

Bringing Science to Life: Promoting Scientific Thinking in Primary School

A research report prepared for the
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Contents

Executive Summary	Page 3
Acknowledgements	Page 4
Background	
National Science achievement in New Zealand	Page 5
The Long Bay Primary Context	Page 6
An outline of the Travelling Fellowship Study	Page 7
Section One: Primary School Science	
The purpose of science education	Page 8
New Zealand Curriculum science requirements	Page 8
Instructional time for teaching science	
The components of a future focused science curriculum	Page 10
Developing citizenship capabilities in science	
Section Two: Approaches to promote learning in science	
Effective Pedagogy	Page 13
Tapping into what is known about child development and learning	Page 14
Creative Exploration	
Imaginative Education	
The Big Ideas and Principles in Education	Page 16
Inquiry Learning	Page 18
Content Representation (CoRe) design to develop a science implementation plan	
The Social Construction of Knowledge	
Citizen Science	Page 20
Section Three: Implementing a culturally inclusive pedagogy	
Barriers to Accommodating Indigenous Science Concepts within Science Education	Page 22
Developing a culturally responsive science curriculum	Page 22
The New Zealand Experience	Page 24
Incorporating Kaupapa Māori Pedagogy in New Zealand primary science education	Page 25
– what does it mean to teach Māori students as Māori?	
Section Four: Support for schools to deliver science programmes	
New Zealand Professional Learning Opportunities and Resourcing for Science	Page 27
Canadian Professional Learning Opportunities and Resourcing for Science	Page 29
E-Learning: Tools to enrich student understanding of science concepts	Page 31
Recommendations	Page 33
Summary	Page 36
References	Page 38
Appendices	
Appendix 1: A comparison of the NZ and Canadian Schooling Grade Systems	Page 42
Appendix 2: An outline of the Science Capabilities and the Nature of Science Strands	Page 43
Appendix 3: Science Capabilities, discussion prompts, learning intentions and concepts	Page 44
Appendix 4: The dimensions of Discipline Based Inquiry	Page 46
Appendix 5: Summary of the Effective Teaching Profile, based on the Te Kotahitanga Māori research development project	Page 47

Executive Summary

The importance of fostering scientific thinking and innovation is recognised by countries within the OECD (Organisation for Economic Co-operation and Development), as a critical component in addressing the future needs of society. The demands of the 21st century requires a new approach to science education to fully prepare students for college, career, and citizenship.

In New Zealand, documents such as Sir Peter Gluckman's report, *Looking ahead: Science education for the twenty-first century* (2011), noted the importance of science in finding solutions to the challenges faced by society, and the benefits, socially and economically, of having citizens that are scientifically literate. It was identified that many New Zealand teachers did not feel confident in delivering science, and the level of student achievement and engagement in science was varied. Concern regarding educational and societal engagement in STEM topics (science, technology, engineering and maths) is echoed in reports and research overseas and a number of countries have developed their science education delivery in response to this.

A number of initiatives were launched in New Zealand; science was included in the Ministry of Education funded PLD in 2012 and the strategic plan, *A Nation of Curious Minds*, was launched in 2014 to encourage and enable better engagement with science and technology across all sectors of society.

The purpose of this study was to draw upon research and educator expertise in New Zealand and Canada to learn more about what an effective, future-focused primary school science programme looks like and how schools can be best supported to make the implementation of such a programme a reality. A range of approaches to promote learning in science were explored, including ways to link more closely with how children naturally learn and considering how we can make stronger connections in science education with Maori culture.

What was found was that the New Zealand Curriculum is aligned with future focused education, we recognise the purpose of science for citizenship, the science capabilities provide a guide for developing scientific dispositions and there are commonalities between New Zealand and Canadian curriculum educational objectives for science. The Fellowship study also revealed that we could draw ideas from the Canadian experience for lifting the profile of science in society and building coherence among those involved in science education to support student learning. Building leadership and teacher capacity continues to be a crucial component of science education development for school leaders, the Ministry of Education and the wider science community.

The intention of this report is to share with principal colleagues and educational leaders what I learnt during the Fellowship study in order to inspire reflection and rich conversation about the future development of science education in New Zealand primary schools.

Together we need to foster engagement in science, innovative thinking, and the science-for-citizenship objectives that Gluckman noted as crucial for NZ's future development.

Acknowledgements

First and foremost, I wish to acknowledge the ASB for sponsoring the Travelling Fellowship programme and the Ministry of Education for valuing this professional opportunity and providing salary funding. Thank you to the Auckland Primary Principals Association and the Fellows' Board of Trustees for making this exceptional opportunity possible, and for their professional encouragement along the way.

The children of New Zealand continue to inspire me to learn how we can collectively provide for them the best educational opportunities. The ASB / APPA Travelling Fellowship provides principals' with the opportunity to reflect upon New Zealand's education system and learn from educators across the world. I do regard my selection as a Travelling Fellow as an honour and I recognise the professional growth I have gained from the Fellowship and the positive gains for my school.

I wish to acknowledge the Long Bay Primary Board of Trustees in supporting my application and subsequent leave, the wonderful Long Bay Primary Senior Leadership team for stepping so ably into roles of higher responsibility and the collegial support I received from the full school staff and fellow educators.

It has been a pleasure to speak with and visit school leaders and science educators in New Zealand, Canada and America. I wish to express my gratitude for the generosity shown by educators in New Zealand and those I met in my travels through Canada and America - thank you for welcoming me into your places of work and sharing your ideas and enthusiasm with me.

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Finally I wish to thank Alan Jermaine, secretary of the ASB-APPA Trust for his guidance, and my husband Bruce for his companionship and continual support throughout my career and during the Fellowship journey.

Background

National Science achievement in New Zealand

Along with other countries within the OECD, in recent years there has been increased government acknowledgement of the importance of science for our country's economic and social future. In 2009 Professor Sir Peter Gluckman was appointed as the first Chief Science advisor to the Prime Minister of New Zealand. In 2011 the Ministry of Science and Innovation was formed (later incorporated into the Ministry of Business, Innovation and Employment) and Professor Gluckman presented a report entitled *Looking Ahead: Science Education for the 21st Century*.

Gluckman noted that, "There is no doubt that the role of science in modern society is changing. It is very different to that of a generation ago. Increasingly the challenges we face as a community - be it at the global level such as dealing with climate change, or at the local level such as the problems of an ageing population, of environmental degradation, or of enhancing our economic productivity through science and innovation – all depend on science" (p. 3).

The 2011, Gluckman report reinforced the fundamental need for New Zealand to have a forward looking science education system that would grow future scientists and scientifically literate citizens – and raised some challenging questions:

- How can we engage and enthuse more young New Zealanders in science?
- Is the science we teach preparing students to address important questions we will all face in the future?
- How might science education assist New Zealand's development as a smart, innovative, knowledge-orientated country?

The case was made for science literacy to be a key focus for science education.

Following on from Gluckman's report, the New Zealand Council for Educational Research commissioned Gilbert and Bull (2013) to conduct a study, *Building a Future Orientated Science Education System in NZ: How are we doing?* The authors noted that achieving a future focused science curriculum was still a long way off and emphasised the need to develop our science education was now urgent. They cited three big societal changes we need to accommodate:

1. **The digital revolution** – and the exponential growth of digital technologies and their impact on employment and economic development.
2. **The Knowledge Age** – the definition of knowledge is changing – it is now a verb not a noun. Rather than being something we have it, is something we do and is developed within networks - the network *enables* connected groups to take ideas further and faster than any individual could. The knowledge they create is *in* the collaborative space, not in individual heads.
3. **The need for innovation:** to be able to connect, create new knowledge and to innovate (pp. 11-12).

Other available research supported their recommendation to focus upon developing NZ science education. Data from both the National Education Monitoring Project (NEMP) and the National Monitoring Study of Student Achievement (NMSSA) showed that interest in science declined as students moved through school. The 2012 Education Review Office (ERO) report *Science in the New Zealand Curriculum—Years 5–8* found effective science teaching practice in less than a third of a hundred schools reviewed in 2011, and wide variation in practice. ERO found that knowledge/content based programmes were more evident than approaches focusing on thinking, talking and experimenting and there were limitations in teacher knowledge and little professional development in science for teachers. It concluded that science appears to be a low priority in Years 5–8. The NZCER 2012/13 Science in the Curriculum Projects (focused upon e-learning in science, school–science community engagement and science curriculum support for teachers) also indicated the need for further development. In 2014 the *Nation of Curious Minds* strategic plan was developed by the Ministry of Business, Innovation and Employment and the Ministry of Education, the plan identified key actions to develop science in education, business and society over the following 10 years.

The latest Programme for International Student Assessment (PISA) was conducted in 2015 and the New Zealand summary published in December 2016. The PISA report is a 3 yearly, international study that compares the test results for randomly selected 15-year-old students in 72 countries across the world. The data is utilised to evaluate how well countries are preparing students to meet real life opportunities and challenges.

In the 2015 PISA report on scientific literacy, New Zealand sits in 12th place for average scores in the science assessment (Singapore, Japan, Estonia, 4 states of China, Finland, Canada (7th), Vietnam and Korea have higher average scores). New Zealand's relative standing compared to other countries has improved since 2012 and remains

above the OECD average. Our average scores however are not as high as they were in 2009.

The 2015 key findings show that our best students continue to do well. Maori and Pasifika students feature at all proficiency levels but have a higher proportion in the lower proficiency level than NZ students overall. The results indicate that there is a wider gap between the top 10 percent (level 5: capable of advanced scientific thinking) and bottom 10 percent of our students (below level 2) than most other OECD countries.

The 2014/15 TIMSS New Zealand report shows an improvement in the Year 5 student science achievement, but no significant change for Year 9 students. Of the 47 countries compared at the Year 5 level, New Zealand ranked higher than 14, lower than 30. As with the PISA result, the range of achievement for NZ students was wider than many other countries. 6% of Year 5 students were advanced, 12% were below low. For TIMSS questions that aligned strongly with NZ Curriculum expectations, the average Year 5 student answered just under half of them correctly. Year 5 boys and girls had similar scores, Maori had a lower average score than non-Maori. When socio-economic factors were the prime focus taken into account, the gaps in achievement scores between Maori and non-Maori narrowed.

The 2014/15 TIMSS study also showed that New Zealand Year 5 teachers had less confidence teaching science and fewer participated in science related PLD than teachers in many other countries. Interestingly the report also showed that more than 90% of the Year 5 students liked learning science and three quarters felt confident with this subject.

We also need to foster engagement in science. The 2012 PISA study found that NZ has students equipped for scientific careers and offered more career opportunities than most other Organisation for Economic Co-operation and Development (OECD) countries. However, only 39 percent of top performers in science said they would like to spend their life doing advanced science— this figure is below the OECD average.

The Long Bay Primary Context

New Zealand school leaders have a responsibility to shape their learning program within the guidelines of the New Zealand Curriculum. As part of every school's ongoing self-review, we reflect upon our practice, the engagement and achievement of our students and the skill of our staff, and select focus areas to enhance our curriculum delivery. The aim is that through careful design, the level of delivery builds upon prior school and professional development focuses and is sustained and enhanced. Within my school, through assessment for learning practice, we have taken the time to build a common language of learning as a foundation that supports transition and enables and encourages student voice and active involvement in their learning. We have also developed collaborative practice through teaching and curriculum teams and encouraged initiatives. We have continued to value the arts and physical education, to build our te reo programme, develop our environmental studies, strengthen e-learning and explore inquiry learning through integrated study. Decisions around curriculum focuses are influenced by the schools own context and by political and ministerial requirements. In recent years the emphasis on National Standards has focused our attention on English and Mathematics.

Whilst focusing upon student achievement in the National Standard areas of reading, writing and mathematics, we must also take care to foster understanding and engagement in all areas of the curriculum. We also need to remind ourselves about the wider purposes of education, think innovatively about how our curriculum is delivered and how we can enrich student engagement in the three R's whilst developing richer learning opportunities that are relevant for New Zealand children.

By their nature, schools are places of reflection and change. In reaching another milestone checkpoint in our school curriculum development, we reflected on the bigger picture in the NZ educational landscape as well as our own school journey. We decided that our next step was to consider delivery of the STEM subjects (Science, Technology, Engineering and Mathematics). Hence my own school, and personal, journey to explore best practice in primary school science education – and to utilise this information to develop our own curriculum delivery and make connections with the wider educational community.

The Fellowship Study

I am immensely grateful for the opportunity afforded by the APPA/ASB Travelling Fellowship. The Travelling Fellowship is designed to provide the resources for New Zealand Principals to research locally and to travel overseas and explore education systems in other parts of the world. Through having the time to broaden our professional knowledge we are able to reflect with a deeper perspective on our own educational landscape.

I was awarded a full school term's leave and upon careful consideration selected Canada as a destination for my Fellowship journey. Canada is achieving better results in international studies of science achievement and there are connections between aspects of the Canadian culture and that of New Zealand; Canada is becoming an increasingly multicultural nation and is recognising the value of the indigenous peoples' culture, plus I was aware of initiatives to explore authentic learning and to establish a stronger profile for science with the wider community.

In terms of land size, Canada is over 37 times the size of New Zealand, and each of the ten Canadian provinces has its own curriculum documents. Within this report I include references to science education, research and educationalists in the Canadian provinces of British Columbia, Alberta, Saskatchewan, Ontario and Quebec. I also attended a STEM conference in Denver, Colorado, to gain further understanding about the promotion of STEM subjects in America. Within New Zealand, I discussed science programmes with educators, attended the Sir Paul Callaghan Academy four day professional development course, attended workshops (including MoE professional learning through Te Toi Tupu) and explored a range of New Zealand online resources.

The report is organised in the following sections, with appendices that provide additional background information:

Section one focuses upon clarifying the purpose of science education and the components of a future focused science programme to meet that purpose.

Section two shares different approaches to promote scientific learning.

Section three considers ways to implement a more culturally inclusive pedagogy.

Section four explores how teachers are supported to deliver the science curriculum – through professional development models, developing science leadership, utilising experts in the field, resources and networks.

The final section of the report highlights recommendations for improving science instruction.

See Appendix 1 for a comparison of the NZ and Canadian Schooling Grade Systems.

Section One: Primary School Science

The Purpose of Science Education

Canadian curriculums recognise the societal need for science education. A goal in the British Columbia Science K to 7 Curriculum is for, “students to have the opportunity to develop attitudes that support the responsible acquisition and application of scientific and technological knowledge to the mutual benefit of self, society, and the environment” (p. 11). Within the New Zealand Curriculum the purpose of science education is outlined as; “In science, students explore how both the natural physical world and science itself work so that they can participate as critical, informed and responsible citizens in a society in which science plays a significant role” (NZC, p. 17). This is an ambitious goal, and what this means in practice is further expanded on the Te Kete Ipurangi (TKI) online site. The focus is on developing citizenship capabilities, citizens who are “ready, willing and able to use their science knowledge” (TKI).

An important point here is how we think about the purpose of our education system – are we preparing students for the future (are our students ‘citizens in waiting?’), or is it also for the present time?

In an audio recording promoting the book, *Key Competencies for the Future*, (2014), co-author Sally Boyd notes that if you look at the sort of things that young people can do in the school setting, they are actually citizens now. They are people who can take action to improve their world and make their school a better place. It is important that we think about our students as active citizens now, rather than that they are being prepared for some future date. The school experience is there to enable them to build and to show these capabilities.

Dr Hans Smits (2014) from the University of Calgary, Alberta, reflects on the observation that talk about the wider aims of education has diminished and been reduced to measurable outcomes. Smits reinforces the message about teaching capabilities for the present and for changes in the future. He quotes a range of researchers who indicate that a great school is built around offering children participation in communities and nurturing capabilities, such as; critical thinking, the ability to understand other situations, a grasp of world history and the current global economic order. “To be a great school requires opportunities for all children to begin, through the arts, humanities and the many ways that subjects like science and mathematics contribute to making sense of and imagining the world, to see themselves as citizens of the world” (Smit, 2014).

Dr Hans Smits (2014) cautions against an overemphasis on testing and notes that education has a deeper responsibility for creating possibilities for children to live well in a changing world. In his paper *Competencies or Capabilities*, he notes identified trends that will challenge how we will have to think about education in the future e.g. focusing on issues such as exploitation of natural resources, environmental changes, globalisation, the impact of new technologies, qualities of citizenship and the nature of personal identity. He questions whether we currently overemphasise that learning is primarily located in the individual. Smit reminds us that our role is bigger than developing individuals that will contribute to the future economy. Central to the question of what makes a great school is not just what people can learn to do (competencies), but equally what they can learn to be (capabilities).

New Zealand Curriculum Science Requirements

In contrast to the curriculum of other countries, the NZ Curriculum is a framework document rather than a directed plan. The intention of this design is to allow schools to shape their curriculum relevant to their learning community. The power to be innovative and respond to the specific interests of students is one of the strengths of the New Zealand system. Indeed, the PISA 2009 survey notes that, “In countries where schools have greater autonomy over what is taught and how students are assessed, students tend to perform better” (p. 15).

The New Zealand Curriculum document (pp. 28-29) clearly states that the Nature of Science is the core, overarching strand, and is required learning for all students from New Entrant up until Year 10.

The Science Learning Hub online site provides the following response to the question, what is the Nature of Science? “Science consists of three domains: a body of knowledge, a wide range of methods or processes to develop this knowledge, and a way of thinking. The nature of science constitutes the third domain and is the most abstract and least familiar of the three. The nature of science as a way of thinking refers to thinking with a particular lens – just as the nature of history would be thinking through a historical lens. This particular way of thinking is underpinned by certain values and characteristics (such as in science, creativity, curiosity, attempts to reduce bias and empiricism). “

Through the Nature of Science, students learn what science is and how scientists work (how to think and behave like a scientist). Students develop “the skills, attitudes, and values to build a foundation for understanding the world. They

come to appreciate that while scientific knowledge is durable, it is also constantly re-evaluated in the light of new evidence. They learn how scientists carry out investigations, and they come to see science as a socially valuable knowledge system. They learn how science ideas are communicated and to make links between scientific knowledge and everyday decisions and actions” (TKI). The Nature of Science achievement aims are: Understanding about Science, Investigating in Science, Communicating in Science and Participating and Contributing.

The other strands (The Living World, Planet Earth and Beyond, The Physical World and The Material World) provide contexts for learning, and must be covered over the course of Years 1 to 10.

It is important to recognise that the New Zealand Curriculum is not a stand-alone document. In response to the TIMMS (2010/11) and ERO (2012) findings, collaboration with the Ministry of Education (MoE) and the New Zealand Council of Educational Research (NZCER) resulted in a new suite of online science resources. The five science capabilities which support the Nature of Science strand were published on the Te Kete Ipurangi (TKI) Science Online site in 2013.

My conversation with New Zealand teachers has revealed that there are misunderstandings about expected coverage; many saw context strands as the central focus rather than the Nature of Science and shared uncertainty about how to effectively teach the capabilities. In their study, Cleary and Bennetts (2016) also noted teacher confusion, “Many teachers have been either unaware that the Nature of Science (NoS) is the core strand ... or have found it challenging to develop programmes with the NoS as the overarching framework” (p. 27).

These misconceptions indicate the need for professional learning and development of science teaching.

*See Appendix 2 for an outline of the Science Capabilities and the Nature of Science Strands they relate to.
See Appendix 3 for learning intentions related to the Science Capabilities
(based upon resource handouts from the Sir Paul Callaghan Science Academy).*

Instructional time for teaching science within primary school

Given that the importance of instruction in the STEM subjects has been recognised, it is interesting to compare the New Zealand instructional time requirement in this area with Canadian states. Looking at science in particular, the Saskatchewan Core Curriculum document states that the provincial requirement for teaching science is 150 minutes of instruction per week at Grades 1 through to 8. The British Columbia Science Curriculum for Grade 1 to 7 students recommends 25-30 hours a year for instruction in each of the Life, Physical and Space Sciences, plus integration of the Applications of Science in other curriculum subjects.

New Zealand science instruction time is less defined. The 2006/7 TIMMS study report on the Education Counts website showed that on average, New Zealand Year 5 students spent only 5 percent of class instructional time on science, which was 3 percentage points less than the international average of 8 percent. Over a year, the average amount of time Year 5 students spent on science was 45 hours in 2006/07.

The 2010/11 TIMMS study did not give specifics for instruction time, but did indicate that 41% of time was spent on life science, 28% on physical science and 28% on earth science, with the remaining 3% spent on other general topics. The 2014/15 study reported that Year 5 students spent far less time studying science than the international average, however there was an increase in the emphasis on science experiments or investigations compared to the 2010/11 report.

The Components of a Future Focused Science Curriculum

Traditionally school science education focused upon teaching science concepts and facts to build student understanding. However, as noted by Bolstad and Buntting (2013), in *Digital Technologies and Future-Orientated Science Education: A discussion document for schools*, “in a world where the content, volume and accessibility of knowledge, including science knowledge, increase vastly on a daily basis, an educational emphasis on acquiring existing science knowledge no longer seems sufficient. Rather, there is growing recognition of the need for students to develop skills such as adaptability, complex communication/social skills; non-routine problem-solving skills; self-management/self-development; and systems thinking. Expert knowledge is still needed. But it will not, own its own, be enough” (p. 4).

Bolstad and Buntting (2013), developed the diagram to the right to show how science practice has changed over the last 100 years (based on Gilbert’s 2012 article, Science 2.0 and school science). In the 21st century scientists are more likely to collaborate with others, in the field and across disciplines. They need to be able to think and communicate clearly; to contribute effectively and meaningfully by listening to others in an open minded manner, articulating their ideas, seeking clarification and utilising scientific literacy skills.

To build their science and citizenship capability, these are also the skills we need to support our students to develop. They need to learn how to think like a scientist.

I draw upon the research and expertise of Ally Bull, Chris Joyce and Rosemary Hipkins, who have provided an outline of the key features of a future focused science curriculum in their book, *Constructing your primary school’s science curriculum. Confident, Connected, Lifelong learners: What’s science got to do with it?* (2014). I do encourage school leaders to read this book.

A future-orientated science curriculum, as described by Bull et al. (2014, p. 5 and Chapter 3) should:

- **engage students intellectually and emotionally** – nurture student curiosity and positive attitudes towards science, build a ‘library of experiences’ for students, generate interest, utilise a science table and encourage exploration.

- **foster the development of science capabilities**

Bull et al (2014) remind us that, “the call to develop the capabilities does not mean that knowledge is no longer important. Remember that the capabilities combine knowledge with skills, values and attitudes. Research in cognitive science shows that skills and knowledge are bound together: you need something to think with, and knowing things makes it easier to learn new things” (p. 11).

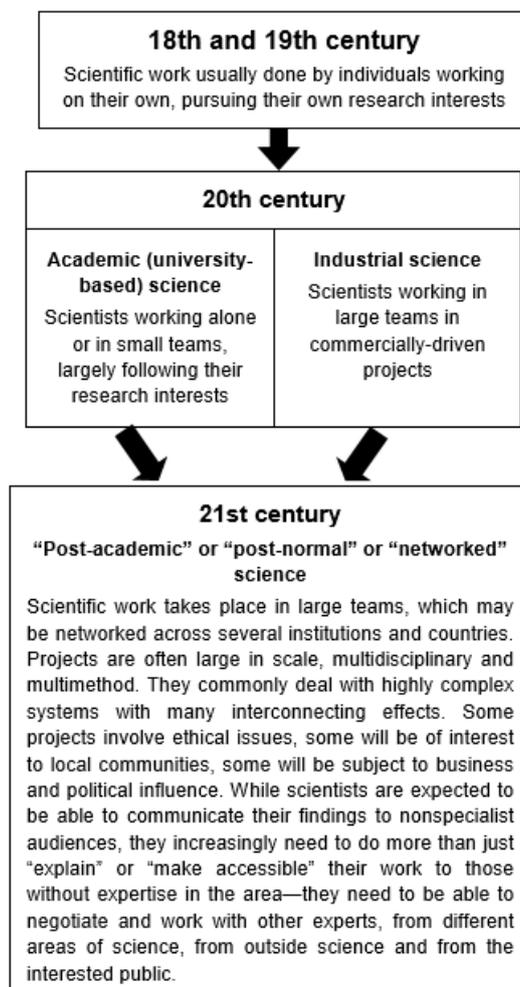
In this context, knowledge is defined as understanding and key ideas that help students make meaning of their world, as opposed to a collection of facts.

- **build understanding of powerful science ideas and ideas about science itself** – activities should aim to contribute to deepening student understanding of scientific ideas, plus fostering positive attitudes and capabilities (p. 11).

- **provide opportunities for creativity and knowledge building** – students working “collaboratively to improve ideas that are of use to them as a community” (p. 12).

- **carefully balance depth and breadth** – expose students “to a range of experiences but also provide the opportunity to study some things in depth” (p. 13).

- **provide opportunities for students to engage with complexity and uncertainty in real world issues** – opportunity for students to practice taking action.



What does it mean to develop citizenship capabilities in science?

The science capabilities are designed to assist development of the thinking styles, questioning and actions needed to become informed citizens. Through attending the Sir Paul Callaghan four-day Academy I learnt that if you see science education in this manner, as a vehicle for developing a person rather than solely passing on knowledge, that focuses you differently.

On the TKI Science Online site, being able to use science citizenship capabilities is described as being ready, willing and able to use science knowledge. "Engaging with science is a bit like being a book or theatre critic. To do this well, learners need a functional knowledge of science in order to be able to: say what science is, say what its strengths and weaknesses are and ask informed questions about science issues. Building knowledge of science content and the processes of science is important, and so is building knowledge of the nature of science."

Within the book *Key Competencies for the Future*, Hipkins, Bolstad, Boyd and McDowall (2014), provide the example of a futures-thinking process based around a 'wicked problem.' A wicked problem can be described as a worthy problem that may affect our collective futures. They are often value laden and difficult to solve because of complexity, incomplete, contradictory and changing requirements, e.g. loss of biodiversity, persistent poverty and educational underachievement.

An example given by Hipkins et al., (2014) was related to climate change. Within the book they show how scientific literacy skills can be utilised to critique information given. Strategies that have been used to misinform are outlined, such as: conspiracy theories, quoting fake experts, having impossible expectations of scientific certainty, misrepresentations and fallacies and cherry picking evidence to support a point of view. This book is a useful read because it provides an example of how a scientifically literate adult might apply the capabilities when critiquing the evidence given. Equipping our students with an understanding of the capabilities, and providing lots of encouragement and practice to build their skills in a range of contexts, will enable them to build their confidence in engaging with science-related issues.

Section One Key Points:

The purpose for teaching science is to enable students to participate as critical, informed and responsible citizens in a society in which science plays a significant role (NZC p. 17), citizens who are “ready, willing and able to use their science knowledge” (TKI).

It is important to think about our students as active citizens now. We need to plan for our students to participate within the learning community in authentic contexts and provide opportunity to demonstrate their capabilities as they develop.

We must teach the Nature of Science as the core strand. This is required learning for all students from New Entrant up till Year 10.

The other strands, The Living World, Planet Earth and Beyond, The Physical World and The Material World, provide contexts for learning, and must be covered over the course of Years 1-10 (NZC pp. 28-29).

The five Science Capabilities enable links between the purpose of teaching science, the four science content strands, the Nature of Science strand and the key competencies. The science capabilities are:

- Gather and interpret data
- Use Evidence
- Critique evidence
- Interpret representations
- Engage with science

As educators we need to consider the amount of quality instruction time that is spent focusing on developing primary student science understandings. International comparison indicates that NZ educators dedicate less time to science instruction than other countries.

A future focused curriculum aims to:

- engage students intellectually and emotionally
- foster the development of science capabilities
- build understanding of powerful science ideas and ideas about science itself
- provide opportunities for creativity and knowledge building
- carefully balance depth and breadth
- provide opportunities for students to engage with complexity and uncertainty in real world issues

Citizenship capabilities develop over time and require specific teaching and appropriate ongoing learning opportunities.

Section Two: Approaches to Promote Learning in Science

It is noted on the Science Learning Hub site that research shows that students often develop significant misconceptions about science from what they learn through popular media. Increasingly however science is being presented in a more engaging manner, through such programmes as, 'Nigel Latta Blows Stuff Up', 'Myth Busters' and through advocates like Dr. Michelle Dickinson, dubbed Nanogirl.

Within classroom science there can also be too much emphasis on 'what we know, rather than how we know it' and this has led to students being uninspired through experiencing science as an accumulation of facts and strict following of 'scientific method.' In their study Clearly and Bennetts (2016) reported that student engagement increased as teachers focused more on the purpose of teaching science.

This section of the report incorporates approaches and research that I found of interest and stimulated my thinking about the possibilities of science education. The ideas presented are not intended to provide a programme as such but to supplement the guidelines already provided for us in the New Zealand Curriculum and on TKI Science Online through the capabilities.

Effective Pedagogy

I firstly draw attention to the excellent Effective Pedagogy section within our own New Zealand Curriculum. As noted by Clearly and Bennetts (2016), these were the factors that the teachers involved in their study reported as making a difference for students:

- Creating a supportive learning environment
- Encouraging reflective thought and action
- Enhancing the relevance of new learning
- Facilitating shared learning
- Making connections to prior learning and experience
- Providing sufficient opportunities to learn
- Teaching as Inquiry

(NZC, pp. 24-35)

Effective pedagogy in science needs to link with student prior experience (including cultural perspectives) and interests, be designed so students are actively involved in exploring concepts and collaborating to build knowledge, and engage with contemporary science practice – so students are able to see science as, “a complex, multidisciplinary endeavour addressing real world issues” (Bolstad, R., & Bunting, 2013, p. 13).

Bolstad and Bunting, (2013, p. 33), suggest that future-focused science teachers have many of the following characteristics:

- They enjoy science and assisting students to develop scientific understandings.
- They understand the wider purpose of science education to develop science citizenship.
- They are curious, embrace ongoing learning opportunities and are open to trying new ideas to improve science education.
- They are able to reflect on their own practice and classroom programme and consider how it could be improved e.g. importance of learning objectives, relevance for students, suitability of activities for that student group, opportunity for students to engage in and collaborate to build knowledge and ideas, development of deeper understandings, means of assessment.
- They create a network of relationships that allows them to explore their thinking through professional discussions and access knowledge and resources (this includes online contacts and connections).
- They demonstrate robust digital literacy and enjoy exploring how digital technologies can enhance learning.
- They are resilient and motivated – as 'sustaining innovative practice is challenging and time consuming' (Bolstad and Bunting, 2013, p. 34).

Teaching students assessment for learning practices, and creating space in the crowded curriculum for students to work collaboratively, reflect on their learning and make changes for improvement are important components.

Tapping into what is known about child development and learning – do we do this well enough?

My research, and those I met on my travels, encouraged me to consider how well we transition our students from the early childhood learning environment to primary school and whether we can better match the learning environment with the stages of child development. I incorporate information from both New Zealand and Canadian educators within this section and introduce the Creative Exploration Process and the Imaginative Education Research Group.

Gilbert and Bull (2013) reinforce the idea of building upon what is known about learning and human development in their report, *Building a future-orientated science education system*. It is suggested that the focus of science education should be different at different levels of schooling, “In Years 1–6 the emphasis should be on stimulating students’ interest and curiosity, and in Years 7–10 socio-scientific issues should be the focus, along with opportunities for students to see possible future careers for themselves in science. At senior secondary level, students could continue to study an issues-focused programme, but parallel courses in pure or applied science would also be offered. If this model was adopted, building the ‘library of experiences’ young children need to be ready to learn would be the focus of primary science, as would structured classroom talk designed to develop children’s engagement with science and their capacity for subject-specific reasoning” (p. 15).

In 1965 Rachel Carson identified the notion of children having an inborn sense of wonder. Carson’s thinking was that “If a child is to keep alive his/her inborn sense of wonder he/she needs the companionship of at least one adult who can share it, rediscovering with him/her the joy, excitement and mystery of the world in which we live” (as cited in Milne, 2010, p. 103). Carson felt that the years of early childhood are a time to develop emotional connections and curiosity about the world, which she considered as fertile ground on which the later seeds of knowledge and wisdom would grow.

This concept has been developed further by educationalists, including Ian Milne of Auckland University in his 2010 paper, *A Sense of Wonder, arising from Aesthetic Experiences, should be the Starting Point for Inquiry in Primary Science*. Milne comments upon the crowded curriculum and decline in attitude towards further learning in science. He reflects that the focus upon inquiry learning may also provide a cause for the decline in primary science teaching and learning. Milne notes disposition indicators that science education seeks to foster in students, these being;

- displaying curiosity about the world and excitement about how science works
- taking an interest in a particular science topic
- becoming absorbed in a science related activity and pursuing an interest without prompting
- displaying initiative and commitment when seeking answers to their questions
- persevering to solve a problem and overcome difficulties while pursuing their own interest in science.

These indicators were influenced by Margaret Carr’s early childhood learning dispositions. Continuing to support and foster these dispositions should be a goal of science education as students’ transition to primary school.

Menzies (2015) article, *Play-based learning: producing Critical, Creative and Innovative Thinkers*, discusses the social, intellectual and cognitive benefits of play based learning, through encouraging students to use their imagination, explore, interact and learn through discovery play.

Milne also reflects on the value of creative exploration for primary science. Creative exploration involves both the teacher and the students to be hands on ‘doing’ science. It is an approach that models aspects of the scientific process. Creative exploration requires children to be involved in exploration, inquiry, explanation and making connections. It should be based around aesthetic experiences that promote affective, often emotional responses associated with engagement, wonder and interest. This sparking of curiosity can lead to the use of scientific inquiry to develop explanations. The creative exploration process is cyclical and may follow the whole process or just a section. The depth of engagement and understanding increases as more elements of the process are used (see Table 1 below). A fundamental cornerstone of this approach is that the science is made explicit. At any time in the process the teacher and students should be able to answer the question, What makes the activity I am involved in science?

Table 1: The Creative Exploration Process, for developing personal understanding in primary science.

Creative Exploration - Recorded in linear form		
Explore	a problem, situation, phenomenon, artefact, model, event, story	Wonder
Observe	What is happening? What changes happened? What materials are involved? What are the main parts? What are the key aspects? What do these parts/structure do?	Wonder about
Identify evidence	What is the cause and effect of changes? What is the function? What parts are interacting with other parts? What are the outcomes of these interactions? What trends and patterns keep occurring?	
Create explanations	Personal explanations supported by evidence are created and processes to test them are planned	Wonder at
Investigate	Find out, measure, compare, verify, test, clarify identify	
Evaluation	A self-evaluation of these investigations may lead to new or modified explanations, doubts about existing ideas, or tentative conclusions. These tentative explanations need to be communicated to others for peer evaluation and feedback	
Further investigation	Evaluated explanations can lead to: seeking further explanation, leading to further exploration	Wonder whether
Making Connections	Explanations are used or applied to make sense of or clarify other contexts where similar phenomena are involved	

Tapping into students' natural way of learning is the focus for the Imaginative Education Research Group (IERG), based at the Simon Fraser University in Vancouver, British Columbia, Canada. IERG focuses upon ways to engage student and teacher imagination in learning and teaching. I had the privilege of meeting the founder, Kieran Egan whilst in Vancouver. He has continued to be an inspirational leader in education and IERG programmes have been adopted across the world. The following quote from the IERG website home page provides a foundation for understanding their philosophy, *"All the knowledge in the curriculum is a product of someone's hopes, fears, passions or ingenuity. If we want students to learn that knowledge in a manner that will make it meaningful and memorable, then we need to bring it to life for them in the context of those hopes, fears passions and ingenuity. The great agent that will allow us to achieve this routinely in everyday classrooms is the imagination."* This approach is summarised in a short introductory video on http://ierg.ca/wp-content/uploads/2014/02/ierg_short_intro.flv

The IERG do understand the needs of education; that schools desire for their students to be excited by learning, to understand the meaning of the knowledge they gain and to attain improved academic achievement. What Imaginative Education offers is a new approach to meet these objectives by offering a theory, frameworks and techniques to engage student emotions and connecting their imaginations to the curriculum content. IERG shares their ideas and resource material on their website, <http://www.ierg.ca> In connection with science, IERG provide an Imaginative Science Teaching Programme, Imaginative Ecological Education, Learning in Depth programme and a Whole School Project programme.

In section one of this report, an aim for a future focused curriculum was to provide a balance of depth and breadth. Students learn many things superficially throughout their schooling and the basis of the IERG Learning in Depth (LiD) programme is that each student will have the opportunity to become an expert in a particular topic. This programme does tend to prompt a response from educators, who are either enthused or hesitant. The reason being is that to follow the LiD programme as intended, on starting school each child is given a particular topic that they will learn about throughout their whole schooling. An hour a week within school is dedicated to growing their portfolio of knowledge on their subject. There is no formal assessment, plenty of opportunity to share with others and children can work at their own pace. The programme has now been running for a few years and has shown that many children respond positively to this flexible learning and carry out additional research in their own time. See <http://www.youtube.com/watch?v=YR98YjwOM18> for an introduction by Kieran Egan for Learning in Depth.

In the IERG Science Teaching programme cultural tools (such as traditional oral story telling) become cognitive tools for engaging students and teachers with science. These include; story, feelings and images, metaphors and jokes, rhyme and rhythm, stories and wonder, binary opposites, heroes and the exotic, hopes, fears and passions and a sense of wonder. Dr Gillian Judson, a co-director of IERG, discusses within her book *Engaging Imagination in Ecological Education* (2015), the disconnection between knowledge and action. She makes the observation that those who have an emotional and imaginative connection to the natural world are more likely to put their knowledge of

environmental sustainability into action. Examples are given for helping students make these connections and strengthen their literacy development, including the observation that, while media presentations and classroom based teaching can provide knowledge, to develop a connection with the diversity of life that surrounds them, students need to be outside looking at patterns in nature and sensing the world around them. The book utilises the IERG cognitive tools to provide a learning framework that encourages ecological understanding.

The Big Ideas and Principles in Science Education

One approach to planning a school science programme is to think about what students need to know to become scientifically literate citizens. In response to concerns around lack of coherence in science education and reduced interest in students pursuing studies in science, a group of ten international experts in science education gathered in 2009 for a seminar in Scotland. The authors recognised that students need learning experiences that are relevant to their lives and engaging. At their meeting the experts developed the principles they felt should underpin the science education of all students throughout their schooling, and what they termed the 'Big Ideas *of* and *about* science. The subsequent report, *Principles and Big Ideas of Science Education*, proposes that helping students to understand these ideas will enable them to develop an understanding of scientific aspects, and make informed decisions about the applications of science (Harlen et al., 2010).

I do recommend reading the full report, in which each of the Big Ideas is presented in a narrative form as a progression from 'small ideas about specific events, phenomena and objects to more abstract and widely applicable ideas.' The fourteen big ideas in science, as developed in the report (Harlen et al., 2010) are:

Ideas OF science

- All material in the Universe is made of very small particles.
- Objects can affect other objects at a distance.
- Changing the movement of an object requires a net force to be acting on it.
- The total amount of energy in the Universe is always the same but energy can be transformed when things change or are made to happen.
- The composition of the Earth and its atmosphere and the processes occurring within them shape the Earth's surface and its climate.
- The solar system is a very small part of one of millions of galaxies in the Universe.
- Organisms are organised on a cellular basis.
- Organisms require a supply of energy and materials for which they are often dependent on or in competition with other organisms.
- Genetic information is passed down from one generation of organisms to another.
- The diversity of organisms, living and extinct, is the result of evolution.

Ideas ABOUT science

- Science assumes that for every effect there is one or more causes.
- Scientific explanations, theories and models are those that best fit the facts known at a particular time.
- The knowledge produced by science is used in some technologies to create products to serve human ends.
- Applications of science often have ethical, social, economic and political implications

The scientists involved in the project see the Big Ideas as a natural accompaniment to promoting inquiry-based science education. They envisage the Big Ideas accommodating future advances in science, so a curriculum expressed in terms of these ideas should endure beyond the 10 to 15 year lifespan of many national curricula.

To preserve the connections between progressions, the Big Ideas are deliberately expressed in narrative form.

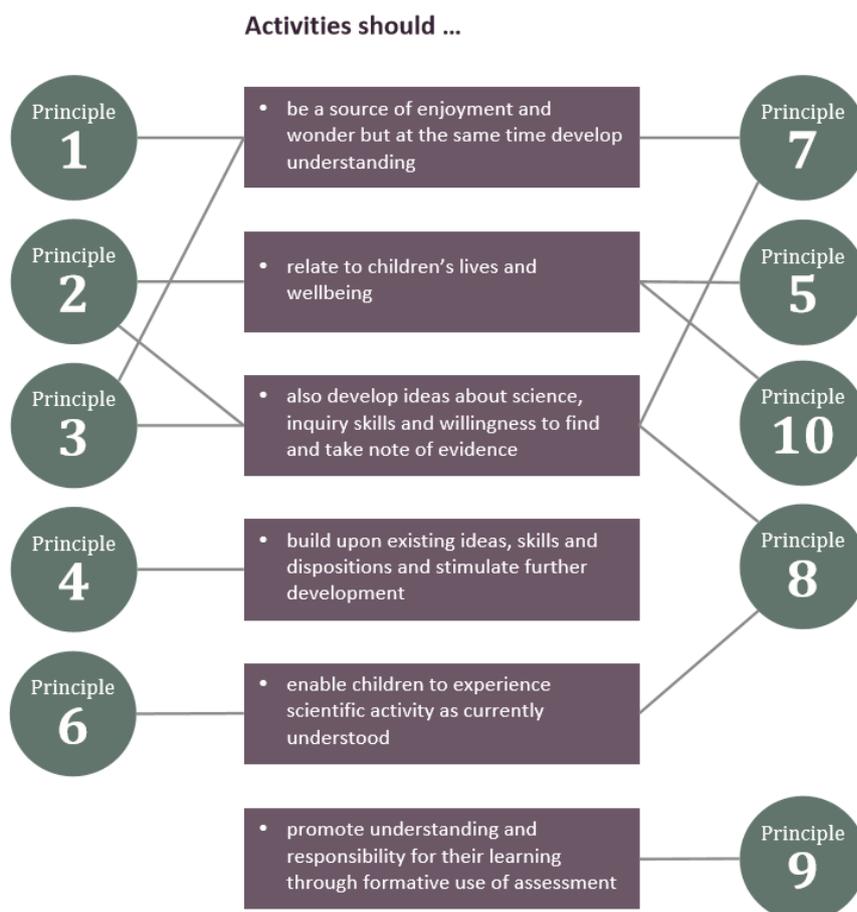
How we view progression in learning is challenged within the Big Ideas reading. Is learning progression like the process of climbing a ladder (where each rung is reached before the next step can be taken), or is progression in learning more like completing a jigsaw puzzle (with different starting points and a growing picture developing as larger ideas grow as smaller pieces are linked), or is it like training for a marathon? (with the capacity to run further is built up gradually from shorter distance training) (pp. 25-26).

Pedagogy is defined by Harlen et al (2010) within *Principles and Big Ideas of Science Education* as the act of teaching, plus the underpinning theories, values and justifications, and the skill and creativity needed to provide effective and engaging learning activities. The challenge for teachers is to build the students scientific understanding from different ideas (jigsaw), grow student experience (marathon training) and develop the students' ability to critique scientific evidence as well as provide foundations of understanding (ladder). The process of broadening student scientific understanding is ongoing.

The ten principles of science education (Harlen et al., 2010) are outlined as:

1. Throughout the years of compulsory schooling, through their science education programmes, schools should aim systematically to develop and sustain learners' curiosity about the world, enjoyment of scientific activity and understanding of how natural phenomena can be explained.
2. The main purpose of science education should be to enable every individual to take an informed part in decisions, and to take appropriate actions, that affect their own wellbeing and the wellbeing of society and the environment.
3. Science education has multiple goals. It should aim to develop: <ul style="list-style-type: none"> • an understanding of a set of 'big ideas' in science which include ideas of science and ideas about science and its role in society • scientific capabilities concerned with gathering and using evidence • scientific attitudes.
4. There should be a clear progression towards the goals of science education, indicating the ideas that need to be achieved at various points (based on careful analysis of concepts and on current research and understanding of how learning takes place).
5. Progression towards big ideas should result from the study of topics of interest to students and relevance in their lives.
6. Learning experiences should reflect a view of scientific knowledge and scientific inquiry that is explicit and in line with current scientific and educational thinking
7. All science curriculum activities should deepen understanding of scientific ideas as well as having other possible aims, such as fostering attitudes and capabilities.
8. Programmes of learning for students, and the initial training and professional development of teachers, should be consistent with the teaching and learning methods required to achieve the goals set out in Principle 3.
9. Assessment has a key role in science education. The formative assessment of students' learning and the summative assessment of their progress must apply to all goals.
10. In working towards these goals, schools' science programmes should promote cooperation among teachers and engagement of the community including the involvement of scientists.

Based on the ten principles of science education, it is suggested that;



The authors caution that students need to be assisted to, “engage with, think about and link the subject matter to other experiences – even potentially relevant and engaging content can fail to advance understanding if the activities are reduced to following instructions and learning answers by rote” (Harlen et al., 2010, p. 45).

Inquiry Learning in Science Education

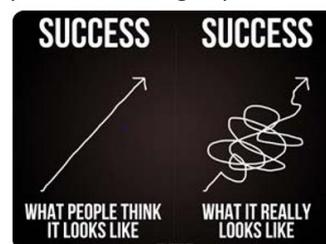
An inquiry based approach to learning is widely advocated as a means of motivating students and advancing their problem solving and critical thinking skills, and this approach was a current professional development focus in schools I visited in Canada. Both the *Focus on Inquiry* (Friesen, 2015), and *Natural Curiosity: Building Children’s Understanding of the World through Environmental Inquiry* (University of Toronto, 2011) documents are excellent guides for teachers to reference.

In inquiry based learning students are actively constructing knowledge through exploration:

- Formulating a question or set of questions
- Designing an investigation to research the question
- Gathering information and resources
- Developing explanations based on evidence and scientific knowledge
- Sharing the investigation and findings
- Reflecting on the learning process and outcomes

Well executed inquiry learning, with regular reflection throughout the process, enables new ideas to develop from earlier ones and can lead to greater depth in understanding. The effectiveness of inquiry-based learning depends on the level of guidance provided by the class teacher. This guidance includes assisting students to develop effective questions for investigation, provision of feedback and prompts to encourage students to work as scientists do as they collect and use evidence to test their ideas, reflect on their work and explain their findings.

I felt the diagram alongside, sourced from *Focus on Inquiry* (Friesen, 2015), illustrates the actual inquiry learning process well.



Source: www.atbreak.com

As noted formulating essential questions is required to set the scene for enriching science inquiry learning. McTighe and Wiggins (2013) present seven defining characteristics that a good essential question will meet all, or most of, as:

1. Is *open-ended*; that is, it typically will not have a single, final, and correct answer.
2. Is *thought-provoking* and *intellectually engaging*, often sparking discussion and debate.
3. Calls for *higher-order thinking*, such as analysis, inference, evaluation, prediction. It cannot be effectively answered by recall alone.
4. Points toward *important, transferable ideas* within (and sometimes across) disciplines.
5. Raises *additional questions* and sparks further inquiry.
6. Requires *support* and *justification*, not just an answer.
7. *Recur*s over time; that is, the question can and should be revisited again and again.

Friesen (2015) outlines the importance of a positive culture that supports inquiry learning and explains that there needs to be a balance between discovery / personal exploration and systematic instruction / guidance (p. 8).

Drawing upon a number of research projects, Friesen, (2015, pp. 24-25), discusses a number of pertinent points when implementing an inquiry based learning programme to reduce the possibility of students gaining incomplete and fragmented understandings:

- there needs to be a coherent and simplified way of increasing subject knowledge as students move through the school grades, so they can see how activities within a subject and how units of study relate to each other.
- utilising the different learning disciplines (maths, science etc.) will enrich the context
- students need to learn how to participate in the process of creating knowledge, rather than just learning about a topic.
- superficial coverage of all topics in a subject area needs to be replaced with in-depth coverage of fewer topics to allow key concepts in that discipline to be understood.

There are a range of inquiry models. The characteristics of Discipline Based Inquiry are outlined in *Focus on Inquiry* (pp. 25-26) as:

- The study is authentic, in that it emanates from a question, problem, issue or idea that connects students to the world beyond school in ways that are central to the ways of knowing, doing and being within the relevant disciplines.
- Students are given opportunities to create products or culminating work that contributes to the building of knowledge.
- Assignments and activities foster deep knowledge and understanding (require complex thinking)
- Ongoing formative assessment loops are woven into the design of the inquiry study and involve detailed descriptive feedback.
- The study requires students to observe and interact with outside expertise, including professionals in the field.
- Students are given the opportunity to communicate their ideas and insights in powerful ways through myriad media.
- Students' final products are communicated through public presentations and exhibitions (Friesen & Scott, 2013).

[See Appendix 4: Dimensions of Discipline Based Inquiry](#)

Developed for schools in Alberta, Canada *Focus on Inquiry* (Friesen, 2015), is designed as a professional learning guide. Aspects of the resource link in with the IERG and Creative Exploration focuses on connecting with students' emotions and natural curiosity, for example looking at how you might connect the selected topic with student experiences by asking the following questions: What is weird about the topic? Are there life and death issues involved? What challenges our sense of justice or fair play? Is there more here than meets the eye? What is secret, hidden or puzzling? (pp. 64-65).

It is recognised that inquiry based learning is demanding of the class teacher, both in terms of skill and time. In order to support understanding in science, Harlen et al., (2010) note that identifying the big ideas in science is "a natural and indeed necessary accompaniment to promoting inquiry-based science education" (p. 3).

Teachers need to be familiar with the development of student thinking and the process of inquiry, as well as understanding about science concepts. Friesen (2015), *Focus on Inquiry*, notes that teachers need, "both disciplinary knowledge and pedagogical knowledge and knowledge of the ways in which these interact together in order to create conditions for learning to occur" (p. 22).

Another important point is that inquiry learning is not meant to be on top of students' regular work. Knowing the various focuses across the curriculum means consideration can be given to designing a range of opportunities to acquire and demonstrate understanding, linked with the key concepts and required outcomes (p. 72).

Content Representation design

The nature of inquiry learning for science differs from other disciplines. In the report *Getting to the Core of the matter: developing a primary school's science plan*, Hume (2016) reports on a university/school partnership to strengthen the alignment of the school science implementation plan (SIP) with the intent of The NZC, using Content Representation (CoRe) design as a development tool. From the study, the researchers cautioned that, "the distinctiveness of science risks being missed if taught as generic inquiry." During inquiry learning in science, students need to "ask scientifically-orientated questions and be given opportunities to design investigations themselves where they collect primary data, build explanations and test and critique those explanations."

It is again emphasised that in order to respond to teachable moments within a science inquiry, teachers must have subject matter knowledge themselves. This report is a worthwhile read for schools looking at approaches to support science development. From their study, researchers developed 6 principles for strengthening teacher pedagogical content knowledge (PCK) as they developed their school implementation plan.

Six Principles for strengthening teacher pedagogical content knowledge (Hume, 2016):

Collaborative CoRe design and unit planning for strengthening teachers' science content knowledge, PCK and feelings of self-efficacy.

A school-wide science implementation plan with a conceptual framework that provides direction and guidance for students' learning progressions in science as they move through their six years of primary schooling.
--

Pedagogies where students engage in inquiry-based learning that mirrors authentic scientific inquiry
--

The development and fostering of scientific capabilities and dispositions in students (i.e. engage with science and ask questions, design investigations, gather and interpret data, use evidence, critique evidence, and interpret representations).
School-wide assessment of sufficient depth to allow students to show that they can perform in increasingly more complex ways as they move through their primary schooling
Evidence in any year to include a range of data to exemplify conceptual development, and science capabilities and dispositions linked to the school's Science Implementation Plan

Sourced from *Getting to the Core of the matter: developing a primary school's science plan*, Hume (2016)

The social construction of knowledge

Whichever model is selected to support students to develop their scientific understanding and literacy, there must be opportunity for the social construction of knowledge. As noted by Fitzgerald, (2013) it is through social interaction that students can communicate their ideas, reflect on, make sense of, and build their own thinking whilst hearing other perspectives. Create opportunities for students to interact and work in teams, to hear others' questions and have robust discussion, and encourage them to draw upon thinking and skills from across the curriculum to construct new ideas and understandings (p. 8-9).

A main message within the Canadian resource, *Focus on Inquiry* is that schooling needs to be more ambitious. A quote from the text states that, "it should be active and constructive, cumulative and more self-directed. It should also be more collaborative, and permit individually different processes of meaning construction and knowledge building" (De Corte, 2007 as cited by Friesen, 2015).

A positive example of developing student scientific thinking in a creative way is provided in the report by Anderson and Baskerville (2016), *Developing science capabilities through drama*. This study aimed to examine the opportunities for developing student science capabilities through a guided drama-science inquiry process. Students were engaged in the process and learning was gained from the in-scientist role play.

Citizen Science

Citizen science or public participation in science enables participants to take part in real life scientific research. Through participation they learn about the particular area of science focus that is relevant to them and develop skills in the methods of science (observation, monitoring, tagging, measuring). The data collected is then analysed by research scientists. Citizen science enriches science education for students because the context is authentic, students are collecting real data for a valuable purpose, participation encourages students to analyse the findings and ask meaningful questions – thus practising the types of thinking, questioning and actions needed to become informed citizens. In addition, partnerships are formed with community groups and scientists in the field.

In New Zealand the value of engaging young people, communities and scientists in collaborative science projects is recognised as part of the '*Nation of Curious Minds*' strategic plan, and the participatory science platform is currently being trialled in three different local environments (South Auckland, Taranaki and Otago). Other citizen science promoters are Forest and Bird and the Department of Conservation, who have regularly recruited volunteers to assist with monitoring and restoration projects. Worldwide the projects are as diverse as searching for extra-terrestrial life among the stars. Zooniverse is the world's most popular platform for citizen science (from astronomy to zoology).

Current Citizenship Science NZ examples include:

Naturewatch, this is an online community and features a range of citizen science programmes, such as Kereru Discovery and monitoring stinkbugs. <http://naturewatch.org.nz/>

Wai NZ which monitors freshwater rivers streams and lakes. <http://www.wainz.org.nz/>

The NZ Marine Studies Centre citizen science project, Marine Metre Squared, where participants are asked to participate in a long term monitoring of the NZ Seashore, check their website <https://www.mm2.net.nz>

The Monarch Butterfly New Zealand Trust butterfly tagging programme. www.monarch.org.nz/monarch

Landcare Trust have prepared a 2016 Inventory of Citizen Science programmes and projects currently underway in NZ. <http://www.landcare.org.nz/files/file/2023/Inventory%20of%20Citizen%20Science.pdf>

The New Zealand Curious Minds project is also piloting extreme participatory science where non-scientists are involved in collaborative science projects from the ideas stage through to sharing of results.

<http://www.curiousminds.nz/about/participatory-science-platform/>

Section Two Key Points:

Students need to engage with learning about the Nature of Science through content that is relevant to their lives.

Consideration of the stages of human development and what we know about how children learn is important.

The focus of science education should be different for different levels. In Years 1 – 6 it is suggested that the emphasis should be on stimulating student interest and curiosity about science through building a library of experiences that also develop the Nature of Science capability skills.

Transition to school from Early Childhood should incorporate aspects of play based learning to develop students' exploration, socialisation, creativity and thinking skills.

Learning Approaches for Science Programmes included within this section:

Creative Exploration – structured exploration stages that connect with students sense of wonder and where science is made explicit. At any time during the lesson the teacher and students should be able to answer, “What makes the activity I am involved in science?”

Imaginative Education – utilising student imagination and emotion is the key for connecting with curriculum content in a meaningful way. A range of cognitive tools are utilised as a learning framework, linking with what is known about how children learn and what engages them. The Learning in Depth programme offers students an opportunity to work at their own pace and become an expert in a field.

Utilising the Big Ideas in science - 14 Big Ideas of and about science are identified that underpin science education. These ideas are presented in narrative form to show connection from simpler to more complex understandings within that particular big idea.

Inquiry Learning – by following an inquiry based process students actively construct knowledge through exploration and applying capabilities in science. There are a range of inquiry models. Careful design is required to organise the learning process (promoting the development of questions, encouraging reflection etc) to ensure the essential elements of science inquiry are included and to foster deeper understandings of key concepts.

Ensure inquiry learning is structured to support science: investigating scientifically-orientated questions, opportunities to design investigations, collection of data primary data, building explanations, testing and critiquing explanations.

Design learning opportunities to effectively support the social construction of knowledge.

Citizen Science – participants are encouraged to develop science for citizenship skills in real-life scientific research. There are a range of citizen science projects that students in schools can engage in.

Section Three: Implementing a Culturally Inclusive Pedagogy:

Whilst in Vancouver I spoke with a teacher who explained that it was a requirement that Aboriginal Peoples history, culture and perspectives, be integrated across all subject areas and grades in British Columbia's new curriculum (being implemented in 2016). Stepping outside the shores of New Zealand, and developing a sense of how another country is addressing the educational disparities of their indigenous people, encouraged me to learn more about culturally inclusive pedagogy to improve the educational outcomes of our Māori students. In this section I draw upon research and explore parallels with NZ and Canada as both countries recognise the need to reflect upon how we can improve student achievement for our indigenous people. This is followed by a summary of what it means to teach Māori students as Māori.

Barriers to Accommodating Indigenous Science Concepts within Science Education

Canadian researchers (Aikenhead and Huntly, 1999), found that whilst there was general respect for local First Nations culture and a token amount was drawn upon in the Canadian primary school curriculum, as yet cultural materials and ideas were not well integrated into school science programmes. Within their study, barriers were identified in accommodating different cultural views in classrooms. Māori students are identified in New Zealand as a group whose achievement levels are below those of their peers, so I include these barriers within this paper, as they may resonate with New Zealand educators.

The barriers to inclusion of indigenous science concepts within science education in Canada as identified by Aikenhead and Huntly (1999) were:

- **Conceptual understanding:** teachers not recognising that the subject of science has specific features; that students can feel alienated by the foreign 'language of science' and that scientific and everyday ways of reasoning can vary greatly (thus making the subject difficult to learn, and teach).
- **Cultural understanding:** failing to identify cultural differences in learning, and how this could become a barrier to student achievement. Some teachers felt that students were already disengaged from their indigenous culture and would not be interested in making these connections.
- **Pedagogical understanding:** failing to utilise cross-cultural instructional strategies to support students' to make connections and interact with new ideas. The general learning approach supported memorisation rather than deep understandings.
- **Ideological perceptions:** evidence of deficit thinking, citing reasons why the student would not achieve e.g. attributing failure to the student or home situation.
- **Practical aspects:** difficulty in locating appropriate resources and people (this also applied to First Nations teachers who were away from their home area).

Returning to the subject in 2010, a further research paper by Aikenhead and Elliot, *An Emerging Decolonizing Science Education in Canada*, found that indigenous student achievement increased in schools who had effectively incorporated indigenous content into the curriculum and recognised indigenous knowledge as being foundational to understanding the physical world. However, there was still an element of concern that, "indigenous ways of living in nature have not generally been welcomed in science classrooms, and indigenous students must suppress such knowledge to meet the conventional goal of thinking, behaving, and believing like a scientist" (p. 6). The cultural divide was also reflected in the under representation of indigenous students in senior sciences.

Developing a culturally responsive science curriculum

Aikenhead and Elliot (2010) cite a number of Canadian researchers who recognise the importance of an indigenous wisdom tradition to help ensure wise environmental decisions and sustainable progress. They note that, "the two knowledge systems are complementary; they co-exist. Scientists and engineers can expand their perspectives on nature and augment their problem-solving repertoire by learning from the wisdom held by Knowledge Keepers* of an indigenous culture" (p. 10).

**Note: A Knowledge Keeper is like a Māori Kaumātua, a respected knowledgeable indigenous person who passes on their knowledge to the next generation.*

A cross-cultural science curriculum is described by Aikenhead and Elliott (2010, p. 9) as one in which indigenous students learn to master and utilize Eurocentric science and technology while maintaining their roots in an indigenous wisdom tradition with cultural ways of knowing nature. “Successful cross-cultural school science avoids tokenism and anticipates that all students will understand how scientists think, behave, and believe without students being expected to think, behave, and believe that way themselves” (Aikenhead & Mitchell, 2011). When teaching cross-cultural school science, teachers learn to build cultural bridges between their own Eurocentric science culture and their students local indigenous culture, and shift their perspective from treating the two cultural ways of knowing nature as mutually exclusive, to treating them as complimentary.

The Canadian Province of Saskatchewan’s curriculum renewal is recognised for the integration of indigenous knowledge into school science. The following aspects are suggested for consideration when developing a culturally responsive science curriculum that links with traditions of the indigenous people:

- Recognising and respecting cultural practices.

Teachers need to honour protocols for obtaining knowledge from a ‘Knowledge Keeper’ and to take responsibility for learning that knowledge. For example, a teacher may learn a story related to seasons, but may only be granted permission to tell this story at a particular time of year, and in a particular context (Aikenhead and Elliot, 2010, p. 15).

- Utilising experiential learning which begins with observation of phenomena in the natural world.

In Canada, an example of this would be students beginning their study of flight by observing the flight patterns of insects and birds with a Knowledge Keeper, as opposed to an instructional approach where the teacher begins the unit by discussing the forces that act on flying objects (Aikenhead and Elliot, 2010, p. 15).

- Respecting the integrity of indigenous knowledge as being different from, yet complementary to traditional school science.

It is important to recognise that a notable point of difference is the centrality of spirit in indigenous worldviews, that indigenous knowledge is often set in a specific region, and that specific indigenous knowledge was gained experientially through life’s journey (as opposed to Eurocentric science knowledge that has been described as disjointed, passively learnt, accumulated and assessed through formal examination). The need for educationalists to establish a relationship with a local Knowledge Keeper was important.

In the Saskatchewan community, common ground between the two was emphasised and indigenous groups assisted the development of the curriculum by sharing connections between scientific topics and indigenous knowledge and perspectives on nature.

- Development of resources to support the cross-cultural curriculum.

Cross cultural school science is about improving scientific literacy for all students and the need to provide resources and professional learning for teachers is recognised. The Saskatchewan Curriculum resources were developed as a result of collaboration through an advisory group consisting of Indigenous Knowledge Keepers, educationalists, the Ministry of Education and a textbook publisher.

The wording in the Saskatchewan Curriculum shows clear intention for cross cultural understandings to be incorporated into the science teaching programmes: “a strong science program recognizes that modern science is not the only form of empirical knowledge about nature and aims to broaden student understanding of traditional and local knowledge systems. The dialogue between scientists and traditional knowledge holders has an extensive history and continues to grow as researchers and practitioners seek to better understand our complex world. Traditional (indigenous) knowledge is recognised as a cumulative body of knowledge, know-how, practices and representations maintained and developed by peoples with extended histories of interaction with the natural environment. These sophisticated sets of understandings, interpretations and meanings are part and parcel of a cultural complex that encompasses language, naming and classification systems, resource use practices, ritual, spirituality and worldview” (International Council for Science, 2002).

Reference to the expectation of inclusion of Indigenous science content is also noted in the British Columbian Science Curriculum, “The incorporating of Aboriginal science with western science can provide a meaningful context for Aboriginal students and enhance the learning experience for all students. The inclusion of Aboriginal examples of science and technologies can make the subject more authentic, exciting, relevant and interesting for all students.” The challenges this may present is also acknowledged, “Numerous difficulties arise when trying to incorporate indigenous knowledge and world views into the western science classroom. The participants of the Ministry of Education Aboriginal Science meetings therefore suggest a model involving a parallel process, where Aboriginal and Western understandings exist separately, yet side-by-side and in partnership with one another. Each side is enriched by the contrasting perspective that the other brings to any discussion” (p. 12).

The New Zealand Experience

We have commonalities with Canadian educationalists in our recognition of the benefits of developing science achievement for our indigenous people (and for all of our students), and in recognising the need to improve in this regard. In the New Zealand curriculum, it is also noted that, “Different cultures and periods of history have contributed to the development of science” (NZC, p. 8).

Aotearoa, New Zealand, is noted within the 2010 Aikenhead and Elliot paper as being “the most advanced country in developing a cross-cultural school science.” They note that pūtaiao, a Māori version of the science curriculum is taught in a network of Māori bilingual and immersion classrooms in elementary and high schools, and that teacher professional development and student achievement has been documented and analysed (p. 12).

Whilst it is heartening to see culturally responsive developments within our own school system recognised internationally, analysis of Māori student achievement data in science continues to show that achievement and engagement of Māori students in science is an area for improvement, as studies have shown that Māori are represented at all levels of achievement but have a higher proportion than non- Māori within lower achievement groups.

The New Zealand Education Review Office report (2013) regarding accelerating priority learner progress found that only a few schools developed specific strategies to respond to Māori priority learners. In the monograph paper she contributed to, *Te Ara Pūtaiao: Māori Insights in Science* (2008), Elizabeth McKinley discusses preconceptions about Māori student learners and the need to engage Māori students in science by making connections between cultural and modern scientific understandings. This subject is further explored within the same paper by Professor Michael Walker. Professor Walker discusses how Māori identity is important for Māori scientists. He notes that a change of perspective by the dominant society, and having a deeper understanding of the different set of operating assumptions that drive Māori research, will expand the intellectual scope of the nation.

Within the New Zealand the report *The Achievement of Māori Students* (Education Review Office, 2006) confirmed that, “student engagement is a pre-requisite for student achievement, as students need to be present and engaged in learning to achieve” (p. 10).

In the 2013 ERO report, the authors reinforced their findings that, “effective teachers recognise the cultural resource that Māori and Pacific students bring to the school. They understand the importance of valuing and responding to students’ identity, language and culture. Teachers then provide opportunities for these students to share aspects of their culture with others and use this to build the students’ confidence to succeed across the curriculum. This does not mean focusing only on the iconic aspects of culture, but understanding and responding to students’ personal culture and learning experiences” (p. 5).

In New Zealand our curriculum for English-medium schools is The New Zealand Curriculum. The Treaty of Waitangi and the bicultural foundations of Aotearoa, New Zealand, are acknowledged within the Vision and Principles. Schools that also offer Māori-medium programmes may use the parallel curriculum, Te Marautanga o Aotearoa as the basis of learning programmes. In 1985 the Treaty of Waitangi Tribunal heard the Te Reo Māori claim which declared that te reo was a Taonga (treasure), and te reo Māori was declared an official language of New Zealand.

The survival of te reo as a living language (used in everyday life rather than just at ceremonial occasions) is dependent on the actions of the New Zealand people. Within the New Zealand Curriculum, it is recognised that, “by understanding and using te reo Māori, New Zealanders become more aware of the indigenous language and culture in defining and asserting our point of difference in the wider world” (NZC, p. 14).

I note here that having one Indigenous language to embrace enables NZ educators to collectively develop resources, as opposed to the challenged posed by the linguistic diversity of Canada, with over 50 distinct indigenous languages currently spoken.

From my observation there is genuine interest in engagement from educators in incorporating te reo and tikanga understandings into the school curriculum. I had the pleasure of visiting Rhode Street School in Hamilton to learn more about their environmental science programme and was welcomed by the principal Shane and Alastair the school property manager and enviro school leader. Shane has a passion for science and the school embraces student led projects. This is well reflected in the environment, with a sensory garden, organic orchard, hydroponics, vege gardens, Kai Time student café and kitchen, media centre and their currently under construction, Ecological Island. The atmosphere was positive and engaging – it also reflected the schools multi-cultural background. Māori culture was weaved into the school programmes but also very visible, including 12 Pou (carved poles), created with student input and each telling the story about the culture they represent - acknowledging and celebrating culture, and cultural difference, connecting learners with their community and learning.

The late Sir Paul Callaghan also felt strongly about science education and connecting with our country's Maori heritage. In the message from the steering committee for the 2012 Transit of Venus Project, he is described as really loving New Zealand, and as a strong advocate for supporting young people and environmentally sound science related initiatives for the future development of our country.

The Transit of Venus Project was a forum where New Zealanders came together to discuss how science could play a role in our economic future; protecting our environment, through the development of technology based and creative industries and in managing our resources to build prosperity for all – with a particular focus on the young generation. The forum was held in June 2012 when the Transit of Venus astronomical event was occurring. Tolaga Bay, Gisborne was deliberately selected as the venue. The first constructive korero took place here between Maori and European, when James Cook arrived in 1769 tasked with measuring the time it would take for the shadow of Venus to pass across the sun's disc, and therefore measure the distance between the Sun and the Earth – critical information for sea going navigation in those times. Sir Paul Callaghan felt strongly that future economic development should involve all of New Zealand and should not be confined to the major cities, he advocated high tech industries that would not harm the environment and wanted Maori people to share that prosperity and lead the way we think about our natural heritage.

Across New Zealand different sectors recognise the importance of engaging with science for future prosperity. The role of science education was eloquently captured by the Ngati Whakaue iwi in their explanation for supporting a science camp for Māori youth: “Our aspirations for our rangatahi (young adults) are that they will be global citizens, with the ability to walk tall anywhere in the world; that their knowledge and understanding of tikanga and kawa (our customs and lore) is strong; and that they will eventually take their turn to contributing to the growth and development of future generations. As such, we believe that cultivating curiosity-driven science amongst our tamariki and rangatahi, supporting the linkages of science back to our tikanga, our whakapapa (lineage) and our stories, and reaffirming an ethos of ‘the enquiring mind’ as a core value will help us achieve our aspirations” (Ngati Whakaue, 2011, p. 5, as cited in Vannier, 2012, pp. 44-45).

By collectively embracing a vision of science citizenship as an essential element of society, we will support future prosperity for New Zealand (Vannier, 2012).

Incorporating Kaupapa Māori Pedagogy in New Zealand primary science education – what does it mean to teach Māori students as Māori?

In her 2016 paper, *STEM and Indigenous students*, Professor Elizabeth McKinley comments upon the surge in research on culturally responsive STEM pedagogies across the globe. She notes the need for STEM educators to, “take into account the nature of knowledge and the importance of cultural identity to Indigenous communities” (p. 64).

McKinley suggests that further research is required to identify ways to support teachers, and that responsibility to develop culturally responsive pedagogy must arise from the actions of an entire school system.

McKinley also cited the success of the New Zealand Ministry of Education Te Kotahitanga project, (Bishop et al 2012).

The focus of this project was to develop a greater understanding of Māori student experiences in the classroom and to use this information to find a way to improve the educational achievement of Māori students in mainstream schools. This was enacted through improving the nature of interpersonal relationships between teachers and their Māori students, and addressing the perception that Māori students were likely to be lower achievers.

An Effective Teaching Profile (ETP) was developed to remove deficit thinking and create a context for learning in which positive relationships, high expectations and progress toward culturally responsive teaching prevailed. Māori students with teachers involved in the project improved their attendance, engaged more as learners and made significant improvement in gaining NCEA Levels compared to the national cohort of Māori students. This result indicates that the strength of the positive relationship between Māori students and their teachers directly impacts upon Māori student achievement regardless of literacy levels. If we are to improve science achievement for Māori students in mainstream schools, we need to know more about what best practice for teaching Māori students as Māori looks like.

See Appendix 5: Summary of the Effective Teaching Profile, based on the Te Kotahitanga Māori research development project (set 2, 2009, p. 27 -33).

It is worth noting here that in the initial dialogue the researchers found that, though the teachers in the study had best intentions, how they saw the schooling experience to be for their students, and how the Māori students' experienced schooling was often disparate. The impression that I get is that the Te Kotahitanga Effective Teaching Profile is not meant to be a checklist, but as a guide for the integration of Māori language, culture and identity into schools. An overriding factor from the study is that the learning focused relationship was key to effective teaching of

Māori students; effective teachers took a positive, non-deficit view of the students' ability to succeed and saw themselves as capable of making a difference for them.

Teachers should be empowered to respond to the prior knowledge and experiences that their students bring with them to the classroom, as described within the report as often involving, "the invisible elements of culture, which are the values, morals, modes of communication, decision making and problem-solving processes, along with the world views and knowledge-producing processes that assist individuals and groups with meaning and sense making. In short, the realisation that improvements in learning outcomes can result from changing the learning relations and interactions in classrooms, not by just changing one of the parties involved, be they the students or the teachers" (Te Kotahitanga project, Bishop et al 2012, p. 31).

Section Three Key Points:

NZ and Canadian data and research shows the need to support science engagement and achievement for indigenous students as a group.

Research indicates that the strength of the positive learning relationship between indigenous students and their teachers influences student achievement.

Research shows that culturally inclusive teaching practice improves engagement and achievement.

There is recognition that provision of culturally inclusive practice would deepen student understanding (for all) and result in wider gains for the community e.g. lifting general scientific literacy, and through incorporating alternative ways of thinking that could strengthen innovation and benefit society.

Suggested areas for further development

Identified potential barriers to incorporating culturally inclusive teaching practice within science education often relate to teacher understanding. Professional development considerations include:

- Strengthening educator content and working knowledge of science to enable clarity in teaching; making clear links and developing deeper student understanding of concepts through flexibility of delivery, acknowledging prior understandings and making connections through interaction and dialogue.
- Developing educator understanding of cultural differences in learning. Removing deficit thinking, strengthening the learning relationship between teachers and students and developing cross-cultural instructional strategies to support connections with new ideas – so we can respond to cultural ways of learning and integrate tikanga more significantly, in a manner that respects culture and strengthens student understanding of science.
- Enabling easier pathways for educators to locate appropriate learning resources and support - including teachers in English-medium New Zealand schools who may not access to someone who can guide them in tikanga.

Suggestions for further reading:

Ministry of Education. (2013). *KaHikitia - Accelerating Success 2013 -2017. The Māori Education Strategy*. Wellington: Ministry of Education.

English version, retrieved from: <http://www.education.govt.nz/assets/Documents/Ministry/Strategies-and-policies/Ka-Hikitia/KaHikitiaAcceleratingSuccessEnglish.pdf>

The following MoE and TKI websites provides stories of engagement and success:

<http://www.education.govt.nz/ministry-of-education/overall-strategies-and-policies/the-maori-education-strategy-ka-hikitia-accelerating-success-20132017/ka-hikitia-case-studies/school-context-for-ka-hikitia/>

<http://nzcurriculum.tki.org.nz/Curriculum-stories/Case-studies/Teachers-as-learners-Inquiry/Learning-stories/Story-3>

Section Four: Support for schools to deliver science programmes

Within this section I introduce some of the opportunities within New Zealand for resources to support science programmes and professional learning and development. I also include some information about science education resourcing in Canada, including initiatives to engage the wider community in science and technology.

New Zealand Professional Learning Opportunities and Resourcing for Science

As reported by Kennedy, Smith and Sexton (2015, pp. 44-45), while the revised New Zealand Curriculum (2007) was mandated to be fully implemented for the start of the 2010 school year, no significant professional development was provided to unpack this new document. As a result, Hipkins and Hodgen (2012) noted two years later that more than half of New Zealand teachers did not understand how the shift in science instruction was supposed to be delivered. The loss of regional curriculum advisors for schools was also felt keenly by educators. Since then, New Zealand school leaders have sought professional development for their teachers, either centrally funded if an application is successful or funded from the schools operating budget.

A number of initiatives, including the Sir Paul Callaghan Science Academy and TKI Science Online, have been introduced to help unpack the Nature of Science strand for educators and I present some of these initiatives below.

TKI Science Online <http://scienceonline.tki.org.nz/>

TKI Science Online is the companion online resource for the New Zealand Science curriculum and a 'must visit' site for NZ primary school teachers. This site is managed by the Ministry of Education and provides resources to support the Nature of Science and science capabilities education. Links to a range of resources are provided to help primary teachers build student science concepts, e.g. Building Science Concepts books, ARBs, the Connected Series.

Assessment Resource Bank <https://arbs.nzcer.org.nz/>

The ARBs are a collection of formative assessment resources in Maths, English and Science for use in New Zealand classrooms.

LEARNZ <http://www.learnz.org.nz/>

LEARNZ is a series of virtual science field trips for Year 1 to 13 students. Covering a wide variety of topics and visiting a wide variety of locations, LEARNZ online field trips are self-contained and free for NZ teachers and their classes. This resource enables students to experience an in-depth learning adventure they would otherwise not have the opportunity to.

University of Waikato Science Learning Hub <http://sciencelearn.org.nz/> <https://beta.sciencelearn.org.nz/>

The Science Learning Hub is an online repository of teaching resources to support science education for teachers, students and communities. The hub is funded by the Ministry of Business, Innovation and Employment and managed by the University of Waikato. The site is well worth visiting and contains an extensive collection of resources based on current NZ research and science activity, images, teacher strategies, videos, downloadable student activities and connections with scientists and citizen science projects. To become familiar with the site I suggest you allow time for initial navigation. The site is currently being redesigned.

Pond, Network for Learning collaborative online resource space www.pond.co.nz

University of Auckland Liggins Educational Institute, LENSscience <http://www.lenscience.auckland.ac.nz/en.html>

The LEN science programme was established by the Liggins Institute founding director Professor Sir Peter Gluckman. It runs for students from Years 7 to 13. The LENSscience programme is a school-university partnership that is closely linked with developing student Nature of Science skills and building student citizenship science capabilities.

Citizenship Science Projects – see Section Two of this report

Community Science Education Each region will have community science groups that may support your school. Such groups in the Auckland region include: Wai Care (promoting healthy waterways) <https://waicare.org.nz>
Enviroschools (environmental education)

<http://www.aucklandcouncil.govt.nz/en/environmentwaste/educationvolunteering/pages/enviroschools.aspx>

You can also apply for council grants to support environmental initiatives.

Royal Society of New Zealand <http://royalsociety.org.nz/>

The stated purpose of the Royal Society is to advance and promote science, technology and the humanities for all New Zealanders. This is a respected organisation. Among their many roles, the Royal Society Science Teaching Leadership Programme supports the national strategic plan for science in society. Approved teachers of Years 1 to 10 gain understanding of the Nature of Science through workshops and working in a scientific organisation for two terms. With their school leader these teachers then enhance the school's science programme.

NZ Science Teacher <http://www.nzscienceteacher.co.nz/>

New Zealand Science Teacher is published on behalf of the New Zealand Association of Science Educators (NZASE) by NZME, Educational Media. The website is updated weekly with news and views relevant to science education in New Zealand. The NZASE supports the Royal Society of NZ teacher leadership programme. There is a membership fee to receive the full print and digital editions and access the archive of resources. The objectives of NZASE include promoting science education throughout NZ, representing the interests of science educators, liaising between regional associations and developing overseas links.

The National Science-Technology Roadshow Trust. <http://www.roadshow.org/>

The Science Roadshow is an outreach programme that first 'hit the road' in 1998. The Roadshow promotes the STEM subjects and provides live shows, interactive exhibits and teacher resources to broaden student knowledge and experiences and connect them with the science and technology in the world around them. The exhibits change each year and link with the Nature of Science Strand. The Roadshow travels throughout New Zealand. \$8 per student in 2017, with teachers and adults attending for free.

The Sir Paul Callaghan Science Academy. <http://www.scienceacademy.co.nz/>

The academy is part of the Roadshow Trust and promotes the STEM subjects. Since 2012 the academy has been running an intensive 4-day professional learning programme for teachers of primary and intermediate students. The academy provides a forum for connecting teachers who celebrate science and sharing best practice in primary science teaching. There is also ongoing support through an alumni network.

I attended in September 2015 and can see why teachers have reported being re-energised by the programme. The presenters are knowledgeable and encouraging and there is a good mix between exploring current educational research, the Nature of Science capabilities and enacting this through hands-on practical inquiry activities. The aim of the project is to encourage teachers and school leaders to become science champions and promote science within their own schools. The Academy is supported by our Ministry of Education who are currently sponsoring course enrolment.

The Te Toi Tupu Consortium (Cognition Education, CORE Education, NZCER, University of Waikato, Waikato-Tainui College for Research and Development).

Te Toi Tupu was awarded a Ministry of Education contract to provide primary science education PLD from 2012 to 2016. Schools applied for the in-depth support, which had limited spaces available. Part of the contract was also to provide a series of workshops to introduce the science capabilities framework to schools catering for Year 0-8 students in the North Island. The two day workshops were open for free registration. Along with science lead teachers from my school I attended a series of Te Toi Tupu workshops in 2015/16. The facilitators were keen to share their expertise and support school science development.

Private Science PLD Providers

An example of private PLD provision is the 2015/16 NZEI Centre of Educational Excellence and the MacDiamid 'Korero with Scientists' pilot programme. Along with science leaders, I attended a couple of these sessions and they were excellent. Our facilitator was Dr Sarah Kenworthy, who arrived with such enthusiasm and a suitcase of resources and ideas to share. <http://www.sarahthescientist.co.nz/>

The other positive about this workshop model was that it provided an opportunity to meet science teachers from other schools.

Reviewed Allocation for Centrally Funded PLD

In 2016 the Ministry of Education reviewed the way in which Ministry sponsored Professional Learning and Development (PLD) would be structured - what it focused on, who delivers it and how schools, kura and Communities of Learning can access it. Facilitators are now accredited and schools have more flexibility in nominating which facilitator they feel would best suit their context. Schools apply for centrally funded PLD by submitting an application that is centred on the inquiry model. The proposal includes details about what the school is hoping to achieve, current practice and achievement, stakeholder input and expertise required to implement the plan.

Science (pūtaiao) is included as a priority area for the next 3-5 years, along with pāngarau/maths, te reo matatini (pānui, tuhiuhi, kōrero)/reading and writing and digital fluency.

Cluster networks and Community of Learners

A culture of collaboration across schools is based around developing a growth mind-set that is keen to explore and initiate ways to make learning work for every student, in every school, better. This means sharing ideas and working together to grow these. Leaders of curriculum areas are charged with developing their school programmes and supporting their colleagues. However, to continue to be inspired, lead teachers also need professional learning and the opportunity to have dialogue and learn at their higher leadership level. Issues of release time and workload can present barriers for network engagement. With principal support in this regard I believe the benefits would be worthwhile. A cluster network for science lead teachers could enable Gluckman's vision of the school science 'champions' to become a reality.

Community of Learners school clusters are currently being initiated across New Zealand. Through collaborative practice and clear action plans these CoLs may provide an opportunity to share practice in science education and explore pathways for student learning from early childhood education to high school level.

New Zealand Science Festivals:

SciFest: The New Zealand International Science Festival www.scifest.org.nz/

This biennial, one-week event is held in Dunedin (since 1998 and most recently in July, 2016). Core sponsors are the Dunedin City Council and the University of Otago. The aim is to celebrate promote and raise awareness of science technology and the environment.

Space and Science Festival <http://spacesciencefestival.org/>

This one-day festival was held for the first time in May 2016, from midday till 10 p.m. so participants could observe the night sky. Themes included space and telescopes, energy and motion, life forms, the elements, light and sound, robots and machines. Sponsors included Wellington City Council, Victoria University, the Carter Observatory and the MacDiarmid Institute.

Canadian Professional Learning Opportunities and Resourcing for Science

There is a high level of public engagement with science and technology in Canada. Every province has a science festival, and universities and science related organisations encourage people in the community to come along and engage with science and scientists. Attendance at many of events is free or at very reasonable rates, and significant numbers of people from all walks of life are attending and engaging with science.

I had the opportunity to attend the tenth 3-day Montreal Eureka Science Festival, it was free and was packed on Friday with school students and on the weekend with people of all ages. It was uplifting to see families enjoying learning about science together – and to see the diverse number of science related organisations that had come along to present.

Canadian teachers have greater support than their New Zealand colleagues to enrich their science programmes by connecting with scientists in the field. I met with co-ordinators of the Science in Schools programme at TELUS World of Science to find out more about how their association supports schools. SiS coordinators make connections and encourage scientists to be part of the volunteer programme, they then value these professionals by supporting them to put together a presentation, providing workshops and advice on communicating with teachers, managing materials and connecting with students. SiS works directly with schools to organise a suitable programme. I certainly was impressed with the range of volunteers and support for schools.

I also visited a range of science centres across Canada, including a number of geological sites, the Vancouver Aquarium Marine Science Centre, Science World at TELUS World of Science, the Royal Tyrrell Museum of Palaeontology, Montreal Biodome, Planetarium and Insectarium, plus a tour of the Triumf Nuclear Physics lab to see one of the world's largest cyclotron vaults. In San Francisco we spent an afternoon at the Exploratorium, which is described as a public learning laboratory exploring the world through science, art and human perception. Though separately owned and managed, many of these centres belong to the **Canadian Association of Science Centres (CASC)**. CASC assists with programme development and holds an annual conference. CASC represents 45 science centres, museums, planetariums and aquariums across Canada. Their role is to increase science literacy among Canadians of all ages – to be meeting places for science and society, to demystify science, convey its beauty and make science accessible for the general public.

Innovation 150 <https://www.canadiansciencecentres.ca/INNOVATION150>

Innovation 150 is being organised by CASC and will take place in 2017. It will be a year-long celebration of Canadian

science and technology innovation, with events held across Canada. It is sponsored by the Ministry of Canadian Heritage.

A Snapshot of Canadian Science Festivals

Science Rendezvous – where people and science meet <http://www.sciencerendezvous.ca/>

Science Rendezvous is an annual festival (held in May) that takes science out of the lab and into the street. The organisers work with Canada's top research institutes (including Toronto University and Let's talk Science) to present a coast to coast festival that is free to attend – over 300 events held in 30 cities across Canada. Over 200,000 people attended the 2015 event.

Science Odyssey <http://www.ic.gc.ca/eic/site/064.nsf/eng/08040.html>

Science Odyssey involves a whole range of outreach science organisations. A week-long celebration of science in Canada, held in September each year. This event includes public talks, science demos, nature hikes, star parties etc. Science Odyssey will take place again in May 2017, with a separate Science Literacy Week planned for September, 2017.

Beakerhead <http://beakerhead.com/about> <http://beakerhead.com/media-archives/stories>
<http://beakerhead.com/media-archives/past-events/>

Beakerhead is described as a festival where technical and creative streams collide: science and engineering presented through art and performances. The core educational purpose is to inspire tomorrow's workforce, stimulate ingenuity and engage the public in these disciplines and learn by doing. The festival runs every second even year in September. Community members are encouraged to volunteer to assist with the event. Calgary University is a major sponsor.

Beakerhead is also connected with other programmes throughout the year, for instance in 2016 there was a community catapult competition, Engineered Eats where restaurants across Calgary created new dishes based on milk (Beakerhead also ran workshops), Extreme Board Gaming where an expert joins your team to play a board game (e.g. Operation with a real doctor or Clue with a forensic scientist), forums where innovative designs from Gen Next are shared, free presentations from interesting speakers and the school programmes

<http://beakerhead.com/programs/school-programs>

Calgary Youth Science Fair <http://www.cysf.org/>

The largest regional science fair in Canada, (with Calgary University a major sponsor) and running since 1962. The fair is held annually in April and open to students from Grade 5 upwards. Enrolments are largely through schools. The aim of the fair is to inspire youth to discover their potential in the STEM subjects (Science, Technology, Engineering and Maths).

The Eureka Festival

The 3-day Eureka Festival is held every year in Montreal (the next event is June 2017). A real celebration of science and innovation, including interactive shows, lectures (some of which are in only in French) and fun workshops (like being a palaeontologist and constructing a bridge model). The stands are diverse and arranged in zones: Nature, Aerospace, Engineering and Discovery. The stands are set up by a range of people; from tertiary students sharing their projects to those in industry and private practice, like chiropractors sharing how skeletons work. Every stand has information, displays, and enthusiastic hosts. People learn well when they are solving problems so every stand has at least one hands-on activity.

A Snapshot of Canadian Outreach School Support Programmes:

Scientists in Schools Programme <http://www.scientistsinschool.ca/index.php>

Founded in 1989, the Scientists in Schools (SiS) programme is a federal initiative and Canadian charity dedicated to assisting students from Kindergarten to Grade 8 become 'scientists in their school' and develop a long term interest in the STEM subjects. The programme connects schools with the opportunity to interact with ecologists, physicists, engineers and scientists in a number of industries, who visit for approximately 45 minutes to share their expertise.

Let's Talk Science Outreach <http://www.letstalkscience.ca/programs-resources/programs/outreach.html>

Let's Talk Science helps schools in provinces across Canada to make connections with STEM tertiary students, professionals and industry partners. Let's Talk Science Outreach sites can be found at over 40 university and colleges across Canada. Outreach volunteers visit schools and community groups to engage youth in hands-on/minds-on STEM learning experiences. These programmes are free of charge.

E-Learning: Tools to enrich student understanding of science concepts

Fitzgerald (2013), notes in *Learning and Teaching Primary Science*, how, “today’s schools operate in the context of a generation of young people who are growing up highly familiar with information and communication technologies” (p. 74). It is easy to assume that the majority of today’s youth have grown up as ‘digital natives’ with access to digital devices, however recent research shows that this is not necessarily so. This is reflected in Wylie and Bonne’s (2016) NZCER report, *Secondary Schools in 2015: Findings from the NZCER national survey*. They note the disparity between secondary students, across all deciles, in their access to digital devices and their ability to utilise digital information effectively for learning. The survey is summarised by Dooney (2016) who briefly discusses the equity issues for schools with Bring Your Own Device (BYOD) environments. Fitzgerald (2013), also notes that even if familiar with the digital environment, students may still be novices when using ICT to effectively support learning (p. 75).

In their report, *Building a Future Orientated Science Education System in NZ: How are we doing?* Gilbert and Bull (2013, p. 6), note that analysed data showed that digital technology was largely one-way (locating information, collecting and analysing data) rather than interactive, two-way collaborations designed to create new knowledge (such as questioning a scientific expert). Digital technologies were in general, being used to support existing practice rather than develop next practice.

Reports of disparity in student ability to utilise technologies and teacher uncertainty in utilising and managing the increasingly digital environment for learning, are important for us to consider when making provision for supporting our school e-learning development. The role for educators is to harness student interest in digital technologies to enrich learning in science. Fitzgerald (2013), supports the findings of Gilbert and Bull (2013, p. 13), that science needs to be relevant for learners, reflect contemporary science practice and connect with real world issues.

So what should future-focused science digital use look like? Access to the internet has provided schools with a rich resource of information and ideas to draw from. Closer engagement with the wider science community would support future-orientated science learning, and the net brings the opportunity to connect with others in the context of real science. An example of this are the citizen science programmes where students have the opportunity to take part in real life scientific research.

The network enables connected groups to take ideas, “further and faster than any individual could. The knowledge created is *in* the collaborative space, not in individual heads” (Gilbert and Bull, 2013, p. 12). They recommend that, “the networks which digital technology use enables need to be utilised. Future-oriented science education would foster students’ active engagement in designing their own learning in the network —doing ‘real research’ in collaborations with people outside schools, including scientists, as well as with other students. This approach scaffolds, mirrors and engages with real-world, 21st century scientific practice, and it is likely to be far more engaging for students than traditional transmission-of-knowledge approaches” (p. 6).

The internet can provide access to information and resources for inquiry learning, including connecting with others and exploring ideas. Different e-networked tools can be utilised at various points in the inquiry cycle (the table below gives examples of how a range of digital tools can be used to support student learning in science).

It is important to support student internet with teaching students e-network inquiry practices, such as:

- How to search for information effectively,
- Critical literacy skills: Gluckman, (2011) noted that the quantity of internet information available means it is important that we teach our students critical literacy skills to distinguish between reliable and unreliable information.
- Digital citizenship: including the responsibility of acknowledging others’ work.

Digital infrastructure for education is an area of considerable investment from the Ministry of Education and schools and selective use of digital technologies and information can enrich learning. Gilbert and Bull, (2013) noted that investment in technology is not enough in itself to effect this paradigm change in approach. School leaders have an important role in developing an environment to support e-learning use and inquiry. As noted by Bolstad and Buntting (2013), e-learning use can be supported by:

- ensuring effective ICT infrastructure, including robust networking platforms and wireless access
- provision of technical support and regular upgrading of system / tools to align with changing needs
- provision of sufficient numbers of, and quality, e-learning devices and tools
- adopting policies that encourage productive e-learning and provide a framework for responsible use

- establishing flexible curriculum structures
- establishing flexible assessment structures
- focusing on developing teacher e-learning pedagogy and capability with ICT (so know why to use it and how)
- support innovation and creative use of e-learning in practice

The following table provides examples of digital technology use:

Digital Tool	Suggestion for use to support science understandings
Search engines, Webquests, YouTube	Accessing ideas and resources (reports, images, videos).
Digital microscopes	Allows for close observation.
Digital photographs and videos	Close observation. Time lapse photography allows viewing changes over time. Videos can be used for presentation of student explanations and for viewing slow motion action.
3-D animations and simulations	Assist in making abstract concepts more understandable.
Apps	Allow for easy manipulation of data and variables.
Digital probes and motion sensors	Collection of accurate data.
Virtual field trips	Ready access to laboratory or industry scenarios e.g. LEARNZ. Online field trips that students can follow in real time. http://www.learnz.org.nz/
Virtual networking	Enables connection between students and others, including scientists.
YouTube, Blogs Online post-it notes e.g. Wallwisher	Sharing of data, communicating ideas and asking questions.
Moodle forums	Facilitating class discussion.
Skype and email	Asking questions and connecting with others, including scientists in the field.
Google survey	Collection and analysis of data.
Google PowerPoint, Prezi, Glogster	Online presentation tools to co-construct and communicate inquiry findings.
Google Maps and Google Earth	Understanding the environment.
Google docs	Building knowledge through the co-construction and sharing of ideas.

Recommendations

For this section I draw upon my own reading and experience plus the analysis of our education system by researchers, including Vannier (2012), who noted commonalities among schools with successful science instruction in the report, *Primary and Secondary School Science Education in New Zealand (Aotearoa) – Policies and Practices for a Better Future*, (2012).

Recommendations to Schools

School leaders are charged with ensuring science programmes align with the New Zealand Curriculum, and link with the wider purpose of science education by providing opportunity for our students to, “explore how both the natural physical world and science itself work so that they can participate as critical, informed and responsible citizens in a society in which science plays a significant role” (NZC, p. 17).

We have a responsibility to continue to develop our understanding of best teaching and learning practice, and link our programmes to an increasingly scientific and technological society. Supporting teachers to develop their practice is a critical component. It is each teacher’s responsibility to keep up with current practice and apply what is learnt from professional learning opportunities.

Recommendations for school leaders include:

- Ensure science is seen as being valued by the school leadership team (principal, lead science teacher and members of the senior leadership team). Promote a shared vision.
- Support teachers in being innovative and taking learning risks with their students as they strive to realise the school/NZC vision.
- Provide professional learning opportunity for teachers. A school-wide focus enables deeper development of instructional practice and assessments, with a focus on student understanding.
- Establish and support an effective team based system to encourage teachers to collaborate to plan and implement instruction.
- Where possible, structure the school timetable to create shared planning periods for teacher teams to meet.
- Where possible, be creative in the way staff are deployed and budgets are allocated to improve science instruction.
- Focus on engaging students and teachers with science that is current and relevant to their lives.
- Structure the science learning practice to link with how children naturally learn (consider student level, opportunity to collaborate, emotional connections and imagination).
- Utilise Inquiry-based, hands-on experiences that engage students and are structured to develop student understanding and capabilities.
- Acknowledge the cultural understandings of students and whanau, and promote valued connection with tikanga Māori.
- Resource so technology can be used in meaningful ways. Provide effective infrastructure, robust networking platform and wireless, digital technical support, provision of e-learning devices, adopting policies that encourage productive e-learning, resource teacher PLD for e-learning pedagogy and capability, and support innovation.
- Look for opportunities to enrich the school based programme by linking with the wider scientific community.

In her paper, *Unlocking the Idea of Capabilities in Science* (2014), Hipkins notes, “The biggest challenge of all relates to dispositions. You can’t make people critically engage with science. If we want today’s students to do so as tomorrow’s citizens we have to show them how, give them lots of practice, *and* support them to see these as things they can do, and want to do, for themselves. A few unrelated experiences in school science experiments won’t be enough because *demonstrations of capability* are multifaceted and context-specific, and you have to want to deploy them. For these reasons capability-building requires lots of related experiences that make a powerful impression on students and that build over time.”

Provide professional development and support for school science lead teachers

In the schools Vannier (2012) identified as having strong practice, there was dedication to ongoing nurturing of science education and team based collegial support. In turn, team work improved the confidence, content knowledge and instructional ability of all teachers. Sir Peter Gluckman (2011) recommended improvement of New Zealand primary science education through development of science strength in a small number of teachers within each school. In his vision, Gluckman called these teachers ‘champions of science.’ Such teachers would be identified on the basis of their willingness and potential to champion science within their schools. Principals could, in return, support their science leaders through the provision of in-depth professional development and membership of a primary science

cluster group to share good practice and strengthen student education pathways (there is a further note about utilising science champions in the recommendations for MoE below).

Recommendations for the Ministry of Education

Leaders of schools in New Zealand are both blessed and challenged by the opportunities and responsibility of such autonomy in guiding our school's curriculum. As noted by Vannier (2012), "Principals and other school leaders play a critical role in carrying out the NZC by the emphasis they place on learning areas and the professional opportunities they seek for their staff" (p. 43). The relationship between principals and Ministry of Education officials is important. School leaders do not make decisions in a vacuum, they are able to use their local context knowledge to make relevant decisions about programme development, but are influenced by ministerial pressures. Vannier's research recognises that there is a "tension for government policies to respect the autonomy of schools while guiding and enabling positive actions towards common goals" and acknowledges that consistency is required in the messages received from MoE, ERO and NZQA about instructional priorities (reducing competing priorities so the value of science curriculum development can be recognised).

Educators and researchers are questioning whether the current provision of support for schools is enough to produce a significant improvement in science engagement for the next generation of New Zealanders, and build a more future-oriented science education system. In research by Wylie & Bonne (2014), 53% of principals responding to an NZCER survey said they could not readily access external expertise or knowledge in science (as cited by Bull, 2016, p. 1).

In Bull's recent research about science PLD provision for New Zealand primary schools, she reports that many of the providers focused on 'one-off sessions' and shorter term support, only 12% said they provided PLD that extended to at least 6 months. The emphasis on short term PLD is questionable. A major concern is the lack of confidence many primary teachers felt regarding their ability to incorporate the Nature of Science capabilities into their teaching. Further time is required for teachers to engage with new ideas, increase their PCK and science understandings, then adjust their practice. The crowded curriculum, competing national priorities and insufficient resourcing are all identified as barriers for developing our science education development.

Vannier (2012, p. 41) made a number of recommendations which I believe are still relevant. I incorporate these here, along with additional suggestions drawn from my readings, including the report from Bull (2016), and my Fellowship study interactions.

- **Provide schools with consistent, tailored support for science.**

Discontinuation of the university science advisory in 2009 left a gap in assisting schools to identify resources and make links across schools and with community science programmes..

Continuing to include science as a priority subject for MoE PLD is a step in the right direction. To meet demand, further investment in professional learning and resourcing for science within schools is required.

- **Increase support for schools to connect with the wider science community.**

As noted by Bolstad and Bunting (2013), "schools on their own simply can't provide all the learning experiences and resources students need in order to truly engage with 21st century science... they also need access to the expertise, knowledge, resources and support of the science community and wider community" (p. 10). Consideration should be given to supporting schools further with making connections with the scientific community (at present it is varied dependent on region and personal contacts). The Canadian Scientists in Schools model is an effective example.

- **Enable collaboration and strong leadership within schools.**

Vannier's positive case study schools all had collaborative environments in common. It is suggested that MoE explore policies that promote and enable collaboration, e.g. improved staffing provision to enable release for meetings, management units for leadership, sponsorship for teachers to complete papers/workshops in science education (some provision of this nature is happening, e.g. sponsorship of the Sir Paul Callaghan Academy attendance and the Hutt Valley Primary Science Education Network).

- **Include science in formulating current policies on pre-service teacher preparation.**

To be successful teachers of science there needs to be subject-specific content and pedagogical knowledge for teaching science within teacher training programmes. One-year post-graduate teacher training programmes limit the time for such professional development, so continued PLD within schools is vital. The necessity for this recommendation is also noted in the Nation of Curious Minds education plan (p. 24).

- **Encourage Ministry funded PLD providers to interact with each other and with the science community.**

The competitive environment for PLD providers is acknowledged as a potential limiting factor. However, opportunity to interact would build a more connected PLD landscape with common goals, whilst still maintaining the ability to be creative about the means of delivery (Bull, 2016, pp 10–11).

Connection with science in the real world is also essential so our education programmes are linked with science in society. The comment below regarding investing in a ‘scientists in schools’ programme applies to MoE as well as other government ministries.

Bull (2016) also makes an alternative suggestion regarding the development of Gluckman’s (2011) school ‘science champions,’ “Instead of these science champion roles being occupied by keen teachers with a passion for science and who do the job on top of all their other responsibilities, what if they were occupied by specialists whose full-time job would be to lead and support science learning across clusters of schools? These people would need to have expertise in science education and to be experienced adult educators who are familiar with how schools work, but would also need to have strong links with the science community. If this type of structure were adopted there would, of course, also be a need to rapidly build a workforce that could fill these roles. Without such career pathways there are currently few incentives (or opportunities) for science educators to commit to the type of in-depth learning and development that is needed” (p. 12).

I can certainly see the rationale behind this suggestion. If designed and managed well (with opportunity to share and grow specialist practice), and funded adequately, such a resource could assist with aligning school programmes with the purpose of science education and connect schools and scientists. As opposed to the current PLD system, this proposal could implement school science development within the time frame outlined in the *A Nation of Curious Minds* project.

Another alternative could be for the Ministry to fund facilitators to run regular cluster science lead teacher workshops, in much the same manner as the maths lead teachers were supported. This would then provide an opportunity to develop and support the school champions of science, who could then be more informed when assisting with their own school development. A package could be developed that provides each school with the opportunity to send lead teachers to two workshops a term, with further opportunity for facilitator support.

Recommendations for the Science Community

Vannier (2012, p. 42) acknowledged the professional science community for their active engagement in promoting science in primary and secondary schools.

His recommendation is to **engage all stakeholders with a focus on science education.**

As noted in the Ministry recommendation above, there is real value in strengthening connections, and discussing common needs and goals. Positive New Zealand examples of such a meeting of minds are the 2012 the Transit of Venus conference and the Nation of Curious Minds Project.

The role of science education is linked with the economic future of our country. Business and government leaders in Canada see science education as playing a critical role in workforce development, as is evidenced in the promotion of STEM subjects through initiatives such as the Canadian festival sponsorship, Scientists in Schools and Let’s Talk Science. The Canadian Association of Science Centres also provides a collaborative model for such enterprises to connect and develop their practice.

It is suggested that our Government Ministries look further at initiatives such as these and expand their investment in science education to enable clearer connection between schools and the wider science community, to inspire young people to forge a career in science and technology, and to developing citizenship capabilities by strengthening public engagement with science and technology.

Summary

My Fellowship travel in Canada indicated to me that educators in both countries are striving toward similar goals. There is a sense of growing concern about the need for STEM subject development for the future prosperity of both our countries. Our curriculums reflect our common understanding about the purpose of science education for citizenship, now and in the future. We wish to inspire our students to be involved in science projects and to use their ideas creatively and collaboratively. We know we need to provide a bank of science related experiences for our young people and teach them what it means to be a scientist, so they can develop science for citizenship skills. Both countries have growing citizen science programmes and have also recognised that society and our science education will be enriched through inclusion of our indigenous peoples' ways of thinking about science.

The most significant difference for me was the higher level of public engagement with science and technology in Canada. Every province has a science festival, which is supported by science related organisations and well attended by the Canadian people. The goal is for every Canadian child to have multiple opportunities to be sparked by science during the formative education years and Canadian teachers have greater support for enriching their programmes by connecting with scientists in the field.

In my research I have found that there is an exciting and diverse science education community in Aotearoa, both in schools and in the science community – and a real willingness to share expertise to improve science education and promote science nationally. However, to navigate such diversity of programmes does take time, and if as a country we are to effect the Twenty-First century vision of, “ensuring young New Zealanders are enthused by science and able to participate fully in a smart country where knowledge and innovation are at the heart of both economic growth and social development” (Gluckman, 2011, p. 1), as has been suggested in a number of research reports - now is the time to take a milestone check point and look at progress and alignment across education, government and business sectors in meeting this common goal.

The 2014, A Nation of Curious minds strategic plan supports this alignment and acknowledges the key role the New Zealand government plays in facilitating better citizen engagement with science (p. 5).

Enhancing the role of education is one of three identified action areas in this plan, the aims of which are to:

- Improve initial teacher education through increased science and technology teaching competencies, leading to increased confidence
- Better in-service professional learning and development for science and technology teachers
- Build stronger links between science and technology educators, learners, technologists and scientists, in the classroom and in the community

This is encouraging for educators. However, though the recommendation to support the development of science education features in a number of research reports, initial implementation of this intention has not yet filtered down to many of those on the chalk-face. Is there a faster way to support schools with their science programme development in the immediate future?

Vannier (2012, p. 44) noted that the autonomy of players in the New Zealand science education arena has resulted in what can be described as a 'patchwork of programmes'. Bull (2016), reported, “Although there is quite a lot of activity in primary science PLD and a reasonable diversity of both providers and programmes, there does not appear to be much connectivity between the different players in the system” (p. 10).

As the principal of a New Zealand primary school I certainly have that impression. The reality for many principals is that leading a school is a multifaceted job, we become clever at managing the complexities of the position, whilst also self-reviewing and developing the learning opportunities for our students – but many of us are pressed for time and restricted by budget requirements. I for one would appreciate the development of an overarching body that would assist schools to develop programmes, and connect with quality science PLD and scientists in the field.

Gluckman (2011) urged us to think laterally about science education - inclusion of programmes such as funding for science lead teacher mentoring and a scientists in schools programme could be part of a development package for schools.

It is in society's interests for all members to be able to constructively and intelligently consider scientific issues, and New Zealand science education would be strengthened by a clearly articulated direction for development. I conclude this report with a quote that I feel is still relevant today:

"New Zealand must embrace science and technology and innovative thinking as a core strategy for its way ahead. There is no doubt in my mind that a population better educated in science, whether or not they will actually use science in their career, is essential.

I believe that by encouraging innovative thinking
by educational policy makers, teachers and the science community,
and by thinking more laterally about how science education might be conducted,
we might move from what is an adequate but promising situation to one that could be outstanding"

Chief Science Advisor, Professor Sir Peter Gluckman, *Looking Ahead: Science Education for the Twenty-First Century* (2011, p. 8)

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Appendix 1: Comparison of New Zealand and Canadian Schooling Grade systems

<p>Canadian Schooling Grade level system Students are required to be in Grade 1 the year they turn 6. As education is managed by different provincial governments in Canada there are some differences between regions. Junior High/Middle school starts in most provinces at Year 6 or 7. A Grade structure by Canadian province is available on Wikipedia https://en.wikipedia.org/wiki/Education_in_Canada</p>			<p>New Zealand Schooling Year level system Students turning 5 enter at Year 1 (if start at beginning of school year or before cut-off date, 31 March in legislation (later in most schools). If enrolling later in the school year they may be considered as Year 0, and start Year 1 at the beginning of the following year. Schooling is compulsory from 6 to 16 years of age.</p>				<p>How curriculum levels typically relate to years at school</p>
Early Childhood Education	Kindergarten	5-6 years old	Primary School		Year 1	5 years old	1
Elementary School	1st Grade	6-7 years old	Contributing Primary to Year 6, Full Primary to Years 7/8		Year 2	6 years old	1
	2nd Grade	7-8 years old			Year 3	7 years old	1-2
	3rd Grade	8-9 years old			Year 4	8 years old	2
	4th Grade	9-10 years old			Year 5	9 years old	2-3
	5th Grade	10-11 years old			Year 6	10 years old	3
(In Quebec High School starts in Grade 7)	Middle/Junior High School 6th Grade	11-12 years old		Intermediate School level Years 7/8		Year 7	11 years old
	7th Grade	12-13 years old			Year 8	12 years old	4
	8th Grade	13-14 years old	High School		Year 9	13 years old	4-5
High School	9th Grade /Freshman	14-15 years old			Year 10	14 years old	5

Appendix 2: An outline of the Science Capabilities and the Nature of Science Strands they relate to

I wish to acknowledge that this layout is based on a resource from the Sir Paul Callaghan Science Academy

The Ministry of Education Five Foundational Science Capabilities for Citizenship Learners need a functional knowledge of science in order to be able to: say what science is, say what its strengths and weaknesses are, ask informed questions about science issues	
Foundational Science Capability	Nature of Science sub-strands they relate to
Gather and Interpret Data Learners make careful observations and differentiate between observation and inference. <i>Science knowledge is based on data derived from direct, or indirect, observations of the natural physical world and often includes measuring something. An inference is a conclusion you draw from observations – the meaning you make from observations. Understanding the difference is an important step towards being scientifically literate.</i>	Understanding About Science and Investigating in Science
Use Evidence Learners support their ideas with evidence and look for evidence supporting others' explanations. <i>Science is a way of explaining the world. Science is empirical and measurable. This means that in science, explanations need to be supported by evidence that is based on, or derived from, observations of the natural world.</i>	
Critique evidence Not all questions can be answered by science. <i>In order to evaluate the trustworthiness of data, students need to know quite a lot about the qualities of scientific tests</i>	
Interpret representations Scientists represent their ideas in a variety of ways, including models, graphs, charts, diagrams and written texts. <i>Learners think about how data is presented and ask questions such as:</i> <ul style="list-style-type: none"> • <i>What does this representation tell us?</i> • <i>What is left out?</i> • <i>How does this representation get the message across?</i> • <i>Why is it presented in this particular way?</i> 	Communicating In Science
Engage with science This capability requires students to use the other capabilities to engage with science in “real life” contexts. <i>It involves students taking an interest in science issues, participating in discussions about science and at times taking action</i>	Participating and Contributing
For further information about the Science Capabilities visit Science Online Te Kite Ipurangi http://scienceonline.tki.org.nz/Science-capabilities-for-citizenship For further information about the Sir Paul Callaghan Science Academy visit www.scienceacademy.co.nz	

Appendix 3: Science Capabilities and related discussion prompts, learning intentions and concepts

I wish to acknowledge the Sir Paul Callaghan Science Academy as the source of this resource.

For further information about the Sir Paul Callaghan Science Academy do visit www.scienceacademy.co.nz

Capabilities	Discussion prompts, specific learning intentions and concepts they may relate to:
<p>Gather and Interpret Data Learners make careful observations and differentiate between observation and inference.</p>	<p>Asking good questions to initiate investigations Observe carefully using all senses Systematic observations (what happens first, second,...) Note taking to record an event or behaviour Counting (as opposed to guessing) Recording data Measuring (length, weight, force, time, angle, temperature) Differentiating between an observation and an inference What is evidence? Gathering evidence Careful labelled diagrams/drawings Estimating Refining observations using instruments e.g. magnifying glasses Repeating and checking observations or data collecting Pooling data and sharing findings Predicting before gathering data Making an experimental model (miniature, large or conceptual) to test an idea Developing a system for testing an idea Being systematic in the way something is investigated (steps are reproducible and traceable so causes can be identified) Trying different approaches Comparisons Identifying and controlling variables. Fair testing The role of creative thinking in investigations What can you infer from this data or these observations? Finding averages, mean, mode, median Identifying trends in data Representing data using tables, graphs, plots, scattergrams, tally charts Pattern and trend seeking Grouping things Classifying the same set of objects in different ways</p>
<p>Use Evidence Learners support their ideas with evidence and look for evidence supporting others' explanations.</p>	<p>Identifying evidence that will support an idea or explanation Identifying things based on their properties or common features What do certain patterns mean? Recognising and naming things using evidence Does your data support your idea? Building on prior knowledge and experiences to develop understanding What do you know already that will help your explanation? Analysing data: what does it mean? Logical thought Creating hypotheses Hypothesis versus Theory versus Law Use a model to support a scientific idea Let's think like a scientist Create analogies to explain something Using graphs and data to support claims Cause and effect Applying scientific ideas and knowledge in unique ways What evidence have you got for that? Simple explanations – what would be the simplest way to explain that? What conclusion can you draw from this? Justify your conclusion Do you know what they used to think in the old days? How could you check that? Is science moral or immoral? What is the accepted theory? Science is an accumulated knowledge system Developing new questions</p>

<p>Critique evidence Not all questions can be answered by science.</p>	<p>What does objectivity mean? Attempting to be objective (intellectual honesty, open minded, thinking critically, no emotions involved) Which evidence supports and which evidence refutes that idea? Questioning the accuracy of information Testing a model to see if it behaves like the real thing How accurate were your measurements? Can they be improved? Is that a fair test? How is the model you made different from the real thing? Identifying similarities and differences in results and what these might mean Do the results support your prediction? Identifying sources of error Have variables been controlled? Is there only one variable? Can we be 100% certain of this? Is that consistent with your other findings? Where are the sources of bias and how could we reduce them? Is there a simpler way of showing that? Comparing and contrasting findings Is the source of information or evidence reliable? How do you know? What would happen if you changed variable x? What further investigations would be needed to support/confirm your ideas? Did x cause y? Critiquing other students' methods Tell me what a scientist would do to check this Peer reviews Did other people find the same thing as you? Is correlation the same thing as causation? How would other cultures or religions interpret this? Can humans truly think objectively? How reliable are newspapers and the internet? What would you think if new evidence showed that...? Can we ever be certain? The tentative nature of science</p>
<p>Interpret representations Scientists represent their ideas in a variety of ways, including models, graphs, charts, diagrams and written texts.</p>	<p>How do we share knowledge and findings? What do these graphs mean? Analyse bar graphs, line graphs, pie charts, scales on axis Interpret labelling and descriptions on graphs, diagrams and posters What is the best way of summarising that data? Scientific vocabulary, specialised terms and writing structure e.g. using the passive voice for reports Discussion and arguing a point of view Listening to and countering others' arguments Alternative forms of communication such as poems, songs, rap, posters, interviews Counting, ordering of data, markers, counters, numeric systems such as averaging (mean, mode, median), basic units e.g. c, m, kg Meanings of symbols, arrows, + and -, H₂O, word equations Conventions of science e.g. placing keys, levels of magnification, scales on drawings, other imagery Scaled drawings, photos, video, written labels Documenting processes Representing findings using a variety of media e.g. visual, oral, text Reading and engaging with specialised text, e.g. through Connected series, newspaper and magazine articles etc. and understanding their purpose Websites, audio/oral, imagery and video Writing paragraphs, report writing Interpreting and following a method or procedure How would a scientist let the world know about this new idea?</p>
<p>Engage with science This capability requires students to use the other capabilities to engage with science in "real life" contexts.</p>	<p>Working cooperatively and sharing findings Engaging in discussions Using a scientific perspective Awareness of science in our lives - how does this science link to my world or everyday life? Science careers Engaging with environmental issues, medical issues, medical ethics, animal ethics, current scientific events Moral values versus science findings, which of these should determine decisions? Community and cultural influences on investigations Being aware of the needs of others Recycling action, energy saving, reduce-reuse-recycle, clean energy, decisions about energy generation, genetically modified organisms etc. Informed action Displaying an inquiring and critically thinking disposition Displaying a willingness to use scientific knowledge, skills and approaches</p>

Appendix 4: Dimensions of Discipline Based Inquiry

Sourced from Friesen, S. (ed). (2015). *Focus on Inquiry*. University of Calgary: Galileo Education Network.

<http://inquiry.galileo.org/>



Appendix 5: Summary of the Effective Teaching Profile, based on the Te Kotahitanga Māori research development project

Sourced from Set 2, 2009, p27 -33.

Māori Metaphor	What does this mean?	What might this look like in the learning environment?
Manaakitanga	<p>Caring for Māori students as Māori - acknowledging that they are culturally located, that they see, understand and interact with the world in different ways.</p> <p>Students in the study spoke of how they reacted to what they saw as unfair treatment; through selective absenteeism, retreating into themselves or 'fighting back'</p>	<p>Teachers thinking positively about Māori students and their families:</p> <p>Demonstrating positive, non-judgemental learning relationships with Māori students.</p> <p>Classrooms where Māori student humour was acceptable,</p> <p>where students could care for and learn with each other;</p> <p>where being different was acceptable,</p> <p>where the learning context enabled self-determination.</p>
Mana motuhake	<p>Caring for the performance of Māori students.</p> <p>Deficit thinking: Māori students in the study emphasised that teachers get what they expect from Māori students – if they perceived that the teacher thought they are not able to achieve they will respond to this perception negatively.</p>	<p>We require teachers who expect and allowed students to work interdependently,</p> <p>who held high expectation of students,</p> <p>who assisted them in reaching their goals.</p>
Ngā whakapiringatanga	<p>Creating a secure, well-managed learning environment</p>	<p>Boundaries and organisation are fundamental to effective learning – including teachers who know their curriculum area well enough to be flexible in delivery in response to learning conversations, to engage all learners and to enable students to contribute to their own learning and support the learning of others.</p>
Wānanga	<p>Engaging in effective learning interactions with Māori students</p> <p>As opposed to the whole class 'chalk and talk' style of delivery,</p>	<p>Teachers supporting a classroom setting where:</p> <p>Students were able to share ideas and interact with their teacher in smaller groups,</p> <p>Feedback and feedforward were provided,</p> <p>Opportunities to share prior knowledge were given,</p> <p>and this was valued and utilised in co-constructing the direction of their learning (described as dialogue and debate to reshape and accommodate new knowledge).</p>
Ako	<p>Using a range of teaching strategies</p> <p>The Māori understanding of ako is to learn as well as to teach</p>	<p>Teachers promoting a learning focused relationship where interaction and discussion is valued, where teachers can learn from students just as students learn from teachers, where co-construction of knowledge is likely to occur.</p>
Kotahitangi	<p>Using student progress to inform future teaching practices</p>	<p>Discussing student achievement with students in a constructive manner, so they are able to actively engage, reflect on and contribute to their own progress.</p>