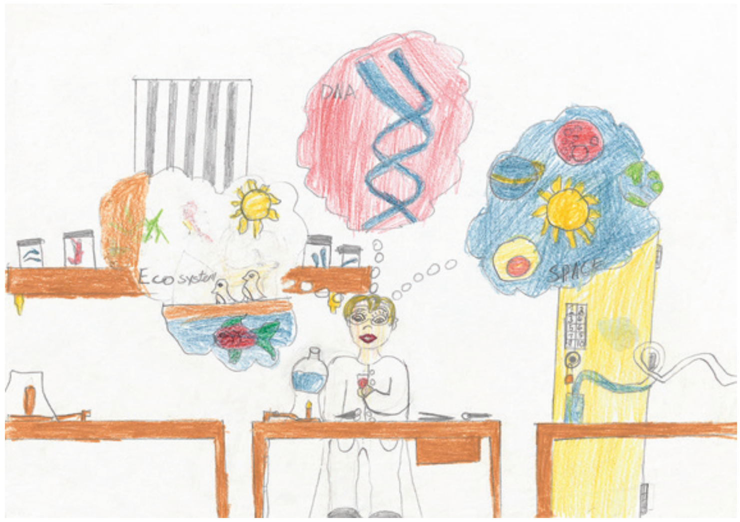


Figure 1.7 A Year 6 student's representation of science

Very few of the students at the school where these pictures were drawn used the stereotypic view of the scientist. In fact, in many cases where a person was drawn the picture was of a female scientist. This picture does not clearly identify the gender of the scientist but the glasses usually seen in images depicting scientists are certainly shown. The student has developed a sophisticated idea of many concepts of science but also that we do hands-on experiments. The student also shows that the scientist is thinking about science.

Figure 1.7 is one of many representations that demonstrated a broad range of scientific concepts and the equipment used in scientific experiments. Yet students in this school would not have had experience of laboratory work nor the equipment shown while learning about science. The concept of classification is also well understood. The clarity of the diagram showing the human body and the position of some organs is very impressive from such a young student and was significantly more accurate than those drawn by many postgraduate pre-service teachers.

The pictures you have just seen are some examples from nearly 300 pictures drawn by primary-school students. They demonstrate a range of sophistication in knowledge and understanding. What they represent is each student's interpretation of what science means to them. Those collected from the early years focused on dinosaurs.

However, once the students entered Year 3 (age 7–8), their view of science diversified. Images of exploding and colourful chemicals were popular. What surprised me was that students started to separate and classify elements of science in their diagrams.

These pictures clearly demonstrate the breadth and depth of knowledge and understanding that children have of science in their early years of schooling and what they already know on their arrival at secondary school. However, not all of that knowledge is correct. Some facts may have been presented incorrectly or the student's interpretation of what was being explained has led to misinformation being learnt and what we refer to as 'alternate views' being constructed. (See pp. 47–8).

Mitch O'Toole

So how should we teach science?

Science is something that people do and sometimes people use different words, or use the same words differently: remember the *testosterone* story. Science is powerful stuff. Scientists do it for personal reasons, such as looking for answers to personal questions about the world; the joy of the discovery; or using the scientific method to confirm or discard out-dated ideas. Sometimes they don't care much about its consequences: remember the Fermi story.

→ Some of the experiments that make up Part 2 are examples of the scientific method.

Adolescents who do not understand how their bodies work can make decisions that may not be in their long-term best interest. The citizens that our learners will become will be called on to make decisions about science that they should understand better. Galileo's predicament may seem very remote. However, more recent events raise many of the same issues: Michael J. Fox pleading for the use of human embryos in gene therapy, Robert Oppenheimer before the US Senate Committee for UnAmerican Activities, Russian scientists imprisoned for teaching Mendelian genetics, and continuing debates about 'germ-line' research, climate change, and dams for electricity generation or flood mitigation.

Our problem as teachers is that science is a moving target. If we understand science, we understand that what we teach is the current best guess. The material in the books and websites we use to prepare our lessons is the product of interaction between models at varying stages of fruitfulness, with differing social contexts supporting or impeding them. We run the risk of confusing our learners and ourselves if we think that what we teach is true. Furthermore, letting them know that science is in no sense 'done and dusted' but very much a work in progress may well humanise the subject and help them to see that there may be a place for them (Slater, 2008).

Think about it 1.2: Science as a 'moving target'

1. How do you feel about the fact that science isn't 'done and dusted'? Is this reassuring, challenging perhaps? How do you think your students might feel about this lack of certainty?
2. What implications do these responses have for you as a teacher?

Scientists do complex work and our job is to make aspects of that work accessible to learners. Which aspects are appropriate for which learner depends very much on the age of the learners, but science is appearing in curricula for all ages. Learner motivation will increase if they see science for the unfinished task that it is and become more skilled at the kind of thinking that it involves. This is a strong argument for the respect of prior conceptions called for by a constructivist approach to teaching science. A person's ideas represent the current state of their understanding, and making them conscious of fruitful ways of evaluating those ideas seems to be a worthwhile aim, whatever their level of schooling.

Learners are more likely to grasp ideas that matter to them, and ideas are more likely to be interesting and significant if they are embedded in stories. Useful stories can be built from events in the history of science. Such events reinforce the tentative nature of the ideas themselves. However, history needs to be treated as respectfully as learners' prior conceptions. Learners feel cheated by tales that later turn out to be false. What else is a lie, if Galileo never dropped anything from the Leaning Tower of Pisa? This can act against their excitement as tentative science models later give way to more fruitful ones.

Summary

Groups of people work together to try to understand the world around them better. These groups work in particular ways and they develop particular ways of thinking and communicating. We call their work 'science'. Its social and economic importance has earned it a place in the school curriculum for the past century.

Learner interest in science could be increased by widening the significance of the science they learn. Science, technology and society; the history and nature of science; applications and the impact of science on the environment; contemporary developments in science and informal approaches have all been suggested as directions in which school science could be widened. The Australian Curriculum: Science draws these together into 'Science as a Human Endeavour'.

Notions of what science actually is fall along a spectrum between realism and conventionalism and can be described under various approaches, each of which explains aspects of the history of science with varying success. The career of Galileo provides examples of the varying usefulness of the differing approaches and of the dangers of looking to history to provide simplistic stories. The interactions between science and technology also demonstrate the fascinating complexity of this thing that people do. It seems clear that science will not ever arrive in a finished form as a publication from an international academy, ready to be applied directly in any and all contexts.

IN THE SCIENCE CLASSROOM

The relevance of science

One way to explore the two-way relationship between scientists and 'everyone else' is to talk to a 'real scientist'. There are many opportunities to do this, for example:

- utilising a parent who is a scientist
- finding someone who is researching in your local community—this could be through organisations such as universities, CSIRO, Catchment Management Authorities, Cooperative Research Centres (see https://crca.asn.au to search for a directory of centres)
- using web chats such as http://news.sciencemag.org/sciencelive.

By talking to a 'real scientist', students can start to make links to their own worlds. For example, a live chat with an aviation meteorologist led to students asking questions such as:

- How do planes stay in the air?
- Does lightning affect a plane?
- Why are flights sometimes bumpy?
- Would you fly in a small plane?

as they connected the science with their own lives and experiences.

FOCUS QUESTION

List two people or organisations in your local community that you could contact to come and talk to students about each of the following topics: astronomy, the environment and local waterways.

CURRICULUM LINKS

Year 5, 7: Science Understanding: Earth and space sciences
Year 5, 6: Science as Human Endeavour: Nature and development of science and Use and influence of science
Also refer to Year 5 Work Sample 6: Australian scientists (Australian Curriculum, ACARA).

Science changes

In the classroom, there are many ways to explore how science changes. You can have your class examine how ideas and knowledge have developed from the past to now, or you could ask students to consider what impact science may make on the future.

- An interesting place to begin is with Leonardo da Vinci's work, specifically his detailed drawings of cars and hot air balloons. These drawings can be examined in light of da Vinci's time (1452–1519), with students investigating what da Vinci's contemporaries thought of his ideas. They could then skip forward in history to when these inventions came to be built, looking into questions such as how realistic his ideas were.
- Students could examine and create a timeline of famous Australian inventions requiring the use of science such as the electric drill, polymer bank notes, the bionic ear and the electric

pacemaker. Students could then identify and list the science that would have been used to make these ideas work. The creation of polymer bank notes, for example, required a knowledge about polymers, the durability of the materials, how the notes could be mass produced right through to their ability to be recycled.

- A technological development that relates more to students' immediate lives is the rapid development in the production and transmission of music from records to tapes, CDs and downloads. Students could explore the science behind these changes as well as possible future developments.

FOCUS QUESTIONS

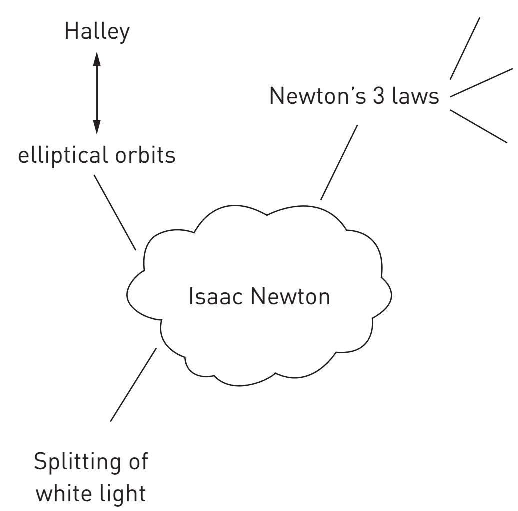
1. Why is it important to include these innovations or developments in the science curriculum?
2. There have been developments in the ability to repair burn victims' skin. Consider how you could have students examine this topic and where future improvements might be made.
3. List at least five recent events in science that demonstrate our evolving understanding of the world. How would these relate to school science? For each event list two ways you might convey the significance of these to students in either a lesson or a unit.

CURRICULUM LINKS

Year 5, 6, 7, 8, 9, 10: Science as Human Endeavour: Nature and development of science and Use and influence of science
Also refer to Year 9 Work Sample 7: Wifi; Year 9 Work Sample 8: Bionic eye (Australian Curriculum, ACARA).

Using narratives

Using narratives can engage students in a different way, as they need to unpack the ideas in the narrative then explore how these developed. Timelines, concept maps and general discussions can all aid in this process.



FOCUS QUESTIONS

1. Using 'Stories about Galileo' as a narrative, construct a timeline to unpack what happens throughout the narrative.
2. Consider how you could have students identify what happened when.
3. What are the ideas about science that are taken from the narrative?
4. How could you explore these ideas further with your class?
5. Consider how a concept map could be used for the example 'Stories about Galileo'.

There are many famous areas of conflict in science that you could have your students explore, including:

- Newton and his laws
- Einstein's theories
- global warming
- genetics and the ethics behind it
- the effects of mining.

NOVA: Science for curious minds (http://www.nova.org.au) is also a rich resource, providing information on current science issues along with teacher and student material.

CURRICULUM LINKS

Year 5, 6, 7, 8, 9, 10: Science as Human Endeavour: Nature and development of science and Use and influence of science

Science and technology

Often technology is thought to be computers and digital devices but it is much more than that; it deals with the creation of objects and materials. Technology is created using technical means, and includes the interaction of materials with life and the environment. A simple ruler is a piece of technology as it is created for a purpose (measurement), it is developed via technical means and has a great impact on human life every day.

Consider medical inventions such as pacemakers, transplants and bionic eyes. What technology is needed to make these things happen? What science is required? What impact have these had on human life?

Let's consider how you could explore technology in the classroom using the creation and design of a hot air balloon as a topic. Students could investigate many aspects including:

- What science is behind a hot air balloon? (How does it rise and fall?)
- What type of gas is used in a hot air balloon?
- Can I make a hot air balloon?
- Who designed and created the hot air balloon?
- What designs were/have been proposed?
- What technical means are used in creating a hot air balloon?
- How are hot air balloons used today?
- What effects does the weather have on hot air balloons?

FOCUS QUESTION

Select any object. List five activities you could do in a classroom with students to investigate the science and technology of this object.

CURRICULUM LINKS

Year 7, 9: Science Understanding: Physical sciences
Also refer to Year 7 Work Sample 5: Parachute design; Year 9 Work Sample 8: Bionic eye (Australian Curriculum, ACARA).

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