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Number 131

ISSN 0110-7801

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Additional copies of the NZ Science Teacher Journal $32.06 per year for three issues

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Cover photo caption: Anybot at the watercooler (see page 16). Photograph courtesy of Bill Murvihill, from Anybots.com

Science 2.0 and school science

School science, the 'smart' economy, 'networked' science and 'wicked' problems: Is there a connection? Should there be? *Jane Gilbert*, NZCER explains:

In an article in this journal last year[1], I wrote about how science is asked to play many different – and often conflicting – roles in the school curriculum. The article explored how and why school science developed as it did, in the larger context of 20th century debates about public education (what public education is *for*, what we thought an 'educated person' looked like, and how learning science was supposed to contribute to that).

The point of the article was to show how past thinking has produced what we have now, and to show how that thinking is constraining our efforts to reshape school science for the 21st century. In the earlier article, I referred briefly to the many and varied pressures for change in school science that are now evident.

In this article, in keeping with the theme of this issue of *NZ Science Teacher*, I look at one of the four pressure areas I listed: changes to the work of being a scientist (and to the world of work generally). Via a quick survey of some big trends in the world beyond education, I explore some difficult issues science educators need to face, if school science education is to play a meaningful role in preparing some young people for science-related work.

The earlier article had an education focus. It looked at how school science is supposed to be 'educative', at how, by providing access to 'powerful' knowledge, studying science is supposed to expand people's mental capacities, while at the same time also providing a platform for higher level study. This article has a different starting point. Beginning from outside the field of education, it questions science education's emphasis on knowledge as a 'thing in itself', arguing that this won't build the attitudes to knowledge needed in today's science workforce.

Science, innovation and New Zealand's future

Recently we have seen increasing government emphasis on science's importance to New Zealand's social and economic future. In current Government policy, science is linked with innovation, and this pairing is seen as a key source of future economic growth.[2] In parallel with this, the last couple of years have seen a renewal of Government interest in school science education.

In 2011, the Prime Minister's Chief Science Advisor released a paper reviewing the "state of play" in New Zealand school science education. This paper's aim was to:

> consider how to ensure that young New Zealanders are enthused by science and able to participate fully in a smart country where knowledge and innovation are at the heart of economic growth and social development.[3]

The paper set out some of the challenges to achieving this, and proposed some priorities for future action. It seems likely that in the immediate future this high-level interest in science will result in some new investment in science education, at both school, and tertiary level.

Alongside this government-level interest in science and science education, there is increasing public concern about our ability to address the complex – or 'wicked' – problems we (and the rest of the planet) face now and in the future.[4] While these problems will not be solved entirely by science, scientific expertise will be required – in collaboration with other, very different, kinds of expertise.

So: what does all this mean for school science education? *Can* school science, as we now know it, produce the 'ideas' generators' and/or 'problem-solvers' the government says are needed for our future economic and social well-being? Can it produce 'wicked' problem-solvers, or at least foster the development of some of the attributes needed by such individuals? *Should* this be its aim?

Whatever one might think about the current policy focus on science's role in the linear "pipeline" model of innovation, and therefore prosperity,[5] it is clear that what it means to "do" science is very different now from what it was, say, a generation ago, and that science education has not kept up with this. While it is possible that current science education programmes *may* produce some of the 'ideas' generators' and 'problem-solvers' we need, if they do, this won't be the result of what has been taught to them, or how it has been taught. At the same time, it is also clear that, in today's context, the non-scientist

1 Gilbert (2011).

2 In February 2011 the former Ministry of Research, Science and Technology was replaced by the Ministry of Science and Innovation (MSI). MSI was established to support a "broader government focus on boosting science and innovation's contribution to economic growth" (see msi.govt.nz). At around this time the Prime Minister appointed Sir Peter Gluckman as his Chief Science Advisor. The current Government's linking of science, first with innovation, and then with business, employment, and prosperity was further consolidated in July 2012, when MSI was merged with the former Ministry of Economic Development, the Department of Labour, and the Department of Building and Housing to form a new "super-Ministry", to be known as the Ministry of Business, Innovation, and Employment (MBIE). This new Ministry is designed to facilitate "closer connections between the scientists and innovators who can generate new ideas and solve problems, and the business people who can translate those ideas into income and jobs" (see: www.msi.govt.nz/update-me/news/2012/MBIE.confirmed).

3 Gluckman, P. (2011), (p.1).

4 The term "complex problem" is now commonly used to refer to problems which are not solvable via conventional approaches, because any cause-effect relationships are clear only in retrospect, and any patterns don't repeat. (See Kurtz and Snowden, 2003; Snowden, 2002). The term 'wicked problem' refers to complex problems that are difficult if not impossible to even define, using tools and techniques from one organisation or discipline. Because they have multiple causes and complex interdependencies, efforts to solve one aspect of a wicked problem often reveal or create other problems. They are common in public planning and policy, where any solution is likely to require large numbers of people to change their mindset and/or behaviours. The standard examples of wicked problems include climate change, natural hazards, public healthcare, nuclear energy and waste, but the term is also widely used in design and business contexts. 'Tame' problems, in contrast, while they can be highly complex, are definable and solvable from within current paradigms. See Conklin (2006) or Australian Public Service Commission (2007).

5 There is of course a well-developed critique of this model of science and innovation – see, for example, Mirowski (2011).

public needs an understanding of science and how it works that perhaps wasn't so necessary a generation ago. But that's another story.

What has changed? Why hasn't science education kept up? In the next section I look at a couple of big changes in the world beyond education: first, changes in science (how it is done, how it is reported, who is doing it, what attributes they need, and how it is connected with innovation), and then changes in *knowledge* (what it is, how it works, and how and where it develops). This discussion is necessarily brief: however, my purpose is to raise the issues, and to (hopefully) stimulate debate. As is probably clear by now, I don't think school science accurately represents science work. Nor do I think it encourages – or attracts – the attributes or skills needed by today's science professionals. Rather, it reproduces some ways of thinking that are *not* helpful in today's world[6], and it turns many potentially science-able students *off* science.[7]

'Post-academic' science

The practice of scientific research has changed significantly over the last century or so; however, this is not reflected in how science is taught in schools. In the 18th and 19th centuries scientific work was usually done by individuals working on their own, pursuing their individual interests (usually in a non-professional capacity).

In the 20th century this model was largely replaced by two parallel cultures: academic (university-based) scientists working alone or in small teams, largely following their own interests; and industrial scientists working in large teams on commercially driven projects. More recently, however, these two cultures have come together into what Ziman calls 'post-academic' science[8], largely as a result of changes to the funding of universities and other public science.

Post-academic scientific work takes place in large teams. These teams are usually networked across several institutions and countries. The work involves a succession of projects that must be justified in advance in order to attract funding. These projects are usually large in scale, multi-disciplinary, and multi-method. They commonly deal with highly complex systems with many interconnecting effects. Some projects involve ethical issues, some will be of interest to local communities, some will be subject to business and political influence. The scientists working on the projects are expected to be able to communicate their findings to non-specialist audiences.[9] Increasingly something more than communication is required: the ability not just to 'explain' or 'make accessible' their work to less knowledgeable others, but to acknowledge, negotiate, and work with other experts – from different areas of science, from outside science, and from the interested public.

The influence of this kind of post-academic science – what it is, how it is done, and, importantly, the skills and knowledge it takes to be successful in it – is not yet evident in school science.[10] Similarly, the influence of the sizeable body of work, built up over the last thirty years or more, on how scientists actually do science (as opposed to what, in theory, they say they do) is not apparent in school science. Nor is the influence of the large literature challenging science's status as universal, objective, knowledge of reality.[11]

Science teachers might say "but that stuff's not science – it's people *studying* science". In response I would want to argue that one of school science's functions is to *represent* science, reasonably accurately, to young people, to give them the richest possible picture of what doing science is *actually* like.

Research involving focus groups of leading scientists in the UK has consistently shown that, for these scientists, the way science is represented in schools is inaccurate: what they see is outdated, narrow and excessively discipline-bound. Other research shows that, in general, only young people with a personal connection to someone involved in science-related work (through family, or through outside school activities) develop a sense of what doing science is actually like.[12] To me, this is a problem.

Everything I've said above would have applied to 20th century science education. Ideally we should have been taking account of the work outlined above then. But now, more than a decade into the 21st century, there are other, much more challenging trends to take account of. There is a huge literature on these trends, which collectively have come to be known as the "knowledge age". All I'm going to try to do here is to give some sense of just how large the issues we face are. First, I'll describe how knowledge has changed, and then I'll make some brief comments about what this means for science.

'Networked' knowledge

The defining feature of the 'knowledge age' we are now in is that knowledge has changed its meaning. The 'new' meaning is very different from past understandings of knowledge, both in the everyday sense, and in the theoretical/philosophical sense. This change is highly significant for education, and for science.

To very briefly summarise the large literature in this area, this change has occurred as part of some very significant world-wide economic changes, it has been accelerated by various technological developments, and it will have far-reaching social – and educational – consequences. Some commentators view these changes negatively, but, in my view there are many positives, *if* we can think this through properly. There is no doubt, however, that these changes call into question some of science education's foundational assumptions.

The 'old' meaning of knowledge goes something like this. At one level, knowledge is a body of truths that express the truths of the world. The standard philosophical view sees knowledge as a subset of beliefs. Knowledge is a set of beliefs that are both true, and justifiable. Knowledge systems are built up by experts, who, by working and thinking with the tools of their discipline, make sense of a particular aspect of the world.

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6 See Hodson (2003, 2011) or Gilbert (2005) for an elaboration of this argument.
7 See Tytler (2007) for a review of the evidence for this.
8 Ziman (2000).
9 One result of this is the recent development of new papers and/or whole programmes on "science communication" in our universities.
10 For a review of research work on how the 'doing' of science is portrayed in schools, see Haigh et al. (2005).
11 The social studies of science is a huge field. For some of the best-known early ethnographic studies of scientists' work see: Knorr-Cetina (1981, 1999); Latour (1987, 1993); Latour and Woolgar 1979) and Traweek (1988, 1989). For an accessible summary of this body of work, see Sardar (2002).
12 See, for example, the work described in Osborne et al. (2003) and Tytler & Symington (2006).

This usually involves reducing and filtering the world in some way, simply to make it manageable.

At another level, knowledge is facts, stuff you 'get' from years of experience and/or study. Knowledge is stuff you find in books, libraries and/or databases. It's something that is divided up into different disciplines, where it is continuously added to, according to the rules of that discipline. It is something that some people have more of than others, and it is powerful – both to the people that have it (knowledge is power, and access to knowledge is liberating), and in itself (in terms of its power to explain things). Knowledge is thus a valuable resource. It is hard-won and scarce, and it is to be treasured and conserved. This meaning of knowledge is the product of a specific period in Western European history, and it is the meaning that underpinned the development of modern science, and the Industrial Age.

However, the advent of the knowledge, or digital-age, has transformed knowledge. In economic terms, as part of the new 'fast capitalism' of the late 20th century, knowledge is the main driver of new economic growth.[13] Alongside this, the development of the Internet has meant that knowledge is now generated in huge volumes, at ever-increasing speeds, and is constantly being updated, by multiple contributors. It is now unmanageable, unthinkable even, in terms of the above model.

The product of this is that what knowledge *is*, and how it is *used*, has changed. Knowledge is seen, not as 'stuff', but as something that *does* stuff. It's like a form of energy,[14] or, as one commentator put it nearly 20 years ago, knowledge is a verb now, not a noun.[15] Rather than being something we *have*, knowledge is something we *do*.

Knowledge is no longer something that lives in the brains of experts, or in objects that contain it, like books or libraries. These are now way too small. It lives – and is created and replaced – in the spaces *between* experts, books databases and so on. It is no longer a 'thing in itself': it exists in, and is a property of, networks.

Knowledge, in the knowledge age, isn't a stable body of facts or truths, it isn't masterable, and it doesn't necessarily reflect the world – rather, it is networked expertise. This doesn't mean that the network is knowledge, that the network creates meaning, or that it is some kind of conscious super-brain. It's not. Rather, the network *enables* connected groups to take ideas further and faster than any individual could. The knowledge they create is *in* the collaborative space, not in individual heads.[16] All this, if we accept it, is of course highly disruptive to most people's ideas about education, and their ideas about science.

There are a number of obvious issues with all this. Much of the material in the network, while it may be what someone believes, is wrong and/or stupid (that is, in 'old' knowledge terms, it is neither true, nor justifiable). And for every knowledge claim, there will be a great many other, *different* knowledge claims. How do we know which of them is 'right'? How do we deal with the huge diversity of views? How do we deal with disagreement? Weinberger (2011) argues that, in the knowledge age, these are the wrong questions to ask. Instead of lamenting and/or trying to stop the 'dumbing down' of ('old') knowledge, he says our primary goal should be to build (and be able to recognise) 'good' networks that make us smarter, not 'bad' networks that make us dumber.[17]

Working in 'third spaces'

Fostering the ability to discriminate between good and bad has, at least in theory, always been an important educational goal. However, the 'old' system's approach was to teach us to do this by following certain universal principles that, we were taught, would always work. According to Weinberger, this is no longer helpful. What we need now are skills to deal with conflict and disagreement (that don't involve appealing to 'authorities'). And we need skills for working productively in the spaces between experts, and between ideas that make up the network. This ability to function in 'third spaces', to be able to connect, translate, or work *across* the space between different expertises, (or different cultures) is, according to some commentators, *the* key knowledge age skill.[18]

At this point it is important to make two things clear. Firstly, working in 'third spaces' is *not* the same thing as 'communication', 'dialogue', or 'knowledge transfer' *across* the space: it involves creating something completely new *in* the space.

Secondly, this new meaning of knowledge does not mean that 'old' knowledge doesn't matter any more. Nor does it mean that all knowledge is equally good, that 'anything goes'. To work in 'third spaces', in the network, people have to *know* something, they have to bring something to contribute to the space. To think in third spaces, people have to have something to think *with*: i.e. they have to have some knowledge – in the 'old' sense. But this knowledge, on its own is not enough. People need to be able to connect with the different knowledge/expertise of others. They need to be able to articulate *their* contribution, and to listen to, seek clarification from, and negotiate with the others in the space. Doing this successfully requires: (i) having knowledge to contribute; (ii) well-developed thinking skills; and (iii) well-developed inter-personal skills. These are, of course, all things that could be developed, from quite an early age, in a knowledge age education system.

Many teachers will say "but we do this now", "we are *required* to do this now – by *The New Zealand Curriculum* and the key competencies framework".[19] However, words in a curriculum document don't, by themselves, change people's thinking or practice. If the curriculum document and the key competencies are 'read' using the lens of the 'old' understanding of knowledge, they will be assimilated back into it. We'll see, among other things, the key competencies being talked about as 'things to be taught'. If this happens, we won't see any change in

[13] In the "developed" world. See Drucker (1993), Gee Hull and Lankshear (1996), Neef (1998), Stehr (1994), Thurow (1996), Leadbeater (2000a. 2000b) for more details on this.

[14] Castells (2000).

[15] Barlow (1994).

[16] See Weinberger (2011) for the full version of these ideas.

[17] Weinberger (2011).

[18] See, for example, Bauman (1992, 2000).

[19] *The New Zealand Curriculum* Ministry of Education (2007) sets out New Zealand's national official school curriculum for all students from Years 1- 13 in English-medium schools. It emphasises five "key competencies" that should be developed in all students. These are: "thinking", "understanding language, symbols and text", "managing self", "relating to others", and "participating and contributing".

thinking or practice. What we will have, however, is the worst of both worlds: we will have lost the good aspects of an education system based on 'old' knowledge, but we won't have replaced it with the good aspects of the "new" knowledge.

Science 2.0: 'Open' science and innovation

Some readers might be thinking, at this point "what does all this have to do with *science* and/or the *teaching* of science?"

I'd say two things in response to this:

1. ***Networking of scientific knowledge has changed science.***
   Science's shape – how it is done, and what it means to know something 'scientifically' – is becoming something rather different from the science we see represented in school science. It is taking on many of the properties of its new medium – the network.

   Like the network, science is now incomprehensibly huge. It's also more public, less hierarchical, less filtered, and more open to difference.[20] More people, many of whom are non-experts, are contributing.[21] Data is 'published' earlier: it is accessible and transparent to all, and is being discussed in interest groups while still in 'unfinished' form. This new form of science, called 'open science' by some commentators, and 'Science 2.0' by others, has new and different practices, which are, according to these commentators, making scientific work much more collaborative and productive.[22]

   This 'open' science is, they say, *the* main source of innovation in today's world.[23] This kind of science requires attributes that weren't encouraged in the previous generation of scientists, and its development will be challenging for many in today's science workforce.

2. ***If science education's role is to represent scientific work with some accuracy, there is a problem.***
   If we accept that something is going on here, and, if we accept that one of science education's roles is to represent scientific work with some accuracy, then we have a problem. At the individual, practical level, there is a problem: many young people won't be making informed choices about whether or not to go on in science, we won't be fostering the qualities needed in today's science professionals, and worse, by giving the 'wrong' messages, we will be selecting the 'wrong' kind of people into science.

   But there is also another problem, at the policy level. If we want to be a 'smart' knowledge, and innovation-oriented country, and if we plan to do this by investing in science and science education, then we need better connections between the different stakeholders, and between the stakeholders and the issues canvassed here. Becoming a 'smart' knowledge and innovation-oriented country does not mean producing more "knowledgeable" people – more people who have been 'filled up' with existing knowledge. It means having more people with a new and different *orientation* to knowledge, people who know enough to *do things with* knowledge, and who can work *with others* to do things with it – in other words, people who are innovation-capable.

This brings us back to a question I raised at the beginning of this article: to what extent are science and innovation connected? Many people would argue that they're not – that 'science' is the 'blue skies' kind of research that contributes to new, '"public good' knowledge, and that this activity should be distinct from the uptake and use of aspects of this knowledge to create new technologies and processes. If we accept what the Science 2.0 commentators are saying, this view of innovation – as a separate activity that turns the 'finished' products of science into something practical – is being called into question in the new 'open' environment.

The conditions are there for science and innovation to be much more closely connected than they were in the past. What does this mean for science education? Should school science education be creating innovators?

Whatever you think about these questions, what is clear is that the way we teach science now is very definitely not designed to produce innovators. The table below, paraphrasing material in a recent book by Tony Wagner, called *Creating Innovators*, compares the conditions

[20] Weinberger (2011).
[21] See Cook (2011) for a description of "crowdsourcing" science.
[22] See, for example, Waldrop (2008), the OpenWetWare project at MIT www.openwetware.org, or the Science Commons project www.science commons.org.
[23] Weinberger (2011), Peters (2011), Peters and Roberts (2011).

Table 1: Conditions needed for innovation

Conditions that facilitate innovation	What is encouraged in our education system
Opportunities for thoughtful risk-taking, trial and error, to explore, to push boundaries	Risk avoidance, compliance, obedience to authority, producing fast, "right" answers
Opportunities to create, to actively produce new things	Passive consumption of existing knowledge
Emphasis on multi-disciplinary learning - STEM + liberal arts *together*	Specialisation – arts or sciences
Intrinsic motivation – "passionate play with a purpose"	Extrinsic motivation – goal is to "achieve" = scoring well on tests
Difference and unconventionality are valued	Standardisation – one size fits all, "production line" model of learning
Space to follow interests, and to develop deep knowledge in those areas	Superficial knowledge, and as a result, limited "real" (conceptual) understanding
Opportunities to collaborate, to work with others with different knowledge/expertise to solve problems that all participants care about.	Emphasis on individual effort and "achievement", on individual learning of pre-set, already existing knowledge.

needed for innovation with those provided in our schools.[24]

Finally...

All I'll say here, in conclusion, is that if we think it is important to: (i) engage more young people in science; (ii) foster the attributes and dispositions to knowledge our science professionals of the future will need; and (iii) create our future innovators, then doing more of what we do now (even if we were to do it better) is very definitely *not enough*. I hope we'll see some thoughtful, robust discussion of these issues – in the 'spaces between' scientists, educators, policymakers, and the interested public.

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References

Australian Public Service Commission. (2007). *Tackling wicked problems: a public policy perspective*. Canberra: Australian Government.

Barlow, J. (1994). The economy of ideas. *Wired* 2.03.

Bauman, Z. (1992). *Intimations of postmodernity*. London: Routledge.

Bauman, Z. (2000). *Liquid modernity*. Cambridge: Polity Press.

Castells, M. (2000). *The rise of the network society*. (2nd ed.) Oxford: Blackwell.

Cook, G. (2011). How crowdsourcing is changing science. *The Boston Globe*, November 2011. Available at http://www.bostonglobe.com/ideas/2011/11/11/how-crowdsourcing-changing-science/dWL4DGWMq2Y-onHKC8uOXZN/story.html

Conklin, J. (2006). *Dialogue mapping: building shared understanding of wicked problems*. Chichester (UK): John Wiley & Sons.

Drucker, P. (1993). *Post-capitalist society*. New York: HarperBusiness.

Gee, J-P., Hull, G., & Lankshear, C. (1996). *The new work order: behind the language of the new capitalism*. Sydney: Allen and Unwin.

Gilbert, J. (2005). *Catching the Knowledge Wave? the Knowledge Society and the future of education*. Wellington: NZCER Press.

Gilbert, J. (2011). School science is like wrestling with an octopus. *New Zealand Science Teacher, 126*, pp. 28-30.

Gluckman, P. (2011). *Looking ahead: science education for the twenty-first century – a report from the Prime Minister's Chief Science Advisor, April 2011*. Available at: http://www.edrsr.co.nz/site/glennvallender/files//Gluckman%20Science-education-in%20NZ.pdf

Haigh, M., France, B., & Forret, M. (2005). Is 'doing science' in New Zealand classrooms an expression of scientific inquiry? *International Journal of Science Education, 27*(2), 215-226.

Hodson, D. (2003). Time for action: science education for an alternative future. *International Journal of Science Education, 25*(6), 645-670.

Hodson. D. (2011). *Looking to the future: building a curriculum for social activism*. Rotterdam: Sense Publishers.

Knorr-Cetina, K. (1981). *The manufacture of knowledge*. Oxford: Pergamon.

Knorr-Cetina, K. (1999). *Epistemic cultures: how the sciences make knowledge*. Cambridge MA: Harvard University Press.

Kurtz, C. & Snowden, D. (2003). The new dynamics of strategy: sense-making in a complex-complicated world. *IBM Systems Journal*, *Fall 2003*, pp.1-23.

Latour, B. (1987). *Science in action: how to follow scientists and engineers through society*. Cambridge MA: Harvard University Press.

Latour, B. (1993). *We have never been modern*. Hemel Hempstead: Harvester Wheatsheaf.

Latour, B. and Woolgar, S. (1979). *Laboratory life: The social construction of scientific facts*. London: Sage.

Leadbeater, C. (2000a). *The weightless society*, New York: Texere.

Leadbeater, C. (2000b). *Living on thin air: The new economy*. Harmondsworth: Penguin.

Ministry of Education (2007). *The New Zealand Curriculum*. Wellington: Ministry of Education.

Mirowski, P. (2011). *ScienceMart: Privatising American science*. Cambridge MA: Harvard University Press.

Neef, D. (1998). *The knowledge economy*. Boston MA: Butterworth Heinemann.

Osborne, J., Ratcliffe, M., Collins, S., Millar, R., & Duschl, R. (2003). What 'ideas about science' should be taught in school science? a Delphi study of the 'expert community'. *Journal of Research in Science Teaching*, *40*(7), 692-720.

Peters, M. (2011). *The changing atlas of world science: towards an open science economy*. Unpublished paper.

Peters, M. & Roberts, P. (2011).*The virtues of openness: education and scholarship in a digital age*. Boulder CO: Paradigm Press.

Sardar, Z. (2002). Thomas Kuhn and the science wars. In: R. Appignanesi (ed.), *Postmodernism and big science*. Cambridge UK: Icon Books. (pp. 87-233).

Snowden, D. (2002). Complex acts of knowing: paradox and descriptive self-awareness. *Journal of Knowledge Management, 6*(2), 1-28.

Stehr, N. (1994). *Knowledge societies*. London: Sage.

Thurow, L. (1996). *The future of capitalism: how today's economic forces will shape tomorrow's world*. New York: William Morrow.

Traweek, S. (1988). *Beamtimes and lifetimes: the world of high-energy physics*. Cambridge MA: Harvard University Press.

Traweek, S. (1989). *Particle physics culture*. Cambridge MA: Harvard University Press.

Tytler, R. (2007). *Re-imagining science education: engaging students in science for Australia's future*. Camberwell: Australian Council for Educational Research. Available at http://www.acer.edu.au/documents/AER51_ReimaginingSciEdu.pdf

Tytler, R. and Symington, D. (2006). Science in school and society. *Teaching Science: The Journal of the Australian Science Teachers Association*, *52*(3), 10-15.

Wagner, T. (2012). *Creating innovators: the making of young people who will change the world*. New York: Scribner.

Waldrop, M. (2008). Science 2.0 – is open access science the future? *Scientific American* (May 2008). Available at www.scientificamerican.com/article.cfm?id=science-2-point-0.

Weinberger. D. (2011). *Too big to know: rethinking knowledge now that the facts aren't the facts, experts are everywhere, and the smartest person in the room is the room*. New York: Basic Books.

Ziman, J. (2000). *Real Science: What it is and what it means*. New York: Cambridge University Press.

[24] See Wagner (2012).

ask-a-scientist created by Dr. John Campbell

Why are waves always parallel to the beach?

John Falloon, Ardgowan School.

John Campbell, a physicist at the University of Canterbury, responded:

Because the speed of waves in shallow water depends on the depth of water.

In deep ocean water waves build up due to the interaction of wind blowing over the sea. A particle of water just goes up and down as the wave passes by. In this case the important distance parameter is the distance between wave crests, which we call the wavelength for short. The speed at which waves in the deep ocean travel depends on this wavelength. The wave speed is proportional to the square root of the wavelength. The longer the wavelength, the faster the wave travels. We observe this after the ocean has been calm. The first sign of a distant storm is often the gentle swells with a large distance between wave crests. An oily ocean.

In shallow water, say where the depth is less than ten times the wavelength of the wave, the bottom has increasing influence on the up and down motion of the passing water wave. The motion of the water particles now goes in and out whilst going up and down. A particle travels in an oval fashion. It is then the depth

which becomes the important length parameter and the wave speed depends on the depth of the water. The wave speed is proportional to the square root of the water depth. The shallower the water, the slower the wave travels.

The next time you are at the beach measure the wave speed of unbroken waves at different depths of water. This can sometimes be done whilst keeping dry by walking along a pier.

If the wave comes in at an angle from deeper water, the part of the wave closest to the beach slows down, allowing the rest to catch up until the entire wave crest is travelling at the same speed; i.e. has the same depth of water under it.

Hence, for gently sloping sandy beaches the waves are always parallel to the shore. There are moves to sink artificial reefs near beaches such that the depth of water above the reef changes slowly along the beach. This would give a uniform shoulder for board riders to ride.

Send questions to: **questions@ask-a-scientist.net**