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Mātauranga and science

prime numbers

water quality

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A forum for the exchange of views on science and science policy

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Contents

Cover: Wave near Wellington South Coast.

Credit Dave Allen NIWA.

Instructions to Authors

New Zealand Science Review provides a forum for the discussion of science policy. It also covers science education, science planning, and freedom of information. It is aimed at scientists, decision makers, and the interested public. Readability and absence of jargon are essential.

Manuscripts on the above topics are welcome, and should be emailed to the editor (editor@scientists.org.nz).

As well as full papers, short contributions, reports on new developments and conferences, and reviews of books, all in the general areas of interest detailed above, are invited. The journal may also accept reviews of a general nature and research reports.

Full manuscripts (with author's name removed) will be sent for peer review, and authors will be sent copies of the reviewer's comments and a decision on publication. Manuscripts should not normally have appeared in print elsewhere, but already published results discussed in the different, special context of the journal will be considered.

Manuscripts should be accompanied by biographies of not more than 100 words on each author's personal history and current interests. Authors are also expected to supply a suitable high-definition passport-size photograph of themselves. This will be published with the article.

Articles may be submitted in MS Office Word, rich text format, or plain text. Diagrams and photographs should be on separate files (preferably eps, tif, jpg, at 300 dpi), not embedded in the text.

All tables and illustrations should be numbered separately – Tables 1, 2, 3, 4, etc., and Figures 1, 2, 3, 4, etc. – and be referred to in the text. Footnotes should be eliminated as far as possible. Diagrams and photographs will be printed in black and white, so symbols should be readily distinguishable without colour, and hatching should be used rather than block shading. However, colour may be used if the author or the author's institute is willing to pay for the added cost.

References should preferably be cited by the author–date (Harvard) system as described in the Lincoln University Press *Write Edit Print: Style Manual for Aotearoa New Zealand* (1997), which is also used as the standard for other editorial conventions. This system entails citing each author's surname and the year of publication in the text and an alphabetical listing of all authors cited at the end. Alternative systems may be acceptable provided that they are used accurately and consistently.

In this issue

In this issue, NZAS' Co-President Heide Friedrich, Deputy Head (Research) of the Department of Civil and Environmental Engineering at Auckland University, introduces herself and shares her thoughts on the need for scientists to take time to build relationships when attempting to tackle complex societal constructs. As Heide outlines, there is also a need to continue to advocate for diversity in science, providing opportunities for career development of emerging researchers and enabling transparent and inclusive science systems.

Mātauranga – Māori knowledge and Māori ways of knowing – encompasses traditional and contemporary knowledge and is becoming increasingly integrated into mainstream education, research, and environmental policy in New Zealand. With 'Vision Mātauranga'[1] now a critical point of engagement for researchers, what does the scientist working in this space need to know about mātauranga? In our first article, *Mātauranga and science,* Victoria University of Wellington's Ocean Mercier (Ngāti Porou) highlights what she sees to be key aspects of the discussion on how scientists work with those who hold and access mātauranga, and with mātauranga itself. In her paper, Ocean describes and explores the potential of research in which mātauranga and science connect and relate.

In *A quick look at prime numbers*, David Lillis, Senior Academic Manger at the NZ Institute of Sport, posits that our fascination with prime numbers is that the inter-relationships between them and the patterns that they appear to create are so difficult to understand. Alternatively, primes appear to exhibit both deterministic behaviours (i.e. fully determined on the basis of naturally-occurring relationships) and random behaviours (i.e. occurring by chance). David's paper explains what a prime number is, their fascination for many over the centuries, the research that has attempted to shed light on their mathematical characteristics, and what may lie ahead with future work on primes.

Current NZAS Council member, Troy Baisden delivered his inaugural professorial lecture at the University of Waikato 17 April 2018. Troy, now Professor and Chair in Lake and Freshwater Science at Waikato University, addressed ways of improving water quality in New Zealand lakes and rivers. The lecture, initially published in *The Conversation,* is republished in the *Review* with permission.

In *Why science gets cut out of policy*, Anthony Bergin, a Senior Research Fellow at the Australian National University, indicates that science has an important role in influencing political decision-making. But he asks whether scientists understand how it needs to be delivered, or what's required from science for the development of policy and achieving consensus. He also asks whether scientists know what constitutes a solution that a policymaker can use. He points out that policymakers are operating in a political context where there are multiple goals and conflicting values. Within this context, 'science is not the new religion', and a Minister may say: 'Well, I've heard the science, but I've also heard the people'.

So scientists have to recognise that, on occasion, politics will override the science – and that there'll often be some gap between the views of experts and decision-makers when it comes to what information is credible and useful.

On evidence-informed policy he indicates that it isn't a requirement of any scientific law. Rather it's a value, and it's up to the scientific community to be prepared to fight for it in the policy process and be fearless in their convictions. This means scientists should speak truth to power, but just not tweet about it after the meeting!

Notable in the news items carried in this issue is the appointment of Professor Juliet Gerrard FRSNZ as the Prime Minister's new chief science advisor and the appointment of Professor Emeritus David Penny FRSNZ as a foreign associate of the US National Academy of Sciences. David, a former NZAS president, has also published a new book, *Evolution Now,* which is reviewed by Mike Berridge.

Finally in this issue is the tribute to Vincent Richard Gray (1922–2018). Vince, a long time NZAS Council member and climate change sceptic, is remembered by three past Association presidents 'who held the reins during parts of Vince's Council membership',

Allen Petrey
Editor

[1] http://www.mbie.govt.nz/info-services/science-innovation/agencies-policies-budget-initiatives/vision-matauranga-policy/?searchterm=vision%20matauranga%2A

President's column

Relationships, luck and inclusiveness

Research institutes and universities should be bastions of our society, where people feel safe and are encouraged to be themselves, to openly debate opinions. Why is there a growing reluctance or inability amongst scientists to be themselves, to speak publicly and voice their opinions in these organisations whose main purpose is to transfer and advance knowledge? We are working in process-heavy science organisations, not only tackling complex knowledge, but ever more complex societal constructs. In times like this it is all the more important to take time to build relationships, to get to know each other, instead of jumping straight into business.

I am a 'glass half full' person, which I attribute to my East German upbringing. One of my sisters left East Germany in 1984 for West Germany, which closed the door for me to go to high school, as education was only open to those whose entire families conformed to the party line. As luck would have it, in 1989 the Wall came down at just the right time for me to unexpectedly attend high school. From there I went on to University to study Engineering, and I continued studying at institutes around the world, completed my PhD in Auckland, and am now an academic there. It's hard not to be optimistic and positive when I consider my own life's path – from a restrictive communist beginning to my current role teaching at a University that is highly regarded internationally. I have lived, worked, and travelled in many parts of the world, but have settled at a place aptly referred to as Godzone. I'm fortunate to call a little piece of land my own, that I share with my Kiwi partner of 15 years and our lovable dog.

All this I would never have dreamt about as a kid, growing up behind the Iron Curtain, in a society where social values trumped individual needs. Don't get me wrong, I had a great childhood in East Germany – lots of play, spending time outdoors and exploring the local neighbourhood. The values I hold strongly stem from my upbringing on our socialised farm; determination, kindness, and hard work are high on my value list. My bias is to support underdogs, as so many of us are. I come from a family where we worked the land to support ourselves, and academic lifestyles were (and often still are) looked down on.

I'm very comfortable doing my work away from the limelight. Stepping up to be Co-President of the Association will draw attention to me, and the subsequent visibility will have some of you looking to categorise or label me. In New Zealand I am often asked why I, as an Engineer, am engaged in the Association of Scientists, assuming Science is exclusive rather than inclusive. But, what's in a name? I am an Engineer who represents Scientists. In German, we use the word 'Wissenschaft' for Science. Science, from the Latin word *Scientia* (knowledge) is the systematic pursuit of knowledge. We try to categorise science disciplines, most broadly as: natural sciences, social sciences, formal sciences, and applied sciences. In my native language we call my choice of Science 'Ingenieurwissenschaft'. In Germany, engineers are seen as highly respected scientists, and often are key participants in decision-making environments, together with representatives from the other disciplines. Engineering is the merger of natural sciences and formal sciences in the application of knowledge, resulting in applied sciences. The product of natural, formal and applied science is technology, which is shaped by, and in turn shapes, social sciences. With this in mind, I don't categorise myself as 'just' an engineer by the English definition but embrace the German definition – an Engineer in Science.

How can I build a relationship with readers of this column whom I might never meet? Traditionally, as humans we have been concerned with our immediate environment. Nowadays, though, it's easier to observe and share our opinion on what happens halfway around the world and put people into categories, than to actively engage with and serve our local environment. In this age of information overload ('infobesity'), it is moral values that guide our path, and moral values are the foundation of strong relationships, morality being *a form of common sense: the sense we have in common of what we all owe to each other*[1]*.*

A couple of summers ago I read the epic *War and Peace*, and the following quote resonated with me: *If we admit that human life can be ruled by reason, then all possibility of life is destroyed*. As scientists we have to remember that, ultimately, we serve the people. Complexities, as observed in the operation of large organisations, technologies and social networks, *lead people to inflate or misconstrue suspicions into mistrust when it's unwarranted*[2]. With science and technology becoming ever more prominent in the life of everybody we need to make science transparent, showing the good, the bad and the ugly. In our quest to reduce fear of science and build trust in science systems, we need to be inclusive, build relationships and communicate with the public – to question categorisations. We need to remember, *ethics is rooted much more in feeling than in thinking, but there is good reason for this. The fundamental impulse to treat others well derives from a kind of empathy, not obedience to authority or a rational principle. Citizens trust the person of generosity and good heart more than the professor of abstract intelligence*[1].

It is an exciting time to be a scientist. I invite you all to see the glass as half full. There is a need to continue to advocate for diversity in science, providing opportunities for career development of emerging researchers and enabling transparent and inclusive science systems; and to communicate science to citizens, fostering engagement. This is needed to transform fearful science environments into supportive and constructive research units. Thank you to members, Council and Co-President Craig Stevens for your engagement and support. I'm looking forward to serving you and the New Zealand science community during my term as Co-President. We have our 2018 annual conference in Auckland on 15 November. With the new government in place and upcoming change in the Office of the Prime Minister's Chief Science Advisor, the conference is developed around a theme of the connections between science and policy. We are looking forward to seeing you there.

Heide Friedrich
Co-President

1. https://www.theguardian.com/commentisfree/2016/apr/08/people-trust-you-common-sense-morality

2. https://www.gsb.stanford.edu/insights/roderick-kramer-how-avoid-paranoia-workplace

Article

Mātauranga and science

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Mātauranga – Māori knowledge and Māori ways of knowing – developed in Aotearoa along with the cultural and epistemological identities of iwi Māori, thus is rooted in these islands and holds a well of human understanding of Aotearoa ecosystems. Mātauranga encompasses traditional and contemporary knowledge and is becoming increasingly sought after and integrated into mainstream education, research, and environmental policy in Aotearoa New Zealand. With 'Vision Mātauranga' a critical point of engagement for researchers, what does the scientist working in this space need to know about mātauranga? I have highlighted what I see to be key aspects of the discussion on how scientists work with those who hold and access mātauranga, and with mātauranga itself. The scholarly literature on mātauranga is extensive, so I focus on that which is relevant to science education and science research. Throughout I describe and explore the potential of research in which mātauranga and science connect and relate.

What is Mātauranga Māori?

Mātauranga Māori, or simply 'mātauranga', has come to refer to Māori knowledge, ways of knowing and knowledge generation practices, and it is a broad system that encompasses time, space, place and discipline. Mātauranga comes from the root word matau, which means 'to know, be acquainted with; to understand; feel certain of' (Williams 1971) and as such, refers to reliable, tested and socially accepted knowledge. In Samoan, 'matau' means memory and in Tahitian 'matau' means 'to be used to or accustomed to' (see Benton *et al.* 2013). 'Mātauranga Māori', with the cultural qualifier included, likely arose with European settlement, to mark out the space of knowing that did not relate to the Western literature, embodied in the Holy Bible: 'historically, mātauranga māori referred to knowledge arising from atua māori or non-Christian gods, which was the preserve of tohunga māori, the non-Christian priests.' (Royal 2012). But mātauranga is now understood more broadly, representing the whole distinctive body of Māori knowledge in relation to society and environment. Furthermore, women were important holders of the knowledge, with many testifying that their mātauranga came from their kuia/grandmothers (see Benton *et al.* 2013). Mātauranga's knowledge and epistemology traces back through the Pacific and Asian ancestral whakapapa of the people who became Māori. According to Māori studies professor Hirini Moko Mead:

> *Mātauranga Māori is not like an archive of information but rather is like a tool for thinking, organising information, considering the ethics of knowledge, the appropriateness of it all and informing us about our world and our place in it.* (Mead 2003, p. 306)

Mātauranga is thus a knowledge-generating system, not just the knowledge itself. The related term 'kaimānga', or 'masticated knowledge' (Royal 2009) alludes to the importance of 'chewing over' and processing of information to create mātauranga. Mātauranga Māori encompasses all branches of Māori knowledge, past, present and still developing' (Mead 2003, p. 305); thus it includes, but is not limited to, traditional Māori knowledge. Professor Whatarangi Winiata concurs, stating that:

> *mātauranga Māori has no beginning and is without end. It is constantly being enhanced and refined. Each passing generation of Māori make their own contribution to mātauranga Māori. The theory, or collection of theories, with associated values and practices, has accumulated mai i te ao Māori / from Māori beginnings and will continue to accumulate providing the whakapapa of mātauranga Māori is unbroken.* (Winiata 2001 cited in Mead 2003, p. 321)

Mātauranga is a system into which values are overtly interwoven. Mātauranga is the theory behind tikanga Māori (values, practices, rituals), the 'procedural knowledge, which is the practice of ideas, beliefs and knowledge of mātauranga Māori' (Duncan & Rewi 2018, p. 33). It also includes tikanga Māori. In pedagogy it is considered as connected to 'mōhiotanga' (know-how, common knowledge) and 'māramatanga' (understanding) (Ministry of Education 2009). As such it has echoes of the Data-Information-Knowledge-Understanding-Wisdom hierarchy (see Mercier *et al.* 2012). Just as 'Western knowledge' is wide, broad-ranging, encompassing of philosophy, religion and ethics, and historically and culturally inflected; so too is mātauranga Māori. And as Western knowledge has various tools

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with which to critique itself, so mātauranga contains tools to epistemologically self-analyse (Sadler 2012).

While mātauranga is used to talk about a 'global' corpus of Māori knowledge, in practice, people will deal with localised knowledge. The term mātauranga-ā-iwi is used to denote knowledge related to specific iwi, hapū (subtribe), places and people. For instance, te matauranga-a-Ngati Porou 'is our unique tribal and hapu knowledge and way of thinking' (Te Runanganui o Ngati Porou 2014). It refers to the mātauranga generated by our tupuna (ancestors), through educational institutions such as traditional whare wānanga (houses of learning), and more recent education forums such as church schools and universities.

He Hononga – Working at a mātauranga–science Interface

Many of the commentators in this field refer to science as modern science, Western science or modern Western science. I try to use the term 'Western science' sparingly in what follows, but its pervasive use in the literature demands reuse, and a brief explanation and justification. 'Western science' is used to differentiate it from other sciences or knowledge-producing practices from the 'non-West'. This can be useful when considering, for example, that printing technology was first developed by the Chinese. 'Western science' is also used when tracing a history of modern science. This version of events usually starts with Greek philosophical traditions (such as attributed to Aristotle and Pythagoras), and ends with the enlightenment and the scientific revolution (key players include Galileo, Descartes and Newton). Those who use the term 'Western science' thus may be drawing attention to historic movements and philosophies that led to, and remain embedded within, modern science. Others see Western science used in this way as ethnocentric, ignoring science's plurality of cultural contributions (see Medin & Bang 2014). In discussions with mātauranga, a preference for 'Western science' signals a desire for perceived distinctions to be maintained, so as to fully differentiate, and allow for renegotiation of what is 'science'. This may be because many link 'Western science' to a broader Western history of imperialism and conquest, and the assimilation and/or suppression of other cultural traditions.

There are many examples of projects and endeavours that incorporate both mātauranga and modern science. In some instances the knowledge streams may 'parallel play', engaging in dialogue but not much interaction. In others there are attempts to exchange and engage. Important to this engagement is understanding about *how* to work at an interface between science and Indigenous knowledge. A coming together of different entities is an opportunity to learn about the Other, and to learn about the Self. An important set of mutual and reflexive learnings at this interface, is to understand that (1) mātauranga includes aspects of what we might understand as a modern scientific nature; and (2) science systems cannot be completely unshackled from a social, values-based nature (Medin & Bang 2014). This may give scientists a more comfortable point of engagement with mātauranga, and give mātauranga holders a more comfortable point of engagement with modern science.

Some of the more commonly used models for engagement are: common ground (Barnhardt & Kawagley 2005; Roberts 1996); converging streams or braided rivers approach, He Awa Whiria (MacFarlane *et al.* 2015); a third 'Treaty house' space (Whatarangi Winiata, cited in Royal 1998); Te Hau Mihi Ata's negotiated space (Smith *et al.* 2008); and the 'superset'[1] (Stewart 2007). A recent report even makes a new interface of interfaces, by braiding together He Awa Whiria and negotiated spaces (Arago-Kemp & Hong 2018). Many suggest particular principles and values that should guide interaction, such as a Treaty-based framework (Harmsworth *et al.* 2013), mutual respect (Durie 2005) and acknowledgement of each other's expertise (Hudson 2012).

Mātauranga contains practices consistent with the scientific method (Hikuroa 2017), such as observation, and trial and error. Theorising of results according to a Māori worldview enabled such knowledge to be stored in and recalled from memory. Controlled experimentation must also have been part of the mātauranga toolkit. Evidence of this includes: the development of growing and storage techniques for kumara; and naming, categorisation, mixing and use, of flora and fauna in Aotearoa for food and medicinal purposes.

Mātauranga was dynamic and changeable across time and place. It could be exchanged, critiqued and reshaped between individuals or communities. It could experience small, iterative changes, or seismic, sudden ones.

> *Encounters with the new land, its weather patterns, and new flora and fauna all challenged the knowledge that was brought with those early ancestors. Slowly, with periods of experience, empirical research, and experiments of cause and effect, the knowledge process led to the development of a uniquely Māori, indigenous knowledge base, intrinsically connected to physical and spiritual environments.* (Duncan & Rewi 2018, p. 32)

Today, a community or individual with new knowledge (scientific or otherwise) can feed this knowledge back into mātauranga through a variety of mechanisms. Ever more frequently this includes peer-reviewed publications and processes. Knowledge in this space is open to new processes of critique and challenge. For instance, engineer Kepa Morgan suggested a theoretical way to quantify mauri (energy, life force). He operationalised this theory through proposing a mauri scale spanning −2 to +2, and from this developed a digital diagnostic tool that he called the 'mauriometer' (Morgan 2013). This has been tested by other researchers (Hikuroa *et al.* 2011), and reused in some cases. Yet others have developed their own diagnostic tool for mauri. The mauri compass, for instance, is specifically designed for waterways in Gisborne / Tūranganui a Kiwa, and engages community, iwi and council (Ruru 2018).

While some commentators muse that the absence of a hypothesis in Indigenous knowledge is what differentiates its scientific aspects from a modernist form of science (Crawford 2009), this is another contestable assertion. Ranginui Walker points out that observations of bird migration led to the hypothesis of land in the direction of the yet-to-be-discovered Aotearoa (Walker 1994).

Mātauranga and science in education

While ecology and environmental studies have long been interested in mātauranga as an evidence base, it is the education discipline that has arguably been the centre for generation of discourse around Māori and science, mātauranga and science. This may be because it often appears with kaupapa Māori discourse, which emerged from education also. Mātauranga

[1] The 'superset' idea posits that 'Western science' is philosophically a subset of Indigenous knowledge.

with a scientific bent has long been a part of the New Zealand educational curriculum for Māori children, beginning with native schools. Philosophical discussion on the epistemological bridging are furthered within tertiary education contexts and courses (for instance Roberts 1996; Mercier 2011). Furthermore, two edited volumes on the subject of mātauranga Māori have been published by the New Zealand Qualifications Authority (Black 2012, 2014). The emphasis is there because, to some, success of Māori in science subjects signals success across education more broadly.

Over several decades now, a purposeful, sustained and widespread effort has been spent on promoting Māori recruitment into and engagement in science, across all levels of schooling: primary, secondary and tertiary. This includes sector-connective programmes such as Te Rōpū Awhina at Victoria University of Wellington and Tuakana at University of Auckland. Postgraduate students act as mentors for undergraduate students, and university students engage in outreach with primary school tamariki and secondary school rangatahi.

The provision of schooling in te reo Māori, through kōhanga reo (early childhood), kura kaupapa (primary) and whare kura (secondary) includes teaching science – pūtaiao – in te reo. Pūtaiao is a relatively recent Māori word used to denote modern science, particularly natural and physical sciences. It translates as the source (pū) of the ebbs and flows (tai) of the phenomenological world (ao). Pūtaiao (the word) thus loosely describes a system of understanding the mechanisms behind the world's material and dynamic characteristics. Pūtaiao presents science explored within a recently developed and developing lexicon in te reo Māori. Pūtaiao words have been carefully selected and developed to connect concepts. For instance, a *transformer* (of voltage) is translated as *tōrua* (two magnets), which efficiently describes the mechanism by which voltage is transformed. The word ngaohiko (voltage, literally energy electric) makes explicit the connection to electrical energetic potential, and its companion concept of iahiko (current, lit. current electric). Post-implementation of a scientific lingua franca in te reo has meant a revisiting of modern science concepts. For better or worse, it has also omitted some of the history of Western science, for example, in the exclusion of inventor 'Volta'[2].

Teaching pūtaiao inherently brings a Māori worldview along with it. The effort of teaching science in Māori language immersion settings was anchored in the New Zealand science curriculum by the translation into te reo, and creation of the Pūtaiao marataunga, in the 1990s. Its continued use and subsequent development have led to many different aligned resources, including papakupu (dictionaries and encyclopaediae) for Pūtaiao and Pangarau (maths), readers in te reo Māori, as well as research-based initiatives and outcomes such as Ngāti Whakaue Charter School Te Rangihakahaka, which teaches STEM subjects in Māori, and Te Whata Kura Ahupūngao, the New Zealand Teachers' Resource Bank, which produces physics teacher and student resources in English and te reo Māori (Lukefahr *et al.* 2007). Many te reo science resources are not simply translations, but acknowledge and draw upon mātauranga. Furthermore, A Nation of Curious Minds funding has supported several projects that enhance learning systems' abilities to draw upon mātauranga and science.

Reaction against deficit-based discourses (that students are the problem, not the educational systems that fail them) have led commentators to critique (amongst other things) the alien culture of science in the classroom (Aikenhead & Jegede 1999), wider societal expectations that women and Māori don't become scientists (McKinley 2008), and the lack of awareness of science history and philosophy amongst teachers (Stewart, 2017). Poor understanding of the historical, social and cultural foundations of modern science, such as was gestured to in a recent debate (Salmond 2018), tends to lead to uncritical acceptance of the ideas that science is universal, value-free and objective, and that science is the only reliable way to produce knowledge. The 'scientistic' perspective that these beliefs foster has excluded opportunities for presenting mātauranga alongside science in educational settings.

> *Combining scientific approaches with mātauranga Māori provides opportunities to involve Māori in additional science education experiences and to develop co-management strategies that engage Māori in scientific research and scientists in mātauranga Māori.* (Keiha cited in Morton, 2018)

Poorer than average achievement of Indigenous students in mainstream education and the deficit-based discourses that have historically accompanied this, are a problem in many colonised nations. Recognition of this has led to many Indigenous peoples looking to their traditions, revitalising and promoting practices that affirm Indigenous knowledges, communicating and sharing their local activity with other Indigenous educators. Indigenous peoples worldwide have worked together to revive Indigenous languages and knowledges, and connect learners of like mind and experience, through both mainstream education and alternative means. The Kaupapa Māori movement, which reimagines education and research, stemmed from academics in tertiary education (Smith 1999) and has arguably inspired and supported other Indigenous initiatives, such as Kāmehameha schools in Hawaii.

This long-term education-led project to engage Māori in science, and science in mātauranga, thus works on multiple fronts to increase cognitive access across different epistemologies. This helps level the playing field for Māori in Western education, but looks ahead to a science that honours Indigenous knowledges through increasing numbers of mātauranga holders as scientists.

Mātauranga and science: stronger together?

The time of encounter brought European and Māori knowledge together. European science and mātauranga had distinctive strengths, and the many society-changing contributions of science are widely known. This section focuses on examples in which mātauranga provided more complete contemporary understandings of our past and present. Furthermore, mātauranga is not just being used as a knowledge archive; mātauranga methodologies also influence contemporary research.

While mātauranga includes traditional multi-media, and is thus contained in historical record by oral recordings, writings, carvings, paintings, weaving, etc., much of it (as described in either English or Māori languages) is contained in anthropological literature, research, in the National Archives and in Waitangi Tribunal hearings and reports. Mātauranga includes numerous examples of science and technology. For instance, waka hull,

[2] The symbol V is used for ngaohiko (voltage)

sail and paddle design required trial and error, experimentation, knowledge of hard and soft materials science, chemistry and fluid dynamics; and application of these in sailing, wayfinding, mapping, and navigation required active in-situ observation, memorisation, physics (for instance, understanding refraction and reflection of waves around land masses) and many other kinds of knowledge. While some of this knowledge was shared intergenerationally in whare wānanga, or 'school'-like contexts, its intertwinedness and complexity meant that 'doing' was often the most reliable way of passing on the understandings.

Mātauranga is unique in that it historically embeds and connects these understandings within a system that includes the social, cultural and spiritual, as well as the physical and natural. What is packaged as a proverb, folk tale, myth or legend, requires context and experience to interpret and unpack. In what follows, I select and discuss some research that reveals some surprising points of contact between mātauranga and science. Just as sailing experience meant that Polynesians knew the Earth was round, the first example shows Māori knowledge filling a gap in European understanding at the time of encounter. Other examples show how contributions of mātauranga are useful to contemporary science research.

Pūrākau are stories or narrative accounts of events that can be tailored to audience and by genre. In Hikuroa's scientific documentary retelling of a pūrākau, we hear about Ngātoroirangi who was exploring Te Ika a Māui (the North Island), a long way from home, when he was stranded at altitude, in a blizzard. He cried out for help, and his sisters responded by travelling from Hawaiki to Mt Ruapehu. Ngātoroirangi's sisters were subterranean, and burrowed under the landscape, popping up at various times to check on their progress towards their destination. They found Ngātoroirangi just in time to be saved. As Hikuroa points out, while this story is told in a narrative style, it contains evidence that Māori knew that geothermal sources followed subterranean networks – not a geological understanding of the place at the time. One could also argue it presents a mātauranga version of a scatter diagram. Hikuroa reveals this by overlaying the story on a map of the known geothermal sources in the Taupō Volcanic Zone (Hikuroa 2009). What one might call a naming of data points operated in other contexts too, most notably in the phenomenon of an 'oral map' (Davis 1990), in which waiata (songs) such as oriori (historical epic song) marked out places of significance, boundaries between iwi, trails from place to place, etc. As Tipene O'Regan points out, place names on their own can reveal something about a particular place. They reveal even more when understood in the context of other names. This 'web of memory that ties many Aotearoa place names together' (Davis *et al.* 1990, p. 6) is a 3-dimensional oral construct pinned by 'survey pegs of memory' (Davis *et al.* 1990, p. 5). Furthermore, in recognising the differences and similarities between contemporary and historical naming configurations in the Pacific, the possibility arises of exploring across a broad area encompassing the Pacific, but also into the past, covering the time dimension. Could this present as data for an Indigenous kind of 4-dimensional complex network?

Mātauranga in the form of whakataukī, or proverbs (Mead & Grove 2004), have formed the basis for additional understanding in exchange between mātauranga and science. Multi-disciplinary work on whakataukī of marine species considers importance of different fauna across different times, and presence or absence in archaeological records (Wehi *et al.* 2013). Tom Roa's dating of whakatauki to different linguistic periods enabled understanding of how mātauranga developed over time. Their work to draw out the significance of 'ururoa' and 'mako' (sharks) invites a re-evaluation of the conclusions drawn from an analysis of archaeological middens. Taken as the sole piece of evidence, the appearance of moa bones and shells suggests an interpretation that moa extinction led to heavy reliance on shellfish in the human diet. This in turn leads to a 'Maori were starving' narrative, reinforcing notions about Māori as savages in need of salvation. Without mātauranga's archive of different species names, their connections to other species, and connections with humans, contained within the hundreds of recorded whakatauki, a full and complete understanding of past diet was out of reach.

Surveyor and archaeologist McFadgen's tsunami-related work recognises this, and his book (McFadgen 2007) pieces together what is known about oral histories in relation to tsunamis, presenting a record of possible tsunami events that can be correlated with current-day observations of landscape morphology. His continued research on the historic site at Wairau Bar seeks to understand the relative impact of tsunamis, climate change, erosion and other factors, and recognises that interdisciplinary effort is needed, with indigenous knowledge an important source of information (McFadgen & Adds 2018).

There are many examples in which 'innovation' (Durie 2005) was an outcome of mātauranga sitting alongside science. Some reveal recognition that Indigenous languages themselves encode other forms of knowledge. The online publication of a scientific paper abstract in te reo Māori, in the *Journal of Ecology* was driven by the paper's authors: 'If western science is to become relevant to indigenous cultures, one way forward is through the language of that culture' (Perrott, cited in Morton 2018). This may extend the journal's policy to publish abstracts in other languages, it could be politically or economically motivated, or it could reflect a natural evolution of practice within the ecological sciences. If the latter, it may herald a sea change across other sciences in relation to acceptance of Indigenous languages.

Vision Mātauranga: 'Māori success is New Zealand's success'

Vision Mātauranga (VM) is a policy framework that was published by the Labour-led government's Ministry of Research Science and Technology in 2007, and continues to be implemented as a research and science strategy. The aim of VM is to 'unlock the potential of Māori knowledge, resources and people' (Ministry of Research Science and Technology 2007). It is designed to support the recognition and aspiration that 'Māori success is New Zealand's success' (Ministry of Business Innovation and Employment 2018a). The recent case of Australia seeking to patent 'Manuka', a Māori word, has galvanised New Zealanders into throwing their support behind the legal response. We collectively recognise that protecting mātauranga in this case, is protecting a taonga of immense economic, social and cultural benefit to New Zealand.

In the VM climate, researchers and scientists now consider questions that, in essence, relate to how their disciplines can become more accessible spaces for Māori. These include how their research: relates to organisational-level Treaty-based policy; may support Māori partnership, grow Māori capacity and capability; and may be relevant to mātauranga. Attempts at 'the

VM section' reveal diverse levels of familiarity and knowledge. Support for those addressing the VM strategy has been found in multiple quarters, especially amongst Māori researchers. Weaknesses in researchers' VM strategies have led to the development of further guidelines for engagement, for instance, MBIE's Endeavour Round 2018 principles on how to 'Give effect to the Vision Mātauranga Policy'.

Vision Mātauranga comes alive when the following principles guide proposals that involve Māori (Ministry of Business Innovation and Employment 2018b):

- Partnership
  - genuine co-development with Māori, integrated through the programme
  - not last minute, token or to get 'a Māori view'.
- Reciprocity
  - co-development and contribution each way, sharing of benefits
  - not one way, appropriating Māori knowledge and practices.
- Empowering Māori
  - active roles and responsibilities for Māori, contributing to Māori capability
  - not gratuitous or out of context.

Treaty principles of 'partnership' and 'reciprocity' have been used here as an organising mechanism for more specific advice. 'Not appropriating' resonates with the principle of 'protection'. 'Empowering Māori' may be seen as supporting the principle of 'participation'. In a globalising world it benefits New Zealanders to support mechanisms that work to protect local relationships with each other, and with our taonga.

Te Tiriti / The Treaty

When Māori traded with Europeans, they did so with agency, volition and appreciation of the value of their transactions, including new technologies. The signing of the Treaty of Waitangi likely signalled their expectation to continue to access, contribute to and benefit from scientific advances. Amongst other things, the Treaty guaranteed to them the rights of equal citizenship – meaning equal rights and equal access to employment, markets, democratic and state processes, health, education and justice. Tangata whenua would have also expected to benefit equally from scientific and technological advances. However:

> *If we directly contrast historical scientific discoveries with what was happening in Aotearoa, particularly taking note of aforementioned government legislation during this time, we see that during the technological explosion that gave rise to electricity, communication and motorised transport, Māori were slowly but steadily being marginalised – from their own lands, their own culture and their own traditions* (Harris & Mercier 2006).

As Māori became locked in a battle for retention of their lands, their language, their knowledge and the lives of their people, their ability to engage as equal citizens was eroded. While Māori demonstrated resilience and now thrive in many areas, colonisation and its legacy of coloniality still cast shadows over Māori. While on the increase, the still relatively low engagement of Māori in science is one of the legacies of science's implicit and explicit historic exclusion of them (Walker 1998).

Dame Anne Salmond reminds us that when the 'Western scientific project' arose out of the Enlightenment period, the arts and humanities were a part of this endeavour. She argues, as many others have, that separating out the humanities disciplines has caused an unhelpful fragmentation between 'nature' and 'culture'. This has led to a 'dysfunctional' system that compromises our ability to deal with complex environmental and social problems, and undermines the credibility of science itself. Further undermining science, she argues, are self-appointed bastions of traditional, modern science:

> *Far from protecting the scientific project from bias and political interest, they are trying to uphold a status quo based on ethnocentric bias and outmoded dualisms (and the power relations embedded in them), at a time when new ways of thinking about socio-environmental challenges are urgently needed. In so doing, and by speaking loudly about matters they have not themselves researched in depth and detail, they show deep disrespect, and do science itself a major disservice.* (Salmond 2018)

This scientistic attitude has been affectionately embodied and lampooned by Jim Parsons in the character Sheldon, of *The Big Bang Theory* (Pigliucci, 2012). The character believes that science systems are objective, universal, and value-free, has faith in a one-truth producing modern science, and takes on the role of a science evangelist. 'But to let these attitudes go unchecked would be a disservice to the scientists and researchers who value indigenous knowledge.' (Hayden 2017)

Someone who represents the body who 'value indigenous knowledge' is the President of the Royal Society: Te Apārangi. He added that 150 years on, in 2017, a time of reflection and renewal, a science society that seeks to represent all New Zealanders must acknowledge multiple ways of knowing. The RSNZ Code of Conduct was designed to better reflect multiple positions and worldviews, describing two of those systems at their point of interaction nearly 250 years ago.

> *Aotearoa New Zealand is a nation that has multiple knowledge systems. Next year is the 250 year anniversary of when two of these knowledge systems first met - when Tupaia, a Polynesian navigator who used the science of star-referenced navigation, guided James Cook on the Endeavour. The visitors brought science as known then in England and met other quite different forms of science from Māori – for example in food preservation and medicinal use of plant materials. We confirm our commitment to value all forms of research and scholarship. Though the methods of humanities research and Māori research may differ from the natural and physical sciences, they are no less rigorous.* (Bedford 2018)

In concert with research organisations such as Ngā Pae o te Māramatanga, the Centre for Research Excellence in Māori research, the dialogue is shifting from 'should we' to 'how do we'. Many organisations in Aotearoa acknowledge that a Tiriti-based partnership should underpin research relationships, as gestured to in institutional ethics processes for years now.

Āta haere – Proceed with care

Esteemed anthropologist Sir Peter Buck (Te Rangi Hīroa) was Aotearoa's second Māori medical doctor (after Māui Pōmare). His thesis on Māori medicine was possibly the first Indigenous doctoral thesis to engage Indigenous knowledge. Buck and Pōmare entered medicine in response to Tā Apirana Ngata's plea in 1897, for more Māori medical practitioners. 120 years later, the need is still pressing for Māori across the gamut of scientific professions.

Buck was a prolific writer and his published and unpublished manuscripts continue to be studied and analysed. Some of his writings included letters and contributions to Māori newspapers and he wrote about mātauranga in 1907, in Te Pipiwharauroa's 115th issue:

> *Homai nga korero me nga matauranga o mua hei taiaha ma matou ki te patu i nga Pakeha e ki nei he iwi kuare te Maori.*
>
> *Give us the stories and the knowledge of the past as a weapon for us to combat the Pākehā who say the Māori are an ignorant people.* (Te Rangi Hīroa cited in Benton *et al.* 2013, p. 222)

One hundred years later, the discourse has shifted to one in which policy presents an open invitation to and expectation for educationalists, environmentalists, researchers and scientists to engage with mātauranga. The sorts of attitudes towards Māori that Buck hoped to pre-empt at the turn of the last century, may not be an issue requiring a defensive 'weapon', nevertheless mātauranga is seen as a 21st century tool or key for unlocking Māori potential.

In this paper I've talked about mātauranga as a 'thing' – constrained partly by the English language and partly by the socialisation of mātauranga into our popular discourse. This encourages descriptions of mātauranga that make it sound like a mine to 'tap into', a wild creature to 'capture', a 'vehicle' or 'way' to infiltrate, or a treasure trove to be 'unlocked'. A discourse in which matauranga is 'incorporated' or made tributary to modern science can be isolating and fragmentary, performing a dissection and disconnection of mātauranga from its context and its people. Mātauranga may not respond kindly to other epistemological tools, particularly ones whose own validity is contingent upon them maintaining the boundary between knowledge tested on Western terms and the 'epistemic wilderness'[3] (Cooper 2012).

Relatedly, mātauranga may not be fully understandable outside of discussions in te reo Māori (Black 2012; Hunkin 2012; Royal 2008). Te reo Māori, like other indigenous languages, places emphasis on verb and action, rather than object and subject in English (Bohm & Peat 1987). Traditionally thus, we might have seen more emphasis on the concepts 'matau' (to understand), 'mōhio' (to know), 'mārama' (to understand) and the matrix connecting these.

Finally, mātauranga is a whole system incorporating the humanities and social sciences. Policy does not differentiate aspects of mātauranga, so thrusting scientists not accustomed to working across the nature/culture divide into this territory may be unwise. Working with researchers in the social sciences and humanities disciplines first, may be a vital stepping stone.

He kupa whakamutunga – Final words

In Aotearoa New Zealand we have an opportunity to draw upon two knowledge traditions to produce a unique 'mātauranga Aotearoa' (Tauwhare 2008). But we might need to move cautiously to ensure coordinated 'dancing at the interfaces' (ibid), and not step on each others' toes. This contribution has pointed out some innovations at the borders of knowledge systems. The theory and praxis that Māori, in particular, are contributing to the discourse and practice at the interface is prodigious. As such, the bibliography provided here constitutes perhaps a helpful reading list, but is just the tip of the iceberg in relation to mātauranga and science activity.

The most successful projects that engage with mātauranga: address a problem of shared concern so that there can be equal input from contributors; cannot be solved by one knowledge system alone; have equitable outcomes; build capability and capacity; are underpinned by Treaty principles such as protection and partnership; have Māori in leadership roles; and crucially, are injected with human values of honesty, truth-seeking, kindness, generosity and humility.

Many efforts have contributed to developing a way of doing science that is moderate, reflexive and uses respect, dialogue and negotiation at the borders of knowledge systems, not incursion or mining strategies. First, we should continue strengthening and revitalising mātauranga Māori. Second, the position and autonomy of mātauranga in relation to science should be strengthened. Rather than science doing the unlocking, we must ensure mātauranga has its own rangatiratanga (autonomy) (Broughton & McBreen 2015), its own right to selectively unlock and reveal. Finally, with an awareness of historical pitfalls, and with several Indigenous-led tools (such as definitions, models, frameworks, principals and ethics) for doing research here, working with mātauranga and science can be interesting, mutually enlightening, paradigm-shifting and transformative.

Glossary

Atua	god, phenomenological power
Hapū	sub-tribe
Iwi	tribe
Maramatanga	understanding
Marautanga	curriculum
Matau	to know, to understand, to feel certain of
Mātauranga	Māori knowledge, knowing, epistemology
Mauri	life force, vital essence
Mōhiotanga/mōhioranga	know-how, common knowledge
Oriori	song that recounts a historical event, epic historical tale
Pangarau	mathematics
Pūrākau	stories, narratives
Pūtaiao	science, 'Western science'
Rangatahi	young people
Rangatiratanga	leadership, self-governance, autonomy
Tamariki	children
Taonga	treasure
Te Ika a Māui	The Fish of Māui, North Island
Te reo Māori	the Māori language
Te Tiriti o Waitangi	the Treaty of Waitangi
Tikanga	values, rituals
Tohunga	priest, expert
Waiata	song
Whakapapa	genealogy
Whakatauki	proverbial saying
Whare wānanga	house of learning

[3] The 'epistemic wilderness' is a place to which the West is argued to consign 'other knowledges'. Being in the epistemic wilderness allows mātauranga to be ignored, mythologised and even feared. But for mātauranga wilderness can be a place of freedom (Cooper, 2012).

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Article

A quick look at prime numbers

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Our fascination with the primes

Since the time of the ancient Greeks, and probably long before then, we have been fascinated by prime numbers. One possible reason for our fascination with prime numbers is that the inter-relationships between them and the patterns that they appear to create are so difficult to understand. Another possible reason is that the primes appear to exhibit both deterministic behaviours (i.e. fully determined on the basis of naturally-occurring relationships) and random behaviours (i.e. occurring by chance). Nobody has succeeded in creating mathematical models that predict the magnitudes of prime numbers exactly or the numbers of prime numbers up to a given natural number. Other reasons for our fascination with primes may involve unexpected and quite exquisite relationships between prime numbers and certain mathematical functions and the seemingly disconnected islands of prime numbers, each surrounded by a sea of numbers that are not prime but which are related mysteriously to one another.

What are prime numbers?

Primes are positive natural numbers, greater than 1, that have two positive divisors (i.e. have no divisors other than themselves and 1). Numbers that are not prime (i.e. have divisors other than themselves and 1) are known as composite numbers. The so-called Fundamental Theorem of Arithmetic tells us that every whole number greater than 1 is either prime or is a unique product of primes, apart from the order of multiplication. For example, 30 can be written as the product of three primes: $2 \times 3 \times 5$. Figure 1 gives a table of the 25 prime numbers that lie between 1 and 100, in which the primes are shown against a shaded background.

Because 1 has only a single positive divisor (itself), it is not a prime. In fact, because a composite number has more than one divisor, 1 is neither prime nor composite.

We note that the gaps between these primes (which we define as the difference between a given prime and the next prime) vary considerably. We see from Figure 1 that, for numbers between 1 and 100, the gaps vary from 1 (i.e. the gap between 2 and 3) to 8 (that between 89 and 97). All prime gaps are even, apart from the first gap and, in fact, the first prime number (2) is the only even prime number.

1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28	29	30
31	32	33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48	49	50
51	52	53	54	55	56	57	58	59	60
61	62	63	64	65	66	67	68	69	70
71	72	73	74	75	76	77	78	79	80
81	82	83	84	85	86	87	88	89	90
91	92	93	94	95	96	97	98	99	100

Figure 1: A table of the 25 prime numbers between 1 and 100.

The first 15 gaps are as follows (compare with Figure 1):

1, 2, 2, 4, 2, 4, 2, 4, 6, 2, 6, 4, 2, 4 and 6

However, though all prime gaps, except the first, are even natural numbers, many even natural numbers are not known prime gaps. Here are the fifteen smallest known gaps in ascending order:

1, 2, 4, 6, 8, 14, 18, 20, 22, 34, 36, 44, 52, 72 and 86.

We see that the even natural numbers 10, 12, 16 and others within the range of this list are not known gap sizes. Thus, the known set of prime gaps is a subset of the even natural numbers.

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How numerous are the primes?

There are 168 primes between 1 and 1000, 1229 primes between 1 and 10,000 and 78,498 of them between 1 and one million. We have tables of primes for much bigger natural numbers, but counting the primes becomes more and more difficult as we move along the number line to very large natural numbers.

Around 300 BC Euclid proved that there are infinitely many prime numbers. In more recent times, other famous names have been associated with prime number theory, notably Leonard Euler (1707–1783), Pafnuty Chebyshev (1821–1894), Bernard Riemann (1826–1866), G.H. Hardy (1877–1947), John Littlewood (1885–1977) and Srinivasa Ramanujan (1877–1920). Today, Yitang Zhang, Ben Green, Terence Tao and James Maynard are among the group that is advancing our knowledge in this very challenging field.

Figure 2 gives a graph of the prime-counting function, the actual number of primes up to and including a given natural number, usually denoted by the Greek symbol **π(n)**. Specifically, Figure 2 gives the number of primes up to 60.

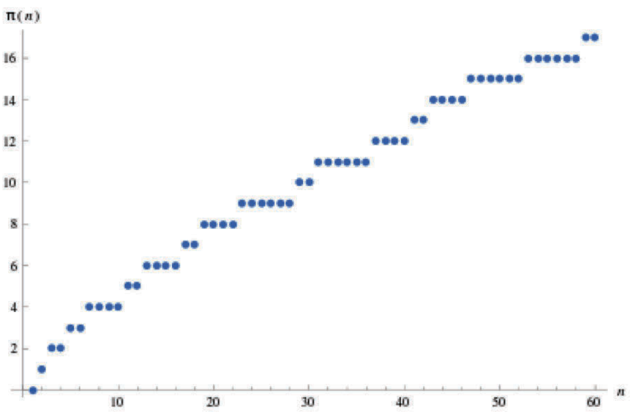


Figure 2: The prime-counting function for natural numbers up to 60.

We see that the number of primes increases in steps as we move along the natural number line and as we encounter each new prime number. Note that $\pi(1) = 0$ because 1 is not a prime, $\pi(2) = 1$, $\pi(3) = 2$, $\pi(4) = 2$ and $\pi(5) = 3$. Notice that there appears to be some curvature in this graph. In fact, as we move to greater and greater natural numbers, on average the primes do become sparser and the gaps between them tend to increase.

Some Mathematical Expressions

Over the last one hundred and fifty years, much work on primes has centered on the development of mathematical models that give:

1. Estimates of the number of primes up to a given natural number n
2. Estimates of the magnitude of the n'th prime number
3. Estimates of the size (average, minimum and maximum) of the gaps between adjacent primes at different scales of the natural numbers
4. Indications of the occurrence and recurrence of patterns within the set of primes (e.g. the occurrence of arithmetic series and even polynomial series).

We now start our beginner's review of prime number theory by examining some results that have been known for well over a century. One approximation for the magnitude of the n'th prime number is the following:

Bernhard Riemann (1826 – 1866)

$$p(n) \sim n\log_e(n)$$

. . . where the tilde means 'approximately equal to. In other words, we have a mathematical model of the size of the n'th prime, but not an exact model.

More of interest to researchers at present is the development of models of the number of primes up to a given natural number. Researchers have produced extensive tables of the numbers of primes that are updated almost every year to larger and larger natural numbers. One useful approximation (due to Carl Friedrich Gauss and Adrien Legendre) for the number of primes up to a given natural number n is:

$$\pi(n) \sim n / \log_e(n)$$

. . . where, of course, **π(n)** represents the actual total number of primes up to **n**.

This expression is known as the prime number theorem and also as the asymptotic law of distribution of prime numbers. Though Chebyshev demonstrated that this expression is correct to within about ten percent of the true number of primes up to n, it appears to underestimate the true number persistently. For **n** = 10^8, the actual number of primes **π(n)** = 5,761,455, while the prime number theorem estimates **π(n)** at 5,438,681, which is 322,774 (about 5.6%) too few.

Aware of the limitations of the prime number theorem, Riemann provided a better estimate (Riemann 1859), as follows:

$$Li(n) \sim \int_0^N dt / \log_e(t)$$

. . . where t is a dummy variable. This expression estimates the true number of primes up to a natural number n with greater precision. Thus, for **n** = 10^8, **Li(n)** = 5,762,209, which is only 754 (about 0.01%) too many. Thus, Riemann's expression represents a significant improvement.

For some years it was believed that **Li(n)** always overestimates the true number. However, Littlewood (1914) demonstrated that for very large natural numbers the expression underestimates the true number and, thereafter at greater and greater scales, successively underestimates and overestimates infinitely often (known as 'Littlewood Violations'). In other words, the difference **π(n) – Li(n)** changes sign infinitely often.

However, violations of the rule that **Li(n)** overestimates **π(n)** occur at numbers that are very large and it is not surprising that it took several decades from the original work of Riemann to identify these violations. We now know that Littlewood Viola-

John Littlewood (1885 – 1977)

tions occur at approximately 1.398 × 10^{316} (Bays and Hudson, 2000) where more than 10^{153} consecutive natural numbers exist for which the sign of **π(n) - Li(n)** is positive. There are large zones of violation at much greater numbers again but Büthe (2015) has demonstrated that Littlewood Violations do not occur at natural numbers below 10^{19}.

Prime numbers and the zeta function

We now consider the zeta function whose relevance to prime numbers will be seen in the next section. One simple version of the zeta function is as follows:

$$Z(s) = 1 + 1/2^s + 1/3^s + 1/4^s + 1/n^s + \ldots = \sum_0^\infty (1 / n^s) = \sum_0^\infty n^{-s}$$

. . . where **s** is a real number.

In 1737 Leonard Euler demonstrated that the zeta function can be re-written as follows:

$$\sum_0^\infty (1 / n^s) = \prod_{primes} [1 / (1 - 1/P_s)]$$

. . .where P_s are the prime numbers and the symbol $\prod_{primes}$ is an instruction to multiply all terms in brackets involving all prime numbers. Thus, we already have a link between an infinite series of inverse powers of natural numbers and an infinite series of primes.

Figure 3 gives a graph of the zeta function.

For **s** > 1 the zeta function always tends asymptotically to infinity as s tends towards 1 from above and tends asymptotically to 1 as **s** becomes larger (though the precise curve depends on the value of **s**). For values of **s** < 1 the graph shows peaks and troughs whose amplitudes depend on the value of **s**. The graph is very complicated but we see roots (places where the graph crosses the horizontal axis) at every negative even whole number. These zeroes at the negative even whole numbers are known as the trivial roots of the zeta function. However, other non-trivial roots exist which are harder to find and harder to understand.

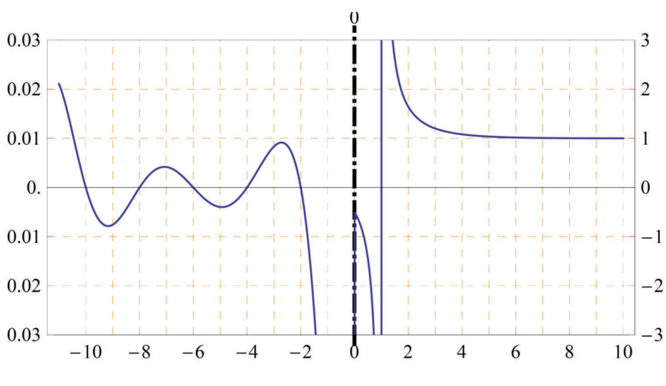


Figure 3: Graph of the zeta function.

For a complete discussion of these roots we must consider the zeta function applied on complex numbers. You may remember from high school that complex numbers are numbers of the form:

a + bi

where **i** is the square root of –1. Many texts discuss the zeta function very clearly, especially that by John Derbyshire (Derbyshire 2004). A discussion of the application of the zeta function on complex numbers is beyond the scope of this article. However, over the last century, a great deal of work has gone into understanding the non-trivial solutions to the zeta function applied on complex numbers.

The Riemann Hypothesis

The Riemann Hypothesis, one of the long-standing challenges of pure mathematics, has implications for prime number theory. The Riemann Hypothesis involves the following conjecture:

All non-trivial zeroes of the zeta function have real part equal to ½.

Hardy (1914) showed that infinitely many of the non-trivial roots have real part ½ but this result does not prove that absolutely all non-trivial roots have that value. If the Riemann Hypothesis can be proved, then certain conjectures about primes will be confirmed or proved untrue. However, it has not yet been proved or disproved and prime number theorists are divided in their opinions on whether the conjecture is true or not. If it is true, then we can write:

$$\pi(n) = Li(n) + O[n^{1/2}\log_e(n)]$$

. . . where the function **O** indicates an error term that remains bounded within the graph of the function $n^{1/2}\log_e(n)$. In other words, we can be more precise in our estimates of the numbers of primes. Figure 4 gives a graph of this error term up to 10,000 (which was created using R, an environment for statistical analysis and graphics).

The error term, the difference between the actual number of primes and the function **Li(n)**, is suppressed within the bounds of our function, enabling increased accuracy in our estimates of **π(n).**

More mathematical expressions

Now we consider a particular function of the prime-counting function – the J function. Due to Riemann (Riemann 1859), it is written as follows:

$$J(n) = \pi(n) + ½\,\pi(n^{1/2}) + 1/3\,\pi(n^{1/3}) + 1/4\,\pi(n^{1/4}) + \ldots$$

This function can be inverted to give the prime-counting function on the left hand side:

$$\pi(n) = J(n) - ½\,J(n^{1/2}) - 1/3\,J(n^{1/3}) - 1/5\,J(n^{1/5}) + 1/6\,J(n^{1/6}) - 1/7\,J(n^{1/7}) + 1/10\,J(n^{1/10}) + \ldots$$

. . . where certain terms appear to be missing (in fact, terms involving 1/4 and 1/9, etc. have disappeared quite legitimately) and we now have both plus and minus signs. It can be demonstrated that:

$$\log_e[Z(s)] = s \int_0^\infty J(t).t^{-s-1}\, dt$$

. . . where **t** is a dummy variable. A proof of this expression is beyond the scope of this article, but it is demonstrated clearly

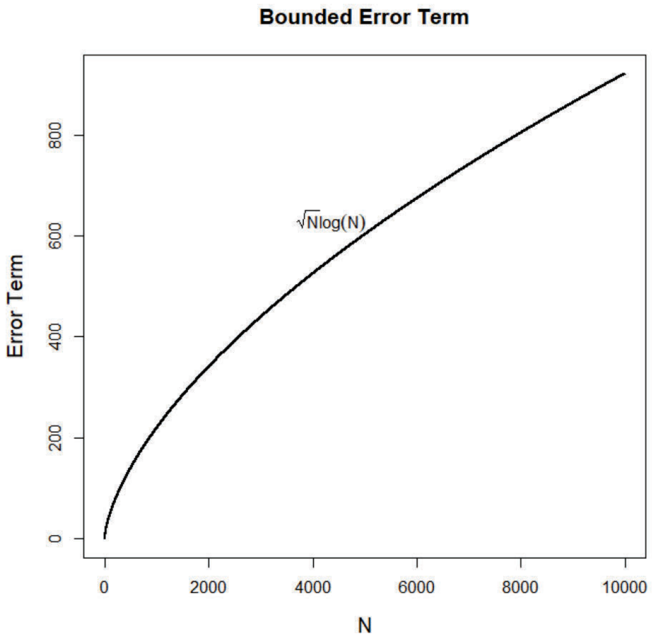


Figure 4: The bounded error term.

in John Derbyshire's book on pages 303–311. The result of interest for us is that, since **J(n)** is a function of the prime-counting function **π(n)**, we have a firm link between the prime-counting function and the zeta function. We have another link between the zeta function and the Riemann Hypothesis and therefore we have a link between the prime numbers and the Riemann Hypothesis.

The Green–Tao Theorem and arithmetic progressions within the primes

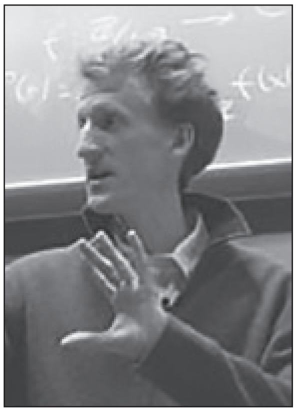
In 2004 Benjamin Green and Terence Tao (Green & Tao 2008) published the Green–Tao Theorem. They showed that the prime numbers include arithmetic progressions of arbitrary length. Thus, there are arithmetic progressions of prime numbers with every possible number of terms. Put another way, for every natural number n, the primes contain arithmetic progressions of length n.

As an example, consider the arithmetic progression of primes: 5, 11, 17,23, 29 in which the gaps are of magnitude 6. This progression is of length 5 and terminates at 29 because 35 is not a prime. The Green–Tao Theorem tells us that arithmetic progressions like this example exist within the primes but does not predict progression length or gap size, how to identify them or where they exist on the number line.

Small gaps between prime numbers

Over the last five years much progress has been made in our understanding of the gaps between the prime numbers. The lectures given by Professor Tao at the Department of Mathematics of the University of California Los Angeles on the gaps between the prime numbers, available on the Internet, provide a very helpful introductory synopsis (the URLs are given in the references for this article).

Much progress is being made on both how small and how large the gaps between adjacent primes can be at different scales of the natural numbers. In fact, gaps can be thought of in terms of the number of composite numbers lying between two adjacent primes (i.e. we could subtract 1 from the difference between the



Ben Green

Terry Tao

two adjacent primes). However, the gap **G[P(n)]** between two primes (the **n**'th and **n**+1'st primes) is usually defined as the difference between those adjacent primes, and that approach has been adopted in this article. Thus:

$$G[\,P(n)\,] = P(n+1) - P(n)$$

We can relate the primes to the prime gaps as follows:

$$P(n+1) = 2 + \sum_{1}^{n} G[\,P(t)\,]$$

Apart from the first gap of size 1 (that between 2 and 3), the smallest possible gap is of size 2 (for example, that between the primes 11 and 13 and between 71 and 73). So, how can small gaps between primes at different scales of the natural numbers be characterised?

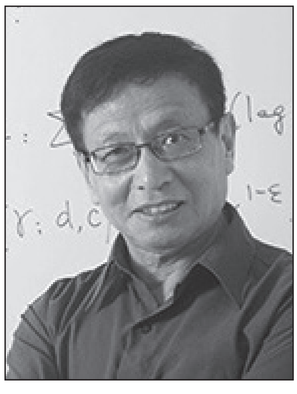
In May 2013 Yitang Zhang demonstrated that gaps less than or equal to 70,000,000 occur infinitely often. This number is not particularly special and simply emerges from the assumptions and approximations that Zhang adopted in his proof.

Within a few months other workers trimmed this number down to 4680 (a group within the Polymath Project – a project in which mathematicians collaborate in solving mathematical problems), then down to 600 (Maynard 2013) and then to 246 (the Polymath Project in April 2014).

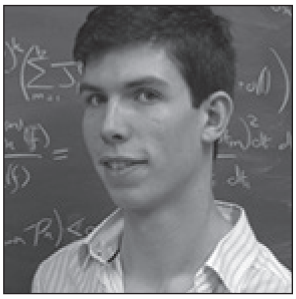
James Maynard's work in this area was undertaken as a very young mathematician, for the most part independently of other workers.

Under certain assumptions it can be demonstrated that gaps less than or equal to 6 occur infinitely often. However, because this result depends critically on those assumptions, we are not entirely sure that gaps of size 6 do occur infinitely often. Gaps less than or equal to 4 (the so-called Cousin Primes) may occur infinitely often but we do not yet have a definitive proof. Gaps equal to 2 may also occur infinitely often (the Twin Prime Con-

Yitang Zhang



James Maynard



jecture). At present, completely new approaches are required in order to verify the Twin Prime Conjecture, and Professor Tao believes that a proof could be more than a decade away.

Large gaps between the primes

Professor Tao's lectures provide an introduction to current work on large gaps between primes, particularly his lecture Small and Large Gaps between the Primes (see the first of the references to his lectures for the relevant URL). Professor Tao states that, across all of the primes, gaps can be of any size (i.e. arbitrarily large). He also states that our best estimate for the upper bound on the gap size between a particular pair of adjacent primes is as follows:

$$P(n+1) - P(n) < P(n)^{0.55}$$

Consider the adjacent primes 89 and 97. The gap between them has size 8 but the above expression predicts an upper bound of 11.8 (which we round up to 12). The expression works in the sense that it gives an estimate of the maximum size of a gap for a pair of adjacent primes, but it does not give us the actual gap size.

Thus, the prime gaps are at most just slightly larger than the square root of **P(n)**. However, if the Riemann Hypothesis is true, then we have a slight improvement:

$$P(n+1) - P(n) < P(n)^{0.5} \log_e[P(n)]$$

For the pair of adjacent primes 89 and 97, the predicted maximum gap size is now 42. Let's also use this expression for the adjacent primes 2393 and 2399. The improved expression predicts an upper bound on the gap size of 381, considerably larger than the actual gap of 6. However, we must remember that these expressions are intended to give upper bounds on gap sizes at different scales of the natural numbers, rather than precise gap sizes.

Even this expression is not expected to be the final, definitive result, and improvements will most probably be found. However, if the Riemann Hypothesis is verified, we will have more precise expressions for the upper bounds on gap sizes for adjacent primes at different scales of the natural numbers.

A voyage down the number line

On the basis of the Green–Tao theorem it appears that we can choose any natural number and there will be at least one arithmetic progression of this length. However, at any given scale of the natural numbers, gap sizes may be constrained to a subset of allowable gaps that are greater than or equal to 2 and less than or equal to certain maximum gap sizes that possibly are roughly consistent with the expressions of the previous section or with extensions of those expressions.

Here are some interesting questions that might be answered in the future:

1. A progression of primes at a certain scale may occur once or finitely often, but could it recur infinitely often and, if so, under what conditions could such a progression recur infinitely often? If progressions do recur, are progressions of small length and small gap size more likely to recur than longer progressions with large gap sizes?
2. If such a progression recurs finitely often or infinitely often then, just as the primes become sparser, on average, at greater and greater scales of the natural numbers, would repetitions of this progression tend to become sparser, on average, as we move to greater and greater scales of the natural numbers?
3. In many or all repetitions of this progression (and other similar progressions), all elements may occur purely deterministically but, in some repetitions, could certain elements appear by chance (i.e. from a purely random process) rather than deterministically?

Perhaps such questions cannot be answered directly through the Green–Tao Theorem (which states only that there are arithmetic progressions of arbitrary length but does not say anything about what those elements should be). It may appear counter-intuitive to have infinitely many recurring progressions of certain arithmetic progressions of particular lengths and gap sizes. However, the primes are infinite in extent and so the possibilities for such progressions to emerge may be limitless, except for possible inherent constraints on recurrences imposed by naturally-occurring relationships between the primes themselves. Nature provides different levels of infinity. Thus, even if we select only one whole number from every thousand trillion, we nevertheless select an infinite number of whole numbers. Applying this line of thought, perhaps it is possible for the primes to contain an infinite number of arithmetic progressions involving particular combinations of length and gap size.

Imagine that we are to travel down the number line at very high speed and stop to look at every occurrence of one particular progression. Our first stop may take only a few minutes to reach and perhaps that is the one and only stop. However, there may be others. Those other stops, further down the number line, if they exist, may take days, weeks or years to get to. As we get to very large scales, our next stops may take thousands of years and possibly much more, but our journey may last forever.

Future work on primes

The primes appear to be characterised by unexpected relationships with certain mathematical functions and those seemingly disconnected islands of prime numbers which are mysteriously related to one another, though they are surrounded by a sea of numbers that are not prime. Like other areas of mathematics, resolution of one question about primes seems to result in other questions.

Our understanding of prime numbers is increasing every year. Future work on primes may depend on a resolution of the Riemann Hypothesis, but could include attempts to prove the Cousin Prime Conjecture (that primes separated by 4 occur infinitely often) and the Twin Prime Conjecture (that primes separated by 2 occur infinitely often). Other valuable work may include refinements of our current models of the magnitudes of the n'th prime and the numbers of primes up to a given natural number.

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Professor Tao's Lectures on the Prime Numbers

Small and Large Gaps between the Primes. https://www.youtube.com/watch?v=pp06oGD4m00

Structure and Randomness in the Prime Numbers. https://www.youtube.com/watch?v=PtsrAw1LR3E

News

ICSU-ISSC merger

At their joint General Assembly in Taipei in October 2017, the members of the International Council for Science (ICSU) and the International Social Science Council (ISSC) took a final decision to merge the two organisations to become the International Science Council (ISC)[1].

The founding General Assembly of the new Council will take place in Paris, France, from 3 to 5 July 2018.

The draft strategy of the new organisation emphasizes that the importance of scientific understanding to society has never been greater, as humanity grapples with the problems of living sustainably and equitably on planet Earth. It stakes out a space for the Council to defend the inherent value and values of all science at a time when it has become harder for the scientific voice to be heard. It will strengthen international, interdisciplinary collaboration and support scientists to contribute solutions to complex and pressing matters of global public concern. It will advise decision makers and practitioners on the use of science in achieving ambitious agendas such as the Sustainable Development Goals (SDGs) adopted by world leaders in 2015. And it will encourage open public engagement with science.

The vision of the new Council, as stated in the High-Level Strategy, is to advance science as a global public good. Scientific knowledge, data and expertise must be universally accessible and its benefits universally shared. The practice of science must be inclusive and equitable, also in opportunities for scientific education and capacity development.

According to its mission statement, the new Council will act as the global voice of science. That voice will:

- Speak for the value of all science and the need for evidence, informed understanding and decision-making;
- Stimulate and support international scientific research and scholarship on major issues of global concern;
- Articulate scientific knowledge on such issues in the public domain;
- Promote the continued and equal advancement of scientific rigour, creativity and relevance in all parts of the world; and
- Defend the free and responsible practice of science.

[1] See: https://www.icsu.org/about-us/icsu-issc-merger

THE CONVERSATION

The following article is republished from The Conversation, dated 17 April 2018. It was Prof Baisden's inaugural professorial lecture at the University of Waikato, delivered on 17 April 2018.
The article has not been edited, but we have attributed the author and his institute, and given the internet citations.

Six ways to improve water quality in New Zealand's lakes and rivers

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Two years ago, New Zealanders were shocked when contaminated drinking water sickened more than 5,000 people in the small town of Havelock North[1], with a population of 14,000. A government inquiry[2] found that sheep faeces were the likely source of bacterial pathogens, which entered an aquifer when heavy rain flooded surrounding farmland.

A second phase of the inquiry[3] identified six principles of international drinking water security that had been bypassed. Had they been followed, the drinking water contamination would have been prevented or greatly reduced.

Here, I ask if the approach recommended by the Havelock North inquiry to prevent drinking water contamination can be extended to reduce the impacts of nutrient contamination of freshwater ecosystems.

Freshwater degraded and in decline

Most measures of the ecological health and recreational value of New Zealand's lowland rivers and lakes have been rated as degraded and still declining[4]. Intensive agriculture often cops much of the blame, but primary industry exports remain the heart of New Zealand's economy[5].

The challenge posed by this trade-off between the economy and the environment has been described as both enormous, and complex[6]. Yet it is a challenge that New Zealand's government aims to tackle, and continues to rate as a top public concern[7].

An important lesson from the Havelock North inquiry is that sometimes there is no recipe – no easy list of steps or rules we can take to work through a problem. Following existing rules resulted in a public health disaster. Instead, practitioners need to follow principles, and be mindful that rules can have exceptions.

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For freshwater, New Zealand has a similar problem with a lack of clear actionable rules, and I've mapped a direct link between the six principles of drinking water security and corresponding principles for managing nutrient impacts in freshwater.

Six principles for freshwater

Of the six principles of drinking water safety, the first is perhaps the most obvious: drinking water safety deserves a 'high standard of care'. Similarly, freshwater nutrient impact management should reflect a duty of care that mirrors the scale of impacts. Our most pristine freshwater, like Lake Taupo[8], and water on the verge of tipping into nearly irreversible degradation, deserve the greatest effort and care.

Second, drinking water safety follows a clear logic from the starting point: 'protecting the integrity of source water is paramount'. For nutrient impact management in freshwater, we must reverse this and focus on a more forensic analysis along flowpaths to the source of excess nutrients entering water. Our current approach of using estimates of sources is not convincing when tracers could point to sources in the same way DNA can help identify who was at a crime scene. We must link impacts to sources.

Third, drinking water safety demands 'multiple barriers to contamination'. For freshwater, we're better off taking a similar but different approach – maximising sequential reductions of contamination. There are at least three main opportunities, including farm management, improving drains and riparian vegetation, and enhancing and restoring wetlands. If each is 50% effective at reducing contaminants reaching waterways, the three are as good as a single barrier that reduces contamination by 90%. The 50% reductions are likely to be much more achievable and cost effective.

Troy Baisden is Professor and Chair in Lake and Freshwater Sciences at the University of Waikato. He specialises in understanding the flow of nutrients, water and carbon through terrestrial ecosystems and resulting impacts in freshwater.

He was formerly at GNS Science's National Isotope Centre, ensuring New Zealand has access to challenging isotope techniques combined with the 'big-picture' understanding required to apply them to the nation's most important environmental issues.

He has an interest in analytics and science policy as they relate to addressing global change issues. He holds a PhD from the Department of Environmental Science, Policy and Management at the University of California, Berkeley. He is also an Investigator in Te Pūnaha Matatini, the Centre of Research Excellence on networks and complexity, and an Associate Editor for the journal *Biogeochemistry*.

Managing hot spots and hot moments

The fourth principle of drinking water safety was perhaps the most dramatic failure in the Havelock North drinking water crisis: 'change precedes contamination'. Despite a storm and flood reaching areas of known risk for contaminating the water supply, there were no steps in place to detect changing conditions that breached the water supply's classification as 'secure' and therefore safe.

A similar, but inverted principle can keep nutrients on farm, where we want them, and keep them out of our water. Almost all processes that lead to nutrient excess and mobilisation, as well as its subsequent removal, occur in hot spots and hot moments[9].

This concept means that when we look, we find that roughly 90% of excess nutrients come from less than 10% of the land area, or events that represent less than 10% of time. We can identify these hot spots and hot moments, and classify them into a system of control points[10] that are managed to limit nutrient contamination of freshwater.

Establishing clear ownership

A fifth principle for drinking water seems obvious: 'suppliers must own the safety of drinking water'. Clear ownership results in clear responsibility.

Two world-leading cap-and-trade schemes created clear ownership of nutrient contaminants reaching iconic water bodies. One is fully in place in the Lake Taupo catchment[11], and another is still under appeal in the Lake Rotorua catchment[12].

These schemes involved government investment of between NZ$70 million and NZ$80 million to 'buy out' a proportion of nutrients reaching the lakes. This cost seems unworkable across the entire nation. Will farmers or taxpayers own this cost, or is there any way to pass it on to investors in new, higher-value land use that reduces nutrient loss to freshwater? A successful example of shifting to higher value has been conversions from sheep and beef farming to vineyards.

As yet, the ownership of water has made headlines[13], but remains largely unclear outside Taupo and Rotorua when it comes to nutrient contaminants. Consideration of taxing the use of our best water[14] could be much more sensible with a clearer framework of ownership for both water and the impacts of contaminants.

The final principle of drinking water safety is to 'apply preventative risk management'. This is a scaled approach that involves thinking ahead of problems to assess risks that can be mitigated at each barrier to contamination.

For nutrient management in water, a principled approach has to start with the basic fact that water flows and must be managed within catchments. From this standpoint, New Zealand has a good case for leading internationally, because regional councils govern the environment based on catchment boundaries[15].

Within catchments we still have a great deal of work to do. This involves understanding how lag effects can lead to a legacy of excess nutrients. We need to manage whole catchments by understanding, monitoring and managing current and future impacts in the entire interconnected system.

If we can focus on these principles, government, industry, researchers, NGOs and the concerned public can build understanding and consensus together, enabling progress towards halting and reversing the declining health and quality of our rivers and lakes.

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Article

Why science gets cut out of policy†

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Science has an important role to play in influencing decision-making in international and national forums. But do scientists understand how it needs to be delivered, or what's required from science for the development of policy and achieving consensus[1]? And do they know what constitutes a solution that a policymaker can use[2]?

The extent to which scientific knowledge gets traction in policy will depend partly on the state of science knowledge on the issue, and partly on the degree of controversy surrounding the issue under consideration. It will also depend on the degree of public and political attention the matter gets.

It's much easier to gain acceptance if the scientific community is united in describing the problem and how to address it. Obviously, the nature of the problem affects the influence of science – the more politically controversial the issue, the less likely it is that scientific evidence will be used to inform important decisions. By the same token, for low-conflict issues, political attention tends to increase the influence of science.

Policymakers do care about scientific evidence insofar as it helps them make better and faster decisions. So scientists must listen and understand the problem they are purporting to solve. Too often, scientists will pop out some recommendation that shows they haven't got a complete grip on the problem and how their knowledge will be used. It's a bit like Monty Python's architect sketch: 'Hmm, that is a lovely abattoir, but I asked you for a block of flats'[3].

Scientists need to be bold in recommending things in a way that allows non-technical decision-makers with political agendas to make decisions in a consensus environment.

Easy, right?

There's also a significant responsibility on scientists to explore uncertainty, but nevertheless be prepared to give their expert opinion in the face of it. Scientists, individually and collectively, need to be more assertive in presenting what they think is right, rather than everything that could be right. There's a need for scientists to engage with policymakers, regulators and industry stakeholders in advance of building science proposals. Credible knowledge-brokers can play a very valuable role in making science useable by policymakers. All this will give the policymaker greater confidence in scientists' expert judgements when they put forward recommendations.

Too often, scientists tend to think they know what is best or what is needed, and then they are disappointed, frustrated or angry when their ideas and hard work are rejected or put on the shelf.

In my experience, policymakers and politicians understand uncertainty because they are constantly making assessments of uncertainty. So it's important that scientists explain the risks involved in basing decisions on particular scientific advice or results. It is often the case that a scientist has to say 'we don't know for sure what is going to happen, or what is driving this change'. But it is also helpful if they add, 'but we do know that it is x, y, or z, and it can really be only one or several of these three things going on. Precisely which one is what we're working on.'

This helps rule out a bunch of possible drivers and offers some guidance to policymakers, who get bombarded with many ideas of the causes of change, some of them quite extreme.

When policymakers say they need the scientific information soon, they normally mean weeks, so scientists need to be able to work to their schedule. It won't help the Minister to say to them: 'Just weather the political storm for five years till we get the advice to you!'

Scientists need to recognise that there are many other inputs to policy, especially resource considerations and public opinion. Effective scientists deliver their advice in forms to suit multiple audiences, including the public.

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†This is an abridged version of a speech given on 11 April 2018 in Hobart to an international conference, *Marine Ecosystem Assessment of the Southern Ocean*, co-hosted by the Australian Antarctic Division and the Antarctic Climate & Ecosystems Cooperative Research Centre. It first appeared in *APPS Policy Forum* at https://www.policyforum.net/science-gets-shut-policy/ and is republished here with permission.

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Dr Bergin's professional training was in political science, law and international relations at Monash University and the ANU. Prior to joining ASPI in 2006, he was an academic engaged for 25 years in professional military education; first at the Royal Australian Naval College and then at the Australian Defence Force Academy. He led the Australian Defence Studies Centre at the academy for 12 years and taught homeland security. For four years, he served as an Adjunct Reader in International Law at the Australian National University, and he has been a visiting professor at the University of Delaware. Dr Bergin has published widely in scholarly journals and policy papers on Australian foreign policy, maritime affairs and national security, and he is a frequent contributor to quality press publications on these issues. He regularly blogs on *The Strategist.*

Scientists must also appreciate that science is expensive and understand that policymakers need to know what is or is not a credible level of scientific investment. A sure-fire way to annoy a Minister is to say you can't offer an opinion till you get a multi-year research grant. Scientists need to work with policymakers on how to manage these things to get a credible result. It has to involve mutual listening and learning.

What politicians want is objective (fact-based), transparent (important underlying assumptions are expressed clearly), and unbiased advice (not manipulated to achieve a particular outcome with selective use of facts and arguments).

It's also important for scientists to recognise that, by and large, policymakers don't like starting from scratch when they get science advice – they prefer solutions that evolve from existing approaches. Policymakers hate the answer: 'Well Minister, if I was going to ... *(insert place),* I wouldn't start from here'.

Scientists should recognise that it is policymakers who will have to sell a decision. Where politics are in play, an issue is unlikely to be resolved through a simple statement of the scientific facts.

And surprise, surprise, politicians may choose to act in their own interest! In the long run, it's fair to say for most politicians the best policies are the best politics.

When scientific advice is perceived merely as advocacy, trust in the advice will be undermined. When employed by government, scientists should publicly highlight what the science says. They are, after all, publicly funded. But that's not to say it should always be the business of publicly funded scientists to comment on government policy. Scientists shouldn't be surprised if they're excluded from policy decisions if they become public commentators or activists.

If the Minister thinks that their stakeholders are being ignored, or worse, threatened, then it's highly likely they will see the science as suspect. Stakeholders' alternative views will be fed into the Minister's office with a foghorn's clarity.

When it comes to offering advice on natural resource management, scientists will often offer advice using economic models. But Ministers will often be focused around social and political matters. That's why scientists should integrate the social sciences with the natural sciences to provide information that will affect important decisions.

Policymakers are operating in a political context where there are multiple goals and conflicting values. So scientists have to recognise that, on occasion, politics will override the science. Science is not the new religion – it's all right for a Minister to say: 'Well, I've heard the science, but I've also heard the people'. A politician who thought science stood at the top of the knowledge hierarchy wouldn't be around for long – public policy is always more complex than it seems, with unpredictable outcomes. So scientists shouldn't just assume they know what questions decision-makers will see as relevant. There'll often be some gap between the views of experts and decision-makers when it comes to what information is credible and useful.

That's a good reason why scientists need to work with industry, so policymakers are not blindsided by different assessments. By talking to industry, scientists can understand how their advice fits in with the bigger picture. Industry leaders will head to Ministers the minute they feel threatened, so engaging them along with the government representatives is wise.

I'd also say that scientists should not be afraid to work with citizen science groups and help them understand what the science is all about. After all, politicians do listen to such groups. If you are a trusted scientific voice (and yes, your personal brand matters, so you've got to keep publishing), and if your advice is given in a tone that's not patronising, your ideas will find a much warmer reception among policymakers.

Evidence-informed policy isn't a requirement of any scientific law. It's a value, and it's up to the scientific community to be prepared to fight for it in the policy process and be fearless in their convictions. This means scientists should speak truth to power, but just not tweet about it after the meeting!

In a way, scientists need an inside and an outside persona. With rights come responsibilities, and good scientists can find a way through this, especially when they talk publicly.

My final thought comes from *The Simpsons*[4]. Lisa Simpson's project for the science fair was a genetically-modified tomato. Bart's project was 'Can hamsters fly planes?' Lisa protests Bart's project has no scientific merit, but the cute hamster flying a miniature plane wins over the school's headmaster, who hands Bart the winning ribbon, much to Lisa's dismay. The school principal tells Lisa: 'Every good scientist is half B.F. Skinner and half P.T. Barnum'.

This isn't an argument for going with style over substance, but rather the need for scientists as a collective to inspire interest in others, including policymakers.

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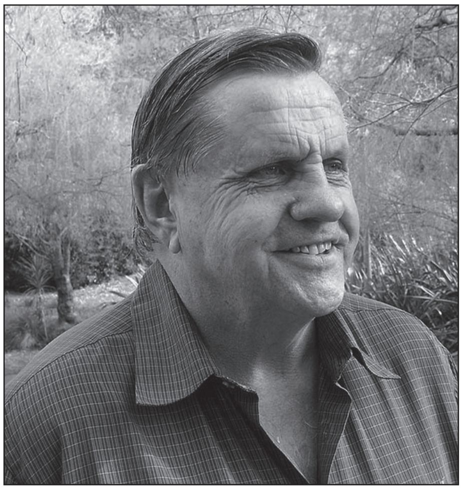
News

Professor Emeritus David Penny honoured by National Academy of Sciences



Professor Emeritus David Penny of Massey University is among 21 distinguished scientists named as foreign associates of the National Academy of Sciences on 1 May this year. This is one of the highest honours in the science world, awarded in recognition of outstanding original research; nearly 500 members of the Academy have won Nobel Prizes. He is just the third living New Zealander to receive the honour, the others being Distinguished Professor Dame Anne Salmond of the University of Auckland, and Emeritus Professor Douglas Coombs of the University of Otago.

Professor Penny has made a lifelong and lasting contribution to the study of molecular evolution. His colleague at the Institute of Fundamental Sciences at Massey University, Professor Peter Lockhart, has said, 'David Penny's work is characterised by great curiosity, intuition and a capacity to cross disciplines. In particular he has repeatedly demonstrated an uncanny ability to recognise innovative solutions to problems and to see proofs that mathematicians would eventually discover.'

A graduate of Canterbury University, where he was inspired by noted philosopher of science Karl Popper, David Penny then completed a PhD at Yale University, followed by postdoctoral research at McMaster University, Ontario. In 1966, he joined the staff at Massey University, working within the Department of Plant Biology, the Institute for Molecular BioSciences and the Institute of Fundamental Sciences. From 2002 to 2010 he was co-leader, with Professor Mike Hendy, of the Allan Wilson Centre, hosted at Massey University, which was one of the original New Zealand Centres of Research Excellence. With Professor Hendy, he developed DNA analysis methods to test the theory of evolution, as well as testing numerous other hypotheses to help resolve major controversies of our time, including the human settlement of New Zealand. An indication of the breadth of Professor Penny's research interests is given in a tribute issue for his 70^{th} birthday of the *New Zealand Science Review* (2009, vol. 66, no. 1), in which collaborators from various research institutions in New Zealand and overseas outline some of his major contributions to their specific fields. In 2005, after 40 years at Massey University, he was named a Distinguished Professor, a title given to only those who have achieved outstanding international eminence in their fields.

The commemorative issue of *New Zealand Science Review* mentioned above also shows that Professor Penny has been very active in science policy, largely through the New Zealand Association of Scientists, in which he was a Council Member for many years and President from 1989 to 1991. He published major contributions about the economic value of R&D and the vital need for research in *New Zealand Science Review* and elsewhere. He was awarded the Association's Marsden Medal in 2000 in recognition of his outstanding service to science and the profession of science, and was made an honorary life member of the Association in 2013.

He is a Fellow of the Royal Society of New Zealand and, in 2004, was awarded the Rutherford Medal in recognition of his distinguished contributions in theoretical biology, molecular evolution, and the analysis of DNA information.
In 2006, he was made a Companion of the New Zealand Order of Merit for services to science.

David Penny retired in 2017 and was made a Professor Emeritus, but colleagues say he retired in name only. Last year he released another book, *Evolution Now*, in which he gave a view of modern evolutionary theory from a Popperian perspective. The book dissects the chronology of evolutionary study starting from the 1600s through to Darwinism.

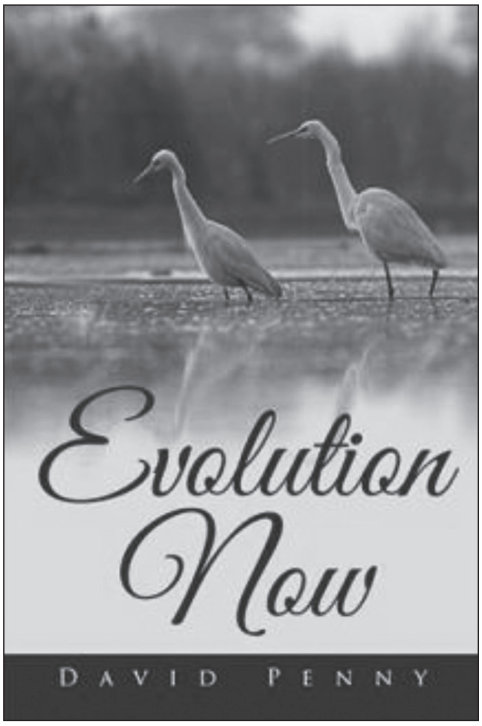
(Adapted from a Massey University press release)

Book review

David Penny

Evolution Now

Reviewed by Mike Berridge*



There is no mistaking the engaging and unconventional conversational writing style used by David Penny in his book *Evolution Now* that traces the development of current evolutionary theories, and provokes thought on unresolved questions. Through undergraduate studies at the University of Canterbury where he was exposed to the teachings of Karl Popper, Penny embraces the Popperian school of science philosophy, in which the words 'believe' and 'prove' are anathema to the scientific method and progress occurs through falsification involving exhaustive testing of hypotheses. Too often today, scientists seek to prove their ideas right rather than testing strong hypotheses, and multiple weak hypotheses are frequently formulated around highly specific objectives, sometimes bordering on anti-science. To a large extent, this is due to our failure to understand the basis of scientific methodology, fuelled by a science funding system where preliminary results, often near publication, are rewarded, and novel game-changing hypotheses are relegated to the bottom of the pile. This is perhaps a lesser problem with Mardsen funding, and with Health Research Council Explorer grants where qualifying transformative applications are subjected to a lottery process.

I first met David Penny in the late 1960s in another life, when as a graduate student working on plant growth hormones under Dick Matthews and Ray Ralph at Auckland University's DSIR Mt Albert campus; I was searching for research opportunities. With a newly minted PhD from Yale, Penny was gaining an international reputation for asking critical questions about stem elongation in plant seedlings at Massey University and my work on another group of plant hormones was a good fit. Although our research interests diverged, mine into developmental biology and David's into the use of phylogenetic trees to investigate evolution, we shared common interests, through the New Zealand Association of Scientists, on several projects including several surveys of scientists perceptions of science, genetic modification, and more recently genes involved in early eukaryotic evolution and the derivation of mitochondria .

So it was a pleasure to again be provoked by David's thoughts on paper, his knowledge and critical thinking about evolution, and his confronting aspects of current evolutionary theory. It was great to be reminded of the cultural context and geological training that moved Darwin to tentatively formulate a testable theory of evolution that has largely stood the test of time, and to see that Darwin painstakingly consolidated his model with further observation and data. The fact that Alfred Russel Wallace independently came to similar conclusions about the mechanism of evolution by natural selection is mentioned briefly. Darwin's awareness of Wallace's specimen collections and notes appear to have been a motivating force behind his publication, but Darwin's status, financial security and links to the Royal Society were also contributing factors. The explanatory detail and mechanistic underpinning of Darwin's theory of evolution by natural selection is then explored in some detail. The following chapter on human evolution is well-presented, and given recent developments, could perhaps already do with an update.

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Length: 229 pages

RRP: Paperback $30.20, Hardcover $47.46, EBook $4.99
Published by XLibrisNZ

*Mike Berridge is Cancer Cell Biology Group Leader at the Malaghan Institute of Medical Research,   Wellington.

Challenging current populist dogma about the role of an extraterrestrial impact on dinosaur extinction, and questioning the cellular events that gave rise to complex organisms, a moving target that may continue to challenge scientists for decades to come, leads on to the final chapters about what we don't know about evolution, and speculation on what we don't know we don't know.

Some areas of evolution such as brain complexity are superficially covered, and the new and extremely challenging areas of epigenetics, non-coding RNAs, DNA (both nuclear and mitochondrial) that does not encode proteins, and inheritance of acquired traits are briefly mentioned, but are perhaps the stuff of future writing projects.

In summary, this book is as much about the processes of science and about scientific culture surrounding evolution over many centuries as it is about the mechanism of evolution itself, and will provoke discussion and frame further thought on this evolving subject, and the consequences of human intervention in natural evolutionary processes.

News

The Prime Minister's new chief science advisor

Professor Juliet Gerrard FRSNZ, the Associate Dean (Research) at the School of Biological Sciences and School of Chemical Sciences, Auckland University, has been named as the Prime Minister's new chief science advisor. She replaces Sir Peter Gluckman, the first government-appointed chief advisor, who served in the role for almost a decade.

Professor Gerrard trained at Oxford University, before moving to New Zealand 21 years ago to work as a scientist at Crop and Food Research. She then worked at Canterbury University in the late 1990s as a lecturer and a director before moving north to Auckland University in 2014.

Professor Gerrard said she was absolutely thrilled about her new role. She wanted to put particular emphasis on using social media to make science more accessible: 'Working alongside all of the quite dry, academic reports to do another release to the public to explain not just the conclusion, but also the essence of the debate that got us there,' she said.

Professor Gerrard's work spans biochemistry, biomaterials design, and health science. Her current research focuses on how the structure and assembly of a protein influences its function, an area which has potential applications in the development of new drugs, materials and foods.

As well as being the second chief science advisor, she is the first woman to be appointed to this position. 'The times are changing ... I hope my appointment will go some way towards encouraging ambition in young female scientists', she said. 'For a long time women were quietly advised to choose between a science career and children, and that's no longer true.'

Prime Minister Jacinda Ardern said, 'Professor Gerrard has had a distinguished career, specialising in a range of disciplines. She was also the past Chair, Royal Society Te Apārangi Marsden Council, giving her wide exposure to all science disciplines. Her new role not only provides me, as Prime Minister, with high-quality scientific advice to support good robust decisionmaking, but plays a vital role in promoting science and technology, explaining its contribution to society and the economy, and promoting the sector to young people as a career opportunity.'

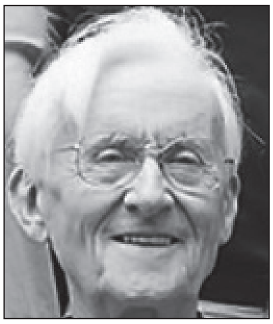
'Given the low number of women in science, and the need to encourage the next generation to enter into this field of study, it is especially pleasing to be able to appoint our first woman as the Prime Minister's chief science advisor,' Jacinda Ardern said.

Ms Ardern also acknowledged and thanked Sir Peter for his commitment and ongoing contribution to New Zealand science matters in this role over the past decade.

On 28 July, Professor Gerrard talked to RNZ's *Nine to Noon* presenter Kathryn Ryan, about her approach to the role: https://www.radionz.co.nz/national/programmes/ninetonoon/audio/2018651757/pm-s-new-science-advisor

Tribute

Vincent Richard Gray (1922–2018)



Vincent Richard Gray, a member of the New Zealand Association of Scientists until his death, and a Council member from 1998 to 2010, passed away on 19 June at the age of 96 years. His wife of 69 years, Mary, passed away 15 days later, aged 94 years.

Vince was born in South London in 1922. He showed considerable academic ability as a boy and won a scholarship to study chemistry, physics and mathematics at Cambridge University, graduating in 1942 with a first-class honours degree in chemistry. Later he completed a PhD in chemistry, also from Cambridge, and enjoyed a short career as a research chemist in the Colloid Science department, where he assisted with the war effort on explosives production. Early in the war, he joined the communist party in support of the Russian initiative against Nazi Germany, a principled move that dogged future employment prospects. In 1970, Vince and family emigrated to New Zealand where he became the first director of the Building Research Association of New Zealand (BRANZ). Later he worked as a chemist for the NZ Coal Research Association in Wellington until his retirement, after which he spent five years in China pursuing coal research.

Vince was well known among scientific circles in New Zealand and internationally as a climate change sceptic – for his opposition to the notion that anthropogenic carbon emissions lead to global warming. Vince believed that much, if not all, of the science that underpins the idea of human contribution to global warming, was flawed, often describing the underlying science as 'fraudulent'. He contended that there is no association between carbon dioxide emissions and global temperature changes, and worked tirelessly in opposition to the growing influence of the International Panel on Climate Change (IPCC) and its regular reports, to expose what he considered to be a bandwagon based on flawed science. For the 4th Assessment Report of the IPCC published in 2007, Vince held the record for the most review comments submitted by any individual world-wide. Challenging the many assumptions made by the IPCC, the quality of data collected, and the accuracy of modelling used to predict human and agricultural contributions to global warming, was central to his strategy on climate change science, and these approaches were underpinned by Popperian science philosophy. Ironically, Vince became quite evangelical about his own cause and may not always have applied the same level of critical scrutiny to his own beliefs. From eulogies presented by his four children and four grandchildren at a celebration-of-life gathering at St Andrews-on-the-Terrace, known for its secular community support, it became quite clear that it was impossible to win an argument with Vince because of his sharp memory, his ability to assemble 'facts' in support of his views on virtually any issue, and his fearsome approach to debating.

His opposition to anthropogenic climate change was legendary. He circulated some 350 NZ Climate Change Newsletters, the vast majority of them written and emailed between 2004 and the time of a debilitating stroke in 2015. One of the reasons why Vince joined the New Zealand Association of Scientists was to use the Association as a vehicle to promote his views. Eventually, Vince resigned from Council of the New Zealand Association of Scientists when he found that his position on climate change was not supported by the Association. His parting shot was a motion of no confidence in the President, ,James Renwick, climate scientist and IPCC author, at the AGM in 2009.

Looking more broadly at his life, Vince was a larger than life character with energy to burn and a job to be done. Both Vincent and Mary were music lovers and they brought some 40 musical instruments with them when they shifted to New Zealand. In Wellington, Vincent played in the Valley Stompers Jazz Band for more than 15 years, and the band farewelled him at St Andrews-on-the-Terrace, along with musical presentations by family members. The large gathering was entertained, not only with music, but also with eloquent and sometimes emotional eulogies from his children and grandchildren, each detailing their personal interface with Vince and recognising distinctive aspects of their characters that they owed to him.

Though members of the New Zealand Association of Scientists often made their disagreement with Vince's position on climate change apparent, Vince was well-liked and even admired for his forthright and outspoken views. He was a lightning rod for action on issues that he chose to pursue that were close to his heart, and was in his own way a sociable and loyal friend, with a network that spanned the globe. He will be remembered by family, friends and colleagues, and by the New Zealand Association of Scientists as a principled and passionate person who was prepared to back his own views to the end in order to change the world.

Mike Berridge
David Lillis
James Renwick
NZAS Past-Presidents who held the reins during parts of Vincent Gray's Council membership.

*Vince's Life Story can be found at https://www.stuff.co.nz/life-style/105746754/Mary-and-Vincent-Gray-couple-die-15-days-apart

New Zealand Association of Scientists

<u>EARLY NOTICE</u>

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University of Auckland, 15 November 2018

The Association's Annual Conference will be held at the University of Auckland in conjunction with the NZAS Awards and the Annual General Meeting.

Further advice will be forthcoming on
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