lifelong science learning

Written by Miles Barker (University of Waikato)

Introduction

There is a story doing the rounds about two English schoolboys taking time out and commiserating about the state of their lives. One says, "More bad news from school." "What?" wails the other. "Now they've discovered LIFELONG learning!"[1]

These days in New Zealand, where 'lifelong learning' is seen as an indisputably desirable outcome of schooling, that story has a somewhat antiquated feel to it. The New Zealand Curriculum of 2007 makes this clear even in its 'Forward', where it outlines what is to follow: "It defines five key competencies that are critical to sustained learning and effective participation in society and that underline the emphasis on lifelong learning."[2] 'Lifelong learning', or equivalent phrases, then appear like a mantra through its pages.[3] Interestingly, however, what lifelong learning actually looks like or – crucially for teachers of science – how you would teach students in such a way that they will continue science learning in the uncharted world of the rest of their lives, is not elaborated.

Two preliminary thoughts

Asking people about what might create a fruitful setting for lifelong learning in science (and I am not thinking here about the small proportion of students who will go on to be professional scientists) is likely to bring forward two preliminary thoughts: that science experiences need to afford sustained enrichment right through schooling; and, more specifically, that having inspiring science teachers is hugely important.

On the first point, there is of course a disquieting body of international research that suggests that at senior levels these days, when students have the option of relinquishing science, they tend (either out of disappointment with school science, or for career-strategic reasons) to choose business-related subjects and ICT.

Schools in many countries are therefore struggling to "… slow, stop and reverse the decline in science enrolments at year 12 and 13"[4]. How far this is true of New Zealand is a moot point. Actually, from a very comprehensive study, Rosemary Hipkins, Rachel Bolstad and Josie Roberts concluded that "caution is needed when interpreting (New Zealand) data that lament a sharp decline in overall numbers of students continuing to study science in the senior secondary school."[5] Nevertheless, if school science is to be an indispensable springboard for learning science lifelong – and one meets few adult citizens who are passionately engaged with science but who profess to have found school science less than meaningful – then the point about school science experiences is a valid one.

On the face of it, the point about having inspiring science teachers is hard to deny. Very few people seem to be set on a lifelong orientation towards science quite independently of their schooling. An exception is British neurologist Oliver Sacks who, as he describes in his classic book *Uncle Tungsten: Memories of a Chemical Boyhood*, resonated lovingly with everything scientific in his youthful world, whether teacher-inspired or not.[6]

By contrast, interactions with teachers are more evident in the biography of New Zealand's greatest astronomer, Beatrice Tinsley, but in her case awe on the part of the teachers is more in evidence that the benefits gained by Tinsley at school: "Already, at the age of 13, Beatrice knew about energy, and force. She had a gift for perceiving and linking things which went well beyond anything her teacher had ever encountered, and she did this while going directly to the heart of the matter and expressing herself in the simplest and most precise way."[7] These two moved into professional science, but New Zealand economics commentator Brian Easton didn't, despite an exceptionally gratifying science schooling: "I almost became a chemist. In the upper forms at Christchurch Boys' High School I had an inspiring chemistry teacher, Alan Wooff … (there was) a chemistry section of the library which I devoured … I still read science for leisure."[8]

For my own part, it was probably the influence of senior biology teacher Stewart Christie in Form Six at Hamilton Boys' High School and his view that evolution by natural selection "… is a whole lot of arrows pointing in the same direction. There are just a few arrows pointing in the opposite direction." I thought, "If 'Sam', who takes the conservative Christian Crusaders group, can apparently accommodate and reconcile the diverse scientific and theological influences in his mind in this way, maybe it is possible for me too." It's a challenge I've cherished lifelong.

But I believe we need to dig deeper. Not everyone relishes

Figure 1: Responses to the 'draw a scientist' task from three Middle Schoolers - a student in South India (1a), and two New Zealanders, Nicole (1b) and Victor (1c) - and from three Kenyan teacher educators (1d).

twelve or thirteen enriching years of science at school; and which teacher one gets for science is often a notorious lottery. In this article, I would like to explore how schools can much more deliberately and systematically offer a form of science learning that both meets the needs of contemporary learners, but is also tailor-made to sustain lifelong science learning.

Lifelong science learning – what is it?

What do we actually mean by 'lifelong learning in science'? What visible forms does it take: reading widely in science all your life; watching science documentaries; trying to understand new science theories; attending lectures and evening classes; using science knowledge to stay employed; or making money from science?

And when we have decided that, how might an anticipatory platform be laid in school to ensure that science learning does persist lifelong?

The lens I bring to this is a very pragmatic one. Although science speaks to me about some of the deepest things in the cosmos, I am no dilettante hobbyist. Rather, I believe that we are increasingly living in a world fraught with urgencies and issues, a world of new directions and new responsibilities, where science learning can empower us and help us to be vital lifelong contributing citizens. With this in mind, I am suggesting that lifelong science learning might entail three major capabilities.

Capability One: Owning, adapting and applying the big stories of science

Adults who are lifelong science learners usually, it seems to me, have one clear characteristic – rather than their science knowledge consisting of isolated fragments, ill-remembered from schooling, they can instead offer you extended explanatory stories in science. More specifically, in response to the big, simply worded questions that arise in our everyday lives, they can give you an articulate and coherent account from the science perspective.[9] They don't claim that their stories are definitive, or even complete, but they have been running these stories in their minds since school, and they have been keeping them up to date, as best they can, and they have been finding them useful to engage with life's complexities.

Here are some examples of such questions – questions that beg for such a narrative: how did we get here; how did Aotearoa/New Zealand get here?; why are there so many types of plants and animals?; where does energy come from and go to?; what are rocks and how are they made?; what causes disease?; what is learning?; how do trees grow?; how old is the Earth?, and how did it come to be?; why is water so special?; how do we change as we get older?; what is air?; why does the moon keep going around the Earth?; what are fossils and how are they made?; how does the heart work?; and so on …

But how do these stories become profoundly sustaining in the living of our adult lives? Let me give you four examples:

Example 1: The New Zealand Herald ran a story in 2008[10] about a water bottling company which claimed that the processing of its Energised Distilled Water and Energised Mineral Water "neutralises the harm caused by toxins through reprogramming the water's polarity and restoring it to its 'primordial' or natural state."

Now water, especially bottled water, is a dominant and controversial aspect of the lives of most of us these days, and the water companies assail us with apparently persuasive scientific justifications for the superiority of their various products. However, any citizen who has been running the 'Why is water so special?' science story since school days, can readily unravel this gobbledegook. They can explain to themselves and others that water simply IS water – that its H_2O molecules, since the Earth was young, have had a fixed negative side and a fixed positive side; that there is simply no way by which this natural condition can be demonically reversed; and that we therefore are awaiting rescue from this pervasive catastrophe by a water bottling company. Incidentally, the company in question was fined $25,000 for breaching the Fair Trading Act.

Example 2: In 2009, *The New Zealand Herald*[11], under the headline 'Garlic offered for hypertension' told how, in an experiment, a 53-year-old man visited 26 randomly selected health food shops. Although he was complaining of supposed high blood pressure, he "was referred to a doctor by only one … If asked, he told the employee his blood pressure was 160/120. In 25 of the shops he bought a wide range of products, with the most popular being garlic." For us citizens, correctly understanding this situation really could be a matter of life and death; but those who run the science narrative 'How does the heart work?', especially as it explains the cardiac cycle and the prescient significance of '160/120', would seemingly be at an enormous advantage in the survival stakes.

Example 3: Earlier in 2009, *The New Zealand Herald*[12] added a new twist to the question of whether or not, around 23 million years ago, Aotearoa/New Zealand was completely submerged for a period, drowning all animal life. In 2007, Earth scientists Hamish Campbell and Gerard Hutching had controversially claimed that this HAD occurred.[13] Now, *The Herald* was reporting a Central Otago tuatara fossil find that suggests to Earth scientist Trevor Worthy that tuatara have had a continuous existence on an Aotearoa/New Zealand land mass (but of greatly varying size) since well before 30 million years ago.

Those citizens who run the 'How did Aotearoa/New Zealand get here?' science story are well placed to appreciate how intriguingly open-ended this story of our homeland's generation currently is. But there is more to it than that. For Pasifika people, this is a science story that deeply intersects with another narrative that is foundational to deep questions of human identity: the role of the great ancestral trickster and demi-god Maui in the creation of Aotearoa. Understanding the tuatara find cuts right down to the bedrock of our national identity.

Example 4: Also in 2009, the *New Zealand Geographic* reported[14] a story which would have shaken the foundations of those Pakeha citizens who run the 'How did we get here?' science story. It announced that a human skull found near Featherston in 2004 was now known to have a radiocarbon age of 296 plus or minus 35 years before the present. The journal commented that, "… mitochondrial molecules have spoken, science has triumphed over common sense and now the historical record had to account for a European woman roaming the banks of the Ruamahunga River centuries before the first record of white women[15] anywhere in New Zealand."

Apprehending this science story, and its intersections with the story of Pakeha social history in New Zealand, again strikes at the very identity of New Zealanders, especially the conventional story of Pakeha women and the New Zealand Company's arrival in 1839.

There are three key points about these great stories of science:

1. ***Knowledge structure:*** The stories overlap between themselves – for example, in the case of the Central Otago tuatara fossil find, the 'What are fossils?' and the 'How did Aotearoa/New Zealand get here?' stories

clearly intersect. Also, the science stories intersect with stories from beyond science, for example, with the social science narrative in the case of the Ruamahunga skull. And in later life, of course, the knowledge in the science stories more and more takes on a new ambience. No longer is the knowledge novel, raw and school-bound – rather, as we confront life's science–related situations (anything from managing a household energy budget within a low income, to raising a child born with Down's syndrome) the science stories increasingly and properly take on the sophisticated, contextual flavour of 'citizen thinking'.[16] In conclusion, one could well suggest that learning itself is the facility to make immediate, fruitful and novel connections between the big stories.

2. ***Pedagogy:*** Because the science stories are *evidence-based*, handing them on intact and unmodified is not one of their features; rather, the stories are being perpetually modified as new evidence comes to hand. Science learning in school therefore has the crucial task of explicating this evidence-seeking aspect of science for students with a clarity that will endure for a lifetime. (I talk more about this below.) Again, what we know about how students construct their knowledge suggests that teachers need to take account of three dimensions in their science teaching: an appropriate form of the story itself, the students' own existing ideas, and a vigorous interrogation of the evidence.
3. ***Curriculum:*** A wise science curriculum will be paced so that students' science stories *are further enriched* as they pass through school. This successive enrichment is, of course, modelling a habit of mind people will hopefully possess for a lifetime. And just as the pacing the ideas is important so, too, is the pacing of the cognitive demand on learners.

In summary, the capability of owning, adapting and applying the big stories of science requires school-fostered expertise in two of the four banner headings that subsume each page of our science curriculum:

- Investigating in science – constructing the story as an amalgam of ideas and evidence
- Communicating in science – articulating the story with clarity and confidence

Capability Two: Understanding the nature of science itself

Another characteristic of adults who are lifelong science learners, it seems to me, is that they have a shrewd idea of what science *is like*. Not only do they have ideas *in* science (its big ideas) but they also have ideas *about* science: what science knowledge is and how it is special; who scientists are and how they do their work; and how scientists and the rest of us affect each other.

I've been exploring people's ideas in this area by inviting them to respond to an imaginary task and to draw a scientist.[17] Usually, students interpret the task as requiring some kind of archetypal scientist, but I'll show you a delightful example of a particular scientist that a Middle School student in South India drew for me earlier in the Darwin Bicentenary year of 2009 (Figure 1a). She has alluded to Darwin's tropical sea voyaging, and she has suggested how seminal were Charles's ideas about tortoises and bird life in creating the *Voyage of the Beagle and The Origin of Species*. A letter "to sweetheart" also acknowledges Darwin's private life – his relationship with Emma.

I'm convinced that it is essential to explore and clarify ideas *about science* with school students because for the rest of their lives they are sure to be exposed to a maze of often quite contradictory ideas about this profound aspect of their lives.[18] Having students 'draw a scientist' can lead to fruitful learning. For example, Middle Schoolers Nicole and Victor suggested somewhat contradictory images: Nicole's sunny upbeat scientist (Figure 1b) bears a test tube, but her rainbow-drenched surroundings[19] comprise symbols of her private life, including a (curiously bespectacled) puppy. By contrast, the environment of Victor's more severe male scientist (Figure 1c) is dominated by aspects of his professional life: a giant nucleic acid, and a skull and crossbones-labelled chemical flask. These images could well lead into class discussion of a classic proposition[20] about the way "scientists participate in public affairs both as specialists and as private citizens."

Perhaps an even more fundamental question that arises from Nicole's and Victor's images is 'How do scientists actually make discoveries?' On the one hand, some explanations appeal to a scientist's inexplicable *flash of genius* – a 'eureka' moment – like the story of Archimedes and the discovery of density. At the other extreme, the fundamental importance of persistent careful observation is seen as the key, for example, Edward Jenner's prolonged observations of milkmaids, their susceptibility to cowpox, but their relative exemption from smallpox. Clearly, both explanations about the discovery process are simplistic parodies of how most scientists work.[21]

But, perhaps Victor's teacher and his class actively pursued the question of how that DNA molecule *was* actually discovered. Exploring the Watson and Crick story can show us that even those most eminent of scientists deliberately used a number of very standard heuristics, or discovery-seeking techniques in combination. They: found out everything that was already known about DNA; did more experiments and thought about other people's experiments; worked out what DNA should be like in theory; and built models in the basement until they were PRETTY sure …

And, with further schooling, Victor may well appreciate that, as Derek Hodson describes it, "real scientific inquiry is holistic, fluid, flexible, reflexive, context-dependent and idiosyncratic. It is characterised by frequent false starts, blind alleys and improvised modifications; it can be, and often is, redirected by unexpected events and by unanticipated technical problems … by the publication of a research paper in the same field or chance conversation with another researcher."[22]

Yes, inquiry in science is a blend of logic and imagination, there is no single 'scientific method', and everyday thinking processes like seeking an analogy and analysing its pros and cons can all play their part. Perhaps, Nicole and Victor, we should now go and visit some scientists, and ask them how they do their work!

Beyond school classrooms, 'drawing a scientist' can raise wonderfully reflective discussions about the science enterprise. I recall how a group of three Kenyan primary school teacher educators – admittedly, being deliberately provocative – drew me a one-year-old scientist (Figure 1d), deeply engrossed in questioning, hypothesising, experimenting, and communicating. By contrast, when scientists self-report, it seems, they often emphasise a socially interactive and environmentally aware view of 'doing science'.[23] I shall return to this aspect below.

In summary, being capable of understanding the nature of science itself requires school-fostered expertise in another of the banner headings that subsume every page of our science curriculum:

- Understanding about science – appreciating that science is a way of explaining the world; that science knowledge changes over time; identifying ways in which scientists work together and provide evidence to support their ideas; knowing about the relationship between investigation and theory and the processes of logical argument; exploring the connections between new and existing knowledge; and understanding the importance of peer review.

Capability Three: Engaging in socio-scientific issues

Adults who are lifelong science learners, it seems to me, are generally not people who take things sitting down. As we have seen above, they respond personally to news media items that speak to them about their own health and identity. However, they are also often people who respond and react in a much wider societal and environmental sense to science-related media items. And, of course, those issues are many, they are frequently complex, and the statements made can be utterly contradictory. One day, we are told that climate change is now near irreversible: "scientists sound dire warning on governments to act quickly to cut greenhouse gases."[24] Another day, we learn that "carbon dioxide, the evil stuff that CGW [Church of Global Warming] wants to outlaw, is actually the compound we exhale every breath we take."[25] How, if at all, do we respond?

If taking action on socio-scientific issues is desirable in adult life, and if school science is a preparation for life, does this mean that school science education should model such action-taking? Hugely respected, now Auckland-based, science educator Derek Hodson says, 'yes': "It is not enough for (science) students to learn that science and technology are influenced by social, political and economic forces; they need to learn how to participate, and they need to experience participation."[26]

But, given the complexity of some of the issues, would it not be wise to postpone action-taking until senior secondary school, when students' understandings will be appropriately mature? Derek Hodson says 'not necessarily – it depends on the context.' "For example," he says, "it is easier to take action on recycling than to reach a considered and critical judgement of recycling versus reduced consumption versus alternative materials."[27] Yet *should* we be advocating social participation of this sort as a basic aspect of school science? Derek Hodson's response is absolutely in line with *The New Zealand Curriculum*'s position on values: "Many teachers avoid confronting the political interests and social values underlying the scientific and technical practices they teach about, and seek to avoid making judgments about them, or influencing students in particular directions. This makes no sense … It asks teachers to do the impossible. Values are embedded in every aspect of the curriculum."[28]

But how do teachers actually approach the teaching of socio-scientific issues? Kathy Saunders, a faculty member of the School of Education at the University of Waikato, has very recently completed a major study[29] investigating this. The secondary school teachers whom she interviewed expressed a number of doubts, hesitancies and even avoidance strategies: "I don't see it as an issue – just facts"; "I teach the science and let the students discuss and make up their own minds on subjects"; "I don't understand the issues myself to the degree I would like."

Next, Kathy surveyed teachers about what they felt was constraining their teaching of controversial science issues. Lack of time in their current programmes (68%), lack of personal background knowledge (50%), lack of time to plan (35%), lack of teaching resources (35%), and – significantly for Kathy – lack of knowledge of effective teaching and learning strategies (23%) turned out to be major factors in the teachers' minds. Only 20% cited lack of interest by the students.

Kathy decided to channel her research towards developing and trialling a novel teaching and learning model to help teachers navigate through the process. Evolving from international research, especially in the United Kingdom, Kathy's 'Model for ethical inquiry into scientific issues' draws the class through processes of engagement, backgrounding, reflection, discussion, and question identification. Then comes, what is for Kathy, the key step: introducing a choice from five ethical frameworks or lenses ('the right to choose', 'pluralism', etc.) by which students can focus on their question and generate processes of ethical decision-making, with justification, from which action-taking (Derek Hodson's key point) results. Kathy presents persuasive evidence that students considered her approach to be a gratifying exploration of, as one student put it, "the reasons why people think differently"; and teachers were attracted to the security of the stepwise process[30] and the clear action-generating outcomes. Yes, Kathy's work was in secondary schools, but she is convinced that the approach would be equally effective with much younger learners.[31]

In summary, being capable of engaging with socio-scientific issues requires school-fostered expertise in another of the banner headings that subsume every page of our science curriculum:

- Participating and contributing – linking science learning to daily living, using science knowledge when considering issues of concern, exploring various aspects of an issue, drawing evidence-based conclusions, making decisions about possible actions (both personal and societal), and taking action where appropriate.[32]

Living science lifelong: What do we need to do in school?

I have suggested three capabilities that lifelong learners in science might need to have, and which therefore need to be a focus of school science programmes. Fortunately, these three capabilities are legitimised by the banner headings, the Nature of Science, across every page of our school science curriculum:

Capabilities for Lifelong Science Learning	NZ Science Curriculum: The Nature of Science
1. Owning, adapting and applying the big stories of science	• Investigating in science • Communicating in science
2. Understanding the nature of science itself	• Understanding about science
3. Engaging in socio-scientific issues	• Participating in science

It turns out, on this view, that preparing our students for lifelong science learning entails no big *additional* new directions and responsibilities. What is needed is simply a willingness to accept wholeheartedly the radical course that our new science curriculum has already set us on: to accept that our science curriculum *actually means what it says*.

Living science lifelong and *The New Zealand Curriculum* at large

Thinking about school science learning as an anticipation of life encourages us to take even more seriously the underpinnings of our science curriculum in the front half of *The New Zealand Curriculum*.[33] Take the 'Values' section (page 10). A fundamental aspect in living science lifelong is surely never to forget the question "What do we value, and why?" Another angle is for we teachers of science to ask ourselves which of the eight listed values ('excellence', 'integrity', etc.) does science learning, in school and lifelong, provide an especially fruitful context for developing? I would say that 'integrity' has a high loading for science. An invaluable lifelong habit of mind might be to be to perpetually have at the ready the question: "How do I bring *scientific* integrity" (objectivity, respect for evidence, open-mindedness, willingness to suspend judgement, logic and analysis, attention to variables) "to whatever situation is in front of me?"

The 'Vision' section on page 8 (which is about "What we want for our young people") is highly relevant. Living science, lifelong, could be seen as the working out of visionary, science-related questions like: "What kind of world do we want to live in?", and "What kind of people do we want to be?"

And more serious thinking needs to be done about how the 'Key Competencies' (page 12) relate to the 'Nature of Science' banner on each page of the science curriculum. Given some obvious resonances (both catalogues contain 'participating and contributing'; clearly, 'using language symbols and text' channels specifically into 'communicating in science') let me propose the following alignment:

<table>
<tr><th>KEY COMPETENCIES
Capabilities for Living and Lifelong Learning, p.12</th><th colspan="2">NATURE OF SCIENCE
Level One – Eight Science
'The New Zealand Curriculum'</th></tr>
<tr><td>Participating & Contributing</td><td>Participating & Contributing</td><td rowspan="5">Understanding about Science</td></tr>
<tr><td>Using Lang., Symbols & Text</td><td>Communicating in Science</td></tr>
<tr><td>Thinking</td><td rowspan="3">Investigating in Science</td></tr>
<tr><td>Relating to Others</td></tr>
<tr><td>Managing Self</td></tr>
</table>

Here, I am thinking of 'Investigating in science' not only as students carrying out traditional experiments but, rather, the very broad range of technical, mental and social processes involved in students 'finding out' in science. Construed this way, 'Investigating in science' demands broadly competent 'thinking', 'relating to others' and 'managing self'. And, of course, this column of descriptors for students engaged in science has intriguing similarities and differences with what happens when professional scientists engage in science ('Understanding about science'). Thought about this way, living science throughout adult life calls for a lifelong application of all of the Key Competencies learned in school.

Living science lifelong: a final word

A quotation attributed to Mohandas Gandhi deserves to stand as a final word on what we might hope for in a world where school science learning and lifelong science learning would be seamless: "Be the change you want to see in the world. Live as though you were to die tomorrow. Learn as though you were to live forever."[34]

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Footnotes

1 I am indebted to Guy Claxton for this anecdote.

2 Ministry of Education (2007), *The New Zealand Curriculum*. Wellington: Learning Media, p.4.

3 Refer pp.6, 7, 8, 20, 37, 41 and 42.

4 Jonathan Osborne, speaking at the Australian Council for Educational Research Conference, Canberra, quoted in: Foster, G. (2006). Boosting science learning – What will it take? *New Zealand Science Teacher*, 113, 15-18.

5 Hipkins, R., Bolstad, R., & Roberts, J. (2006). Encouraging a greater range of students to stay in science: What can teachers do? *New Zealand Science Teacher*, 113, pp.7-11.

6 Sacks, Oliver (2001). *Uncle Tungsten: Memories of a Chemical Boyhood*. London: Picador.

7 Catley, Christine Cole (2006). *Bright Star: Beatrice Hill Tinsley, Astronomer*. Auckland: Cape Catley, p.64.

8 *New Zealand Listener*' January 24, 2009, p.54.

9 This notion is certainly not all my own. It was first persuasively voiced in Millar, R., & Osborne, J. (1998) (Eds.), *Beyond 2000: Science Education for Future*. London: King's College, section 5.2.1.

10 14th January 2009.

11 24th April 2009.

12 23rd January 2009.

13 Campbell, H., & Hutching, G. (2007). *In search of ancient New Zealand*. London: Penguin Books.

14 Yarwood, Vaughan (2009). Written in blood: How a chance discovery shook our notions of the past. *New Zealand Geographic*, 96 (March-April), 36-47.

15 The article cites this as 1806, with the arrival of two escaped convicts, Kathleen Hargety and Charlotte Edgar, from the New South Wales colony.

16 Jenkins, E. W. (1999). School science, citizenship and public understanding of science. *International Journal of Science Education*, 21(7), 703-710.

17 "Draw a geneticist" or "Draw an ecologist" are interesting variants on this task. See: Jordan, R., & Duncan, R. G. (2009). Student teachers' images of science in ecology and genetics. *Journal of Biological Education*, 43(2), 62-69.

18 On my recent flight to India I was bemused by the wrapping on my serving of 'Gourmet Ice Cream' which promoted itself by claiming to be "created by connoisseurs not chemists."

19 The original drawing is in colour (as is Fig. 1d).

20 Rutherford, J., & Ahlgren, A. (1990). *Science for all Americans*. New York: Oxford University Press, p.11.

21 These two accounts of how discovery occurs in science are often dignified by the names 'hypothetico-deductive' and 'inductive' respectively. See There is a beautifully clear explanation of this in: French, S. (2007). *Science – Key Concepts in Philosophy*. London: Continuum, pp.8-23.

22 Hodson, Derek (2008). *Towards scientific literacy: A teachers' guide to the history, philosophy and sociology of science*. Rotterdam: Sense Publishers, p.133.

23 Barker. M. (2009). Draw a scientist. *New Zealand Science Teacher*, 121, 33-36.

24 *New Straits Times*, 14th March 2009.

25 *Hamilton Press*, 6th May 2009

26 Hodson, Derek (2003). Time for action. *International Journal of Science Education*, 25(6), 645-670.

27 Ibid.

28 Ibid.

29 Saunders, Kathy (2009). Engaging with controversial scientific issues – a professional learning programme for secondary school teachers in New Zealand. Unpublished DScEd, Curtin University of Technology, Perth, Australia.

30 Kathy was even more gratified by the way many teachers skilfully adapted the model to their own circumstances, without losing any of its intent.

31 In fact, Kathy (Kathy@waikato.ac.nz) is very keen to work alongside any teachers who would like to develop the model further with her.

32 Two excellent discussions about science education as societal participation are: Lee, S., & Roth, W.-M. (2003). Science and the "good citizen": community-based scientific literacy. *Science, Technology and Human Values*, 28, 403-424, and Roth, W.-M. (2007). Towards a dialectical notion and praxis of scientific literacy. *Journal of Curriculum Studies*, 39(4), 377-398.

33 See also: Barker, M. (2009). Science and the NZ curriculum. *New Zealand Science Teacher*, 120, 29-33.

34 Quoted in *Australasian Yoga* (2004). Programmes for Satyananda Yoga, p.25.