When schooldays are over, what sense of science lingers?

Rosemary Hipkins ■ NZCER

If everyone has the opportunity to study science at school, they can gain an understanding of how science "works", and of the "big ideas" of science, that will enable them interact with important science issues in their adult lives.

Whether you agree with this statement or not, it is the essence of the "democratic" argument for making science part of the compulsory core curriculum of schools all around the world. In New Zealand it is implicit in all but two of the twelve curriculum aims set out in the introduction to *Science in the New Zealand Curriculum (SNZC)*, and is explicit in three of these:

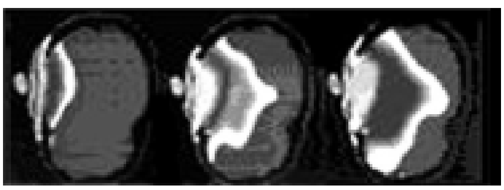
- assisting students to use scientific knowledge and skills to make decisions about the usefulness and worth of ideas;
- helping students to explore issues and to make responsible and considered decisions about the use of science and technology in the environment; and
- developing students' understanding of the different ways people influence, and are influenced by, science and technology (SNZC, 1993, p. 9).

These aims are at least partly directed towards the *future* behaviour of students. Secondary teachers may hope to develop appropriately useful outcomes for their students, but they may also worry about the impossibility of anticipating what exactly will "come in handy" in different future circumstances (Geelan, Larochelle & Lemke 2002). While the question obviously cannot be answered in any direct way, the research reported here provides some insights into the "sense" of school science that a diverse group of adults brought to a short encounter with a science-technology issue. Three different types of science memories are outlined, none of them especially helpful for the challenge that the adults faced. In each case, however, some modifications to existing teaching practice might well modify the memories retained so that they are more broadly useful for democratic decision-making at some future time.

RESEARCH PROJECT FIVE

Lennart Hardell – Orebro Medical Centre

A study was made of 209 people with brain tumours and a control group of 425 people without brain tumours. The researchers found that mobile phone users were no more likely to develop tumours than non-users. Of those with tumours, however, mobile phone users were 2.5 times more likely to develop tumours close to their "phone ear" than non-users. There were only 13 mobile phone users with tumours in the study group, so the result may not be statistically significant.



EXAMPLE ONE: THERMAL IMAGES

Senate Business and Professions Committee April 24, 2000: Senator Hayden presents actual photos of Radiation entering an Adult Brain, as well as the Brain of a 5-year old child: The depth of penetration is markedly more in the child than the adult. Proving radiation from cell phones penetrates the human brain.

Source:www.thegeomancer.netfirms.com

An encounter with a science-technology issue

NZCER was recently commissioned by the Ministry of Research, Science and Technology (MoRST) to research public attitudes to science and technology in New Zealand. As one part of the research project, four small focus groups of adults were observed while they interacted with material related to a science-technology issue. The people in the different focus groups came from different walks of life, and were predominantly clustered in the 25 – 45 age range. One group were on low incomes, one group were mothers of preschool children, one group were young urban professionals, and the fourth group were teachers. School days were well behind them, but all had had the opportunity to study some science at school. Three of the five teachers who made up one of the groups taught secondary school science, but none of the people in any of the other groups worked in a directly science-related job.

Because attitudes to and ideas about science are potentially rather abstract, and in any case are highly likely to vary in different circumstances, a *context* was chosen for the discussions that took place. Each group explored whether the low-level radiation that is given off by the aerial of a cell phone while it is being used is harmful to human health. This topic was chosen because many New Zealanders use cell phones, and the health issues that have been raised by some lobby groups are broadly relevant in modern societies, where "instant" communication is increasingly seen as necessary and important. This is an issue where a great deal of scientific research has already been carried out, and there is a huge volume of information (and in some cases misinformation) available on the Internet. Although there are some areas of conflicting scientific research findings, the current consensus amongst scientists seems to be that cell phones themselves pose few direct health risks, especially if used in moderation. They do, however, pose significant indirect risks where attention is distracted, for example when driving a car and talking on the phone at the same time.

During the first of their two discussion sessions, each group was given a very condensed summary of six pieces of actual scientific research that used differing methods to investigate the biological effects of cell phones. These pieces were a modified sub-sample of examples that were prepared by UK science education researchers for use by senior secondary school students in that country. (See Hind, Leach Ryder, and Prideaux (2001) in the references for details of where to find these on the Internet, with accompanying commentary about what happened when they were used with teachers and students.)

The six examples were chosen to illustrate issues that can arise from different types of experimental design. The *causal* types of research projects looked for evidence of actual effects – for example, whether or not low-level radiation of the type emitted by cell phone aerials makes changes to the activity of living cells that can be described and/or measured. In one case, evidence of such effects on the cells of nematode worms was investigated. A second project looked at whether or not microwave exposure would cause changes to the activity levels and the behaviour of rats. Two other projects investigated whether direct exposure of rats or mice to low level microwaves would cause increased rates of different types of cancer. In all these projects, the assumed connection was that invisible/direct effects on cells cause observable/correlated effects on the whole animal.

The other two research projects looked directly for *correlation* rather than causes. These were projects that sampled human populations to compare cell phone users with non-cell phone users for some specific health effect. The box gives a summary of one such project, Research Project Five.

In the second session, each focus group discussed six commentaries about the question of cell phone safety. These were sourced from a range of Internet sites, chosen to represent both science-orientated views and "alternative" viewpoints. One commentary (see box, Example One) included visual images.

During the discussions, it became evident that the participants drew strongly on "everyday" understandings when they interacted with this science-related issue. While some sense of the science that had been learnt at school might have lingered, for most of the participants in these discussions, this did not appear to provide a useful "toolbox" of ideas for thinking about the research related to cell phone safety. The types of views that emerged suggest that some aspects of science teaching may need to be changed if school science is to meet the broad democratic aims that are outlined in *SNZC*. Three aspects of potential everyday images of school science, with associated change implications, are outlined next.

A sense of "the scientific method"

School science often emphasises the importance of carrying out investigations "scientifically". The phrase "fair testing" has been widely adopted to represent key aspects of this emphasis. Investigations that take this type of approach typically begin with a question (the aim) that can be addressed by identifying and manipulating a range of key variables (the method) as an "experiment" is conducted. The effects that are directly observed and/or measured (the results) are summarised and then explained with respect to the original question (the conclusion).

This sense of what it means to be "scientific" has been criticised from several different perspectives. Jenkins (1996) pointed out that the idea of one common "scientific method" was invented in the first place to settle a political argument that took place within the British Royal Society more than a century ago. The scientists themselves soon abandoned it as unrealistic – the methods of different branches of science were simply too dissimilar – but it seems to have "stuck" as an image for practical work in school science ever since. Mayer and Kumano (1999) pointed out that experiments that can be carried out this way favour some types of science over others. Branches of science that involve the operation of whole systems (ecology, geology and meteorology are good examples) seldom involve these types of investigations.

The NZCER research suggests that an everyday sense of "the scientific method" may not be helpful for making decisions about real science issues. Most of the participants certainly seemed to remember about controlling variables to make things "fair" – the sense that "being scientific" means keeping as much as possible exactly the same is strongly ingrained. However, in the world of real science, things are not so simple. This was clearly highlighted when the focus group participants talked about whether the correlation studies (see Research Project Five, box) provided convincing evidence about the question of cell phone safety. The comments of one participant illustrate the way in which several of the groups puzzled about this:

> A study was made of 209 people with brain tumours and a control group of 425 people without brain tumours [reads out rest of Research Project Five report verbatim]. I find they are very…not at all convincing and it just doesn't even…the number of people in each group…and also why take two groups of people who are the same? They've already got tumours. I don't understand how they can reach a conclusion on that – they're more likely to develop tumours when they've already got it.
>
> *Researcher: So there's something about the sequence in which that worked that you don't find convincing?*
>
> I would be more convinced if they had a similar number of people in the control group, and if they were people without brain tumours at all.

It appears as though the sticking points in this case were that:

- The control group and the study group did not have the same number of people in them to begin with – the comparison was not "fair".
- Everyone in the study group had tumours to begin with. The actual method involved looking backwards to investigate past use of cell phones, whereas typical school experiments begin in the present and move forward in time to reach a result.

A forward focused, "fair testing" way to investigate the question might proceed along the following lines. No one should have had a brain tumour at the outset. Half of the group (selected to be as alike as possible) should have been allowed to have cell phones and half not. After a suitable length of time, evidence of brain tumour development should be sought. The practical and ethical challenges of actually carrying out such a project are immediately apparent! It is important to note that the research participants did talk about human bodies as complex systems. They acknowledged that individual differences in body functioning and in lifestyle factors can impact on the incidence of cancer, and that high cell phone use can go with a stressful lifestyle. They were very tolerant of the uncertainties generated by these complexities, so their view of science was not naively simplistic in this respect. Rather the issue was that when they approached actual science research, most of the participants appeared to have a very narrow "toolbox" of views to bring to the judgments about scientific methods that they had to make.

How could existing practice be modified?

How could secondary science teachers modify their existing practice to leave their students

How do ecologists, gathering data to describe the impact of an environmental change, make their sampling procedures fair? How do geologists, building an argument for meteor impact as the cause of dinosaur extinction, deal fairly with evidence that could be interpreted in ways that support other theories? How do pharmacologists, carrying out trials of potentially promising new medicines, make their investigations of possible side effects fair?

with a more helpful memory of what "being scientific" means? A sense of making "fair comparisons" *is* an important aspect of science. However, students need opportunities to see how that is played out in a much wider range of contexts than the school laboratory can provide. How do ecologists, gathering data to describe the impact of an environmental change, make their sampling procedures fair? How do geologists, building an argument for meteor impact as the cause of dinosaur extinction, deal fairly with evidence that could be interpreted in ways that support other theories? How do pharmacologists, carrying out trials of potentially promising new medicines, make their investigations of possible side effects fair? (The idea of a placebo effect was invented by scientists when they first recognised this methodological challenge.)

These are just three of many examples that could be used to illustrate the huge diversity of scientific methodologies, whilst still using "fairness" as a powerful metaphor for the difference between "being scientific" and less rigorous methods of investigation. Teachers could enhance this lingering sense of "fairness" by introducing their students to stories that include aspects of the *methodology* of actual scientific discoveries and/or disputes across a broad range of scientific disciplines.

A sense of "significance"

All the participants had retained the sense that being scientific means measuring/counting to gather relevant data. But making up their own minds about whether that data was convincing was another matter entirely. The following comment, made by one participant in response to Research Project Five, illustrates the dilemma:

> In project five they talked about the mobile phone users being 2.5 times more likely to develop tumours close to their phone ear than non-users, but there's a phrase there – "statistically significant" – which has actually swayed me on both of them. Like the first one says "the result may not be statistically significant". So I've sort of gone and thrown that out, because then the next one says "this difference is statistically significant". And so I suddenly think that looks quite good. …. I get swayed easily by little comments like that.

Once again the "toolbox" looks somewhat empty. If we want people to make good judgments about the meaning of data presented in support of a scientific argument, then they need far more strategies than simply knowing that the word "significant" is, well, significant. A number of case studies in the "public understanding of science" literature document provide instances where people have deliberately manipulated data collection and/or presentation to present self-serving arguments about environmental concerns (see, for example, Tytler et al., 2001). If democratic outcomes really are valued for school science learning, then the evidence of this research project supports the suggestion that some changes of approach are needed.

How could existing practice be modified?

How might teachers instil the confidence that "significance" can be open to critical scrutiny – if you know how, and what, to ask? The researchers who developed the cell phone safety resource for school students (Hind et al., 2001) suggest that students should be given at least some opportunities to learn how to critique suitably modified data from a range of actual scientific investigations. This would help overcome the limitations that are imposed if students only ever consider data from their own investigative work, where the measuring equipment, range of methods and time available will all have obvious limitations. It would also demonstrate how *contexts* help to determine the type and range of data that are needed to answer each different question.

Stories of real cases could again be explored to learn from other people's lessons. For example, Tytler et al. (2001) describe a situation in which a UK environmental lobby group successfully opposed the waste incineration practices of a cement factory situated near people's homes and farms. The dispute was about the levels of certain hazardous chemicals in the smoke emitted during incineration. The factory owners had misrepresented the emission results by limiting the times at which samples were systematically taken, and by sampling only the main stacks, ignoring the auxiliary stacks that opened when carbon monoxide levels in the emissions became too high. The environmentalists used sound scientific reasoning to detect and expose these flaws in the "fair sampling", and they won the case.

A sense that "seeing is believing"

Comments made about the so-called "actual photographs" of cell phone radiation penetrating the human brain suggest that more attention should be given to the critical examination of visual evidence as part of a "toolbox" for democratic outcomes for science education. The technological products of science present many different ways to construct and manipulate images, not only for entertainment (as in the blurring of the real and the imaginary in *The Lord of the Rings*), but also for serious purposes of scientific investigation (as in the imaging techniques used in medical research). Most participants in the focus groups were, however, prepared initially to accept the image shown in the box at face value. Only when certain inconsistencies were pointed out (the same sized and shaped heads for different individuals; the practical impossibility of taking an "actual photograph" of a split open living head) were second thoughts raised. Here are two comments made by the same person. The first comment was made before the discrepancies were discussed, and the second one after it became obvious to the group that this was a simulated image:

> **First comment**
>
> I think just the visual impact as well as the fact that the last one is a child. That gives you a fright. Well it does to me anyway. A small child having received that much radiation. The word "radiation" too is very emotive, you know you think nuclear power and "frying your brain" and all that kind of stuff. So, yeah. So that makes a definite impact.
>
> **Subsequent comment**
>
> They've been teaching them [the participant's primary school-aged children] how to discern in terms of advertisements. What kind of information are they trying to get across? How are they hooking you in? So children are learning that sort of thing, so this is very relevant to children's education that they should be trying to interpret scientific information, the sources that…from issues like this.

This parent clearly valued learning opportunities for her children that she did not perceive as having been a part of her own schooling. As technology continues to advance, visual misrepresentations of this type will proliferate. There are obvious implications for school science here, as we consider how best to address this challenge.

How could existing practice be modified?

How can teachers help their students to become more discriminating about the validity of "evidence"? Helping students to discriminate between sources of information on the Internet would appear to be a good place to start. Looking critically for links between the *evidence* and the *argument* is also helpful, as this comment from one participant, talking about one of the Internet commentaries, illustrates:

> She [a well known NZ politician] makes some interesting comments about children's skulls, but then she says "there is new evidence" you see. So she has made a valid comment that we have to be sensible about it and protect in terms of children. That's interesting, that's valid. But then she's leaping to evidence of the health effects, where is the evidence?

Again, stories and case studies would be suitable for this purpose. Carefully chosen and constructed, all three of the ideas *about* science described here could be developed together. Students could begin by exploring the measures taken to ensure *fairness* in the inquiry method used in the specific case, broadening their ideas about "fair testing" stereotypes. They could then explore the meaning of the actual *evidence* collected, in relation to the problem or *argument* that had been posed. This would lead in turn to an exploration of the overall *significance* of the findings. The drama of a good story could provide the bonus of a context to linger in the memory, perhaps holding the "toolbox" together for a longer time. Potentially suitable stories abound – see, for example, Barker (1997). If they could be developed and shared collaboratively, many teachers and the future citizens of New Zealand could share the benefits.

Issues of empiricism

This article has addressed ideas about the *methods* of science and has suggested that students need opportunities to gather a much wider "toolbox" of ideas about how real scientific investigations are actually carried out. However, this focus, by itself, gives a one-sided image of what makes science different from other ways of viewing the world. School science is often criticised for developing an "empiricist" view of the nature of science. In such a view, science ideas can be "discovered" out in the "real world" just by looking and/or measuring in carefully scientific ways. Critics of this view say that the actual process of science is much more complex than that. As scientists work, there is a constant interplay between the investigations that they carry out and the deep understandings of relevant existing science concepts that they already hold in their heads. *Evidence* does not stand alone, but is interpreted in the light of currently accepted science *theory*. This is another area where the research project introduced here found that people hold views of science that are not helpful for decision-making about real scientific issues. It will be the subject of an article in the next issue of ***set***.

References

Barker, M. (1997). History in New Zealand science education: progress and prospects. In B. Bell and R. Baker (eds), *Developing the Science Curriculum in Aotearoa New Zealand.* Auckland: Addison Wesley Longman, pp. 187-212.

Geelan, D., Larochelle, M. & Lemke, J. (2002). The laws of science. In J. Wallace and W. Louden (eds), *Dilemmas of science teaching: Perspectives on problems of practice.* London: RoutledgeFalmer, pp. 22-35.

Hind, A., Leach, J., Ryder, J. & Prideaux, N. (2001). *Teaching about science: Assessing data quality: Mobile phones – health risk or scare?* www.nuffieldfoundation.org/aboutscience

Jenkins, E. (1996). The nature of science as a curriculum component. *Journal of Curriculum Studies,* 28(2), pp.137-150.

Mayer, V. & Kumano, Y. (1999). The role of system science in future school science curricula. *Studies in Science Education,* 34, pp.71-91.

Tytler, R., Duggan, S. & Gott, R. (2001). Public participation in an environmental dispute: implications for science education. *Public Understanding of Science,* 10(4), pp.343-364.

ROSEMARY HIPKINS is a senior researcher at NZCER. Her background is in science teaching at secondary school level, and in teacher education. She has been involved in a number of recent science education initiatives, and led the team carrying out the research for MoRST that is discussed in this article. The full report can be accessed from either the NZCER website or the MoRST web site: www.nzcer.org.nz
www.morst.govt.nz/publications/commonsense.html

Email: rose.hipkins@nzcer.org.nz