# Review and Maintenance Programme (RAMP) Science

## Themes in the research literature

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# 1. Introduction

In the second half of 2014 the Ministry of Education initiated a process to review all materials funded and managed by them to support learning in the senior secondary school years – i.e. those years of schooling when achievement is predominantly assessed by achievement standards that build towards NCEA qualifications (National Certificate in Educational Achievement). The process was given the acronym RAMP (Review and Maintenance Programme). The stated focus was to ensure "that materials that support NCEA continue to be aligned with *NZC*[1] and support the development and use of quality teaching and learning programmes in the secondary school" (Ministry of Education briefing materials). For the purposes of the review support materials were to include all those associated with NCEA: the achievement standards themselves; the matrix of key outcomes that accompanies the suite of achievement standards at each of NCEA levels 1-3; student exemplars and other assessment resources; and any specified conditions of assessment. The on-line senior subject guides were also in scope. The science and mathematics & statistics learning areas of *NZC* were selected as the first to be reviewed.

The Ministry of Education sought several types of external input into the review process. By late 2014 a science advisory group had met twice, for two days each time. This group comprised teachers and science educators with demonstrated curriculum leadership and pedagogical expertise in one of the science disciplines (agriculture/horticulture, biology, chemistry, earth science, or physics). At the same time we (the authors) undertook a literature search for recent research related to implementation of NCEA in the sciences, and/or the uptake and enactment of *NZC* in the senior sciences, informed by wider research of science achievement in New Zealand across the years of schooling, and by associated policy debates. External input from teacher and students focus groups was planned for a later stage of the review process. Achievement data for at least three previous years, along with feedback from relevant groups in NZQA and MOE itself, constituted internal sources of feedback.

This report documents written input to the RAMP process from the literature review, which took place across a relatively short time span in late 2014.[2] Three specific areas of importance to MOE were outlined for the advisory group and literature review team as:

- The critical connection between the NZC, teaching and learning, and NCEA
- The needs of priority learners
- The effect of support materials on school programmes

[1] The *New Zealand Curriculum (NZC*) provides an overarching national curriculum structure for all the years of schooling (Years 1-13).

[2] An annotated Endnote file constituted the second source of input from the literature search.

With these priorities in mind the NZCER reviewers searched for all relevant local literature they could locate. A small number of large-scale international reviews were used to help organise the mainly smaller local studies, and to check for emergent issues that might be of interest in MOE as they determine their next steps in the provision of curriculum support for senior science learning. Search and selection processes are described in the appendix. We were surprised by the number of New Zealand-based papers we found. In all 92 references were added to Endnote file before we stopped, confident that we had captured the main themes.

The following sections summarise key findings, organised to reflect the areas of concern for the RAMP process, and informed where appropriate by our awareness of current concerns being debated in the international science education community. Note that this report does not seek to reach specific conclusions, which we see as the prerogative of the MOE's internal RAMP team. However the manner in which we have structured the results of the literature review process inevitably represents our thinking about the significance of the papers we found. Given that our own research is prominent in science education in New Zealand, it is important to note that the themes that emerge in this literature review accord closely with those that came to the fore during the advisory group process. These synergies suggest that the research-based concerns outlined here can be readily triangulated with leading teachers' actual practice and practical concerns, grounded in senior secondary science classrooms in New Zealand.

## A brief note on overarching themes

One important overarching theme is that alternative frameworks for considering issues raised in the literature lead to different sets of conclusions about alignment and support needs. One framework might be characterised as 'business as usual'; in other words, traditional curriculum thinking, assessment and pedagogical practice familiar to adults who were school learners in the 20th century. Alternative frameworks rethink these familiar assumptions and practices to arrive at different conclusions about appropriate curriculum, assessment and pedagogical practices for the 21st century. This reframing is apparent, for example, in the discussion of the nature of culturally responsive science pedagogy (section 2), in views about the how and why of teaching socio-scientific issues (section 3), in how e-technologies are used (section 4), and in how STEM[3] challenges are understood (section 6). Each of these sections outlines an aspect of the complex paradigm shift often referred to by using terms such as '21st century learning'.

*NZC* sends mixed signals in this regard, with a transformative, high-level front half, followed by a more traditional development of the Science learning area achievement objectives. NCEA achievement standards are more closely aligned with the traditional curriculum signals from the back half of *NZC* than with the transformative intent of the front half. However, as examples in the following sections make clear, leading teachers can find ways to transcend the limitations of the achievement standards to design and assess innovative learning programmes. There are limits

[3] STEM = science, technology, engineering and mathematics.

to what they can achieve on their own, however. For example, the paradigm shifts described in the curriculum discussion (section 3) often involve a more coherent weaving together of different learning areas. This demands structural changes that need the support of the school's senior management team.

Another challenge highlighted by the contrast between $20^{th}$ and $21^{st}$ century education paradigms is that support materials will be understood and deployed differently when teachers understand their purposes differently. This observation highlights the need for ongoing advisory support (section 7), not just the provision of yet more resources. There is also evidence throughout the review that paradigm change is difficult. Teachers need sustained support if they are not to revert to traditional practice as work pressures mount.

The voices of parents and whānau are rather ghostly in the review as a whole. There are glimpses here and there, and one documented instance of the consequences when their understanding of the purposes for learning was at cross purposes with the teacher's understanding and intent. Given the challenging nature of the 21st century paradigm shift, with all its complexities, this seems a significant omission. However, there are encouraging signs of recent consensus-building activities within the science and science education policy communities. Conversations between these diverse groups provide a good place to start when considering how to reach out to the community more widely.

# 2. NCEA: Supporting students to lift their achievement levels

NCEA was designed to support *all* students to demonstrate their learning and achievement. This rationale stands in contrast to the more traditional use of assessment as a sorting mechanism, enabling higher-ability students to gain qualifications while those with less academic ability 'fail' (Bolstad & Gilbert, 2008). Bolstad and Gilbert note that a specific reason for moving away from this traditional approach was that messages about being a learning failure run counter to the intention to foster every student's perception that they can be a successful learner.

In this way there is a direct link between the intent of NCEA and key *NZC* messages about building a curriculum that specifically meets learners' needs and supports them to become "confident, connected, actively engaged lifelong learners" (Ministry of Education, 2007). This section distils themes from those papers that inform NCEA's intent to support all students to experience success in science. Related findings from influential NCEA-related research that is not science-specific have been included where relevant.

## Challenges for lifting achievement in senior sciences

There is evidence that some groups of students need greater support in the senior-level sciences than they are currently getting if they are to experience success in NCEA.

**Evidence from the literature**

- Science has a greater spread of NCEA results between the highest- and lowest-performing students than most other subjects. While top science students achieve just as well in most other subjects, the lowest-achieving students struggle to pass any science standards, and average students do not pass as many standards with the same grades as they gain in other subjects (Boustead, 2008).
- Student achievement below expected levels is not confined to schools in poor socioeconomic areas. However, a combination of school decile and *middle leadership practices* is a good overall predictor of student academic achievement at Levels 2 and 3 NCEA (Highfield, 2012).
- Some externally assessed science standards make complex literacy demands, with Māori and Pasifika learners less likely to enrol in these standards and less likely to pass if they do enrol (Wilson & McNaughton, 2014).

- In one online survey, just 10–15 percent of responding secondary science teachers made suggestions about the best resources for supporting those with special education needs, and Māori and Pasifika students, within their science programmes. A third of all the teachers who responded to the survey (36 percent) did not see a need to differentiate between these and other students in their classes because “science is the same for everyone” (Hipkins & Hodgen, 2012).
- Across the curriculum, wharekura students experience higher rates of NCEA success than Māori in mainstream secondary schools. Key factors in this success include whānau involvement and identity—it is normal to be Māori. However, 50 percent of all wharekura students who achieve NCEA Level 1, 2 or 3 do not get any credits at any level in science/pūtaiao, and this outcome is much worse than for Māori in mainstream. Professional learning that addresses the educational focus is needed in order to balance the ideological strengths of a kura kaupapa Māori approach (Stewart, 2012).
- Although equity is intended, inclusive approaches to science education may stereotype students, appropriate their cultural backgrounds and alienate them from experiences of school science learning that could encourage their subsequent participation in science-related careers and/or democratic debates. The conscious juxtaposition of Western science with other cultural views of the natural world is one type of response to this complex set of issues. Three models for aligning Western science with other knowledge systems have been identified: cross-cultural, multicultural and pluralist. Dialogue about the issues raised is a necessary first step to achieving any change in relevant classroom practice (Waiti & Hipkins, 2002).

## What might help lift achievement?

Some research teams have investigated the consequences of providing specific types of support for students as they prepare for NCEA assessments in science. These can be broadly grouped into support that focuses on identifying and proactively addressing either *learning challenges* or *motivation* issues.

### Learning to learn: students and teachers address learning challenges

**Evidence from the literature**

- A deliberate and planned literacy intervention can lead to an increase in the number of Excellence and Merit passes. In one study, an initial analysis of students’ writing showed they could use key content words to compose factual statements in chemistry but could not link these with causal text connectives. This limited students to Achieved grades, even if they knew the content well. After a deliberate and planned year-long literacy intervention, students received more Excellence and Merit passes than students in what the teacher researcher called a 'neutral' class that had not received the literacy teaching (Whitehead & Murphy, 2012).

- Where specific achievement standards have been identified as being problematic because they make particular kinds of literacy demands, working with teachers to highlight achievement patterns motivates them to proactively address the literacy challenges implied. This can lead to increases in achievement levels (Wilson & McNaughton, 2014).
- Actively teaching students research skills is important. In one Level 3 biology study, students indicated they need both general and subject-specific research skills. They said that these were not always taught in other subjects, despite the inclusion of research-based assessments in these subjects (Farrant, 2014).

## Proactively addressing motivation/engagement issues

The papers included here have a specific focus on priority learners. Motivation/engagement in senior sciences is an across-the-board issue, however. Further papers that address this challenge for all students can be found under the 'pathways' theme (section 6).

**Evidence from the literature**

- A teacher who was recently awarded the Prime Minister's Science Teacher Prize has experienced a 30 percent increase in the number of Māori and Pasifika students taking science in the last 2 years, and pass rates have risen to 81 percent. Strategies she has used include: linking science to culture; using contexts relevant to and of interest to students; encouraging students to talk and communicate with each other, thus sharing their ideas; and bringing in knowledgeable community members (Wastney, 2014).
- A study of NCEA and curriculum innovation showed how NCEA's flexibility in the timing of assessments, and in course structures, allows teachers to hold high expectations for all students, and to motivate and (re)engage students in their learning. In this case, NCEA's flexibility was used to attract second-chance students back to school who had drifted away in the aftermath of the Christchurch earthquakes (Hipkins & Spiller, 2012).
- A Marine Studies Centre programme for Māori students highlighted the fact that shared intense work as part of a supportive community lifts learning and facilitates uptake of the science. Key elements of the programme included: teams and autonomy, challenge and risk taking in a supportive environment; overt sharing and deconstruction of thinking and communication; knowledgeable and enthusiastic facilitators/mentors; empowering and purposeful themes and topics; and practical investigation, fun and games (Cutler, 2014).

## Lifting achievement across the curriculum (with implications for science)

More generic NCEA research (i.e., not science specific) also makes useful points about motivation, with implications for raising student achievement levels in science. The following findings come from multiple papers derived from one substantial research programme that had an impact on the ongoing implementation of NCEA.

**Evidence from the literature**

- Attitudes to achievement have an impact on results. Students who say they do just enough to pass do not achieve as well as students who say they strive to do their best (Meyer, McClure, Walkey, Weir, & McKenzie, 2009; Meyer, Weir, McClure, Walkey, & McKenzie, 2007).
- Girls are more likely than boys to make subject choices based on the usefulness and interest of subjects, and more likely to express a desire to do their best. For Māori students, choosing *doing my best* or *doing just enough* was not as predictive of academic performance. This may mean that other attitudinal dimensions show stronger relationships to student achievement for them (Meyer et al., 2009).
- In this study, teachers were inclined to view motivation and ability as fixed, rather than a dynamic orientation that can be changed. Teachers at higher decile schools were less likely overall to see motivation as dynamic, while those in wharekura and low decile schools were more likely to believe that all students can be motivated to do their best (Meyer et al., 2007).
- Māori and Pasifika students emphasised the importance of teachers who hold high expectations and support students to meet learning challenges. Both students and parents/whānau favoured Merit and Excellence certificate endorsements because these motivated students to work harder (Graham, Meyer, McKenzie, McClure, & Weir, 2010).
- The individualism promoted by NCEA can be seen as a pressure on indigenous students. An alternative view is that success in NCEA does not depend on how others perform, so it may be suited to encouraging a *collective* approach to achieving excellence, as appropriate to Māori world views (Graham et al., 2010).

## Challenges begin before the senior secondary years

The papers cited above all have a specific focus on achievement in the senior secondary years. It is important to put these challenges into a wider perspective by noting indications that achievement disparities start at much lower school levels.

**Evidence from the literature**

- In the 2012 round of the OECD's Programme for International Student Assessment (PISA), the average science scores of New Zealand students were higher than the OECD average but had declined since 2009 and relative to other countries. Compared to earlier cycles of PISA there were larger proportions of New Zealand students with low performance in science. The performance of both girls and boys has declined since 2006. Boys had a marginally higher average science score in 2012 than girls. The average score in science for Māori students was below the average score for both New Zealand students and the OECD. Similarly, the average score for Pasifika students in science was below the average score for both New

Zealand students and the OECD. The average science score for low socioeconomic students declined between 2006 and 2012, and achievement in New Zealand is more closely linked to socioeconomic status than in other countries (May with Cowles & Lamy, 2012).

- The first National Monitoring Study of Student Achievement (NMSSA) in science for Year 4 and Year 8 students took place in 2012. While the average results for Year 4 students aligned with the expected level described in *NZC*, the average Year 8 results did not. Students in high decile schools showed greater progress than those in lower decile schools. On average, achievement was lower for Māori and Pasifika students, but the annual average growth between Year 4 and Year 8 Māori and Pasifika students was similar to that for NZ European students (Education Research Unit & New Zealand Council for Educational Research, 2012).
- An Education Review Office (ERO) report on science learning in Years 5–8 noted primary teachers' lack of confidence in teaching science, and that the Nature of Science strand of *NZC* was not being addressed in either the teaching or the planning of science. ERO also noted that the integrity of science was not being maintained within an integrated approach, and that many schools were using unsuitable science assessments (Education Review Office, 2012).

## Ways to engage more students with science

As part of addressing the challenge of achievement disparities that begin before the senior secondary years, one researcher has recently commented on the characteristics of learning programmes that keep a wider range of students engaged with science.

**Evidence from the literature**

- One study gathered student perceptions in Year 9 and 10 science classrooms with the aim of furthering an understanding of collaborative learning environments. It highlighted some ethnicity differences between NZ European, Māori and Pasifika students' perceptions of science lessons. All students preferred relevant contexts that engage them in their science lessons, with particular emphasis on links with their family interests and current events. However, Māori and Pasifika students recorded considerably lower mean scores for the personal relevance scale when compared with NZ European students (Taylor, 2012).
- Students in this study preferred a collaborative and participatory learning environment, but their classes were not usually like this. They were empowered by having a choice about who they worked with and the opportunity to share ideas in a group, but they would have liked more input into planning their science programme. Students appreciated teachers who asked them their opinions about current events that were connected with scientific issues. Taylor concluded that if students are to be collaborators and innovators, they need to be confident about working together and sharing a space where there is opportunity to share and explore quite different viewpoints. The opportunity for teachers to enquire into their own learning by

gaining knowledge of students' perceptions appears to be a useful process in making informed steps to bring about change in science classes (Taylor, 2012, 2014).

This study focused on Year 9 and 10, but there is some evidence that innovative science learning programmes are no more likely in the senior secondary school years. The report of the age-16 phase of the longitudinal Competent Children, Competent Learners study noted that science and maths teachers were less likely than teachers of other subjects to identify any of the following features of their class: we have lots of fun; students do a lot of group activities and discussions; students have the opportunity to act on issues that concern them; students are encouraged to assess others' work and give them feedback; students are encouraged to lead group projects / class activities; students interact with people outside school as part of their school work (Wylie, Hipkins, & Hodgen, 2009). The young people in this study (around 500) were more likely to identify science and maths as their least favourite subjects compared to other subjects they were taking.

## A cautionary note on culturally responsive pedagogy

One recent major review summarised research on culturally responsive science pedagogy (CRSP) internationally, with specific reference to the New Zealand context (McKinley & Gan, 2014). The following points are salient for the RAMP review questions.

- When under-representation of indigenous and some minority students in secondary science is conceptualised as a problem of lack of participation and achievement, there is a tendency to look for solutions that are pragmatic, short term and patchy. These strategies are *added* to existing approaches rather than prompting substantive change in pedagogy. The authors argue for a different conception of where the problem actually lies. They argue for a "need to move toward a cultural perspective that is situated in the science classroom, with a focus on teacher–student relationships and taking into consideration the indigenous and minority community's worldviews in the science curriculum" (p. 287).
- It follows that teachers need to acknowledge differences between students' cultural identities and the culture of their science classroom and take a pro-active approach in helping students to negotiate this cross-cultural environment. This implies that to engage in CRSP, teachers need knowledge about the nature of science, epistemology, and knowledge and cultural competency within indigenous communities.
- There are pervasive challenges for teachers attempting to change their current practice into a CRSP approach. A limited view of CRSP results in learning about other cultural traditions as an end in itself, rather than teaching challenging academic knowledge and skills through cultural processes that draw on the knowledge students bring to the classroom.
- There is a need to address both equity and excellence. Notions of what success or excellence means can give rise to conflict. For example, one pressure that the accountability system puts

on indigenous students is the individualism the system promotes (see also above comment by Graham et al., 2010).

- Teachers who position themselves as learners and build strong relationships with their students are more likely to have stronger CRSP in their classrooms. Developing CRSP is more successful if approached from the whole school system rather than through individual teachers acting alone.[4]

Further support for the type of pedagogy proposed in the CRSP review comes from another major review, this one commissioned by the Royal Society of New Zealand and MORST[5] to inform a paper developed by the Prime Minister's Chief Science Advisor. One section of *Inspired by Science* reviews recent research on the nature of learning *per se*. The authors note that this body of work calls into question traditional understanding of knowledge, learning and ability. New insights into how learning happens provide a "useful basis for developing the kind of 'thinking curriculum' that is needed if we are to engage more young people in science" (Bull, Gilbert, Barwick, Hipkins, & Baker, 2010, p. 31). They note that "effective science learning must take account of the values, aesthetics, feelings and personal stories through which individuals make meaning" (p. 31). For this to happen, traditional science content needs to be *translated* into learning experiences that help students make explicit links between science concepts and "stories or contexts that can allow them to talk their knowledge into place" (p. 31).

[4] Here the meta-analysis draws on the findings of the Te Kotahitanga programme of research.

[5] Ministry of Research, Science and Technology, now subsumed into Ministry of Business, Innovation, and Employment (MBIE)

# 3. Envisaging and assessing outcomes signalled by *NZC*

*NZC* states that students learn science so that "they can participate as critical, informed, and responsible citizens in a society in which science plays a significant role" (Ministry of Education, 2007, p. 17). This overarching purpose should inform both curriculum and assessment decision making, but the literature outlined in this section indicates a considerable gap between the aspiration and current practice.

## The need for clarity around the purposes for learning science

Although the purpose statement in *NZC* identifies informed citizenship as an *overarching* purpose for learning science, the recent literature includes several papers that discuss a range of inter-related purposes. Because these potentially overlap, there are likely to be challenges for deciding what is in the foreground and which purposes stay in the background at different year levels and/or in different learning contexts. This complexity draws attention to the need for everyone (teachers, students, administrators, policy makers) to be clearer about what science learning is for at any specific time.

**Evidence from the literature**

- The most recent policy paper to address this topic is *A Nation of Curious Minds: He Whenua Hihiri i te Mahara* (Ministry of Business Innovation and Employment, Ministry of Education, & Office of the Prime Minister's Science Advisory Committee, 2014). This paper argues that science and technology are critical for enhancing living standards through economic growth and improving social and environmental outcomes. The strategic plan presented in this paper identifies three specific types of outcomes to be achieved over the next 10 years: more learners who are competent in science and technology and more who go on to a career in science, technology, engineering and mathematics (STEM); a more scientifically and technologically engaged public and a more publicly engaged science sector; and a more skilled workforce, along with science and technology that is more responsive to New Zealanders' needs.
- This broad sweep of purposes was classified into four categories for school science education in the review paper *Inspired by Science:* preparing students for a career in science (pre-professional training); equipping students with practical knowledge of how things work (utilitarian purpose); building students' science literacy to enable informed participation in

science-related debates and issues (democratic/citizenship purpose); developing students' skills in scientific thinking and their knowledge of science as part of their intellectual enculturation (cultural/intellectual purpose). The review cites sections of *NZC* to demonstrate that the "description of the science 'learning area' clearly signals that school science programmes should be meeting all four of the purposes outlined" (Bull et al., 2010, p. 10).

- A slightly more recent paper commissioned by the Royal Society of New Zealand, identifies two goals: to produce tertiary graduates in science, and to produce citizens interested in science and able to participate in discussions about science-related issues. At primary school, science should nurture children's interest in the world around them. During middle years the focus is on continuing to provide a wide range of experiences and opportunities for studying some science topics, as well as exploring some socio-scientific issues. At senior secondary school three functions are identified: continue to develop students' thinking and learning capabilities; continue to develop their capacity to participate in socio-scientific issues; and prepare some students for science-related careers. The Royal Society argues that greater clarity and consensus about the purposes of science education at different stages of schooling would enable agencies, community groups and science experts to target their support purposefully (Royal Society of New Zealand, 2012).
- Another commentary, derived from a broad overview of three science education research projects commissioned by the Ministry of Education in 2012/13, also concluded that the focus of science learning should be different at different levels of schooling. The authors argue for an emphasis on stimulating interest and curiosity in Years 1–6; a focus on socio-scientific issues in Years 7–10; and further study of more complex issues for all students in senior secondary school, with parallel specialist courses for those who need these (Gilbert & Bull, 2013).

## Learning science for citizenship

*Inspired by Science* argues that clarity about the purposes intended for science learning is necessary before we can have any debate about achievement:

> If the purpose of science education is primarily to produce future scientists, it could be argued that we are succeeding as a nation if just our top students are achieving well, but if science education is primarily about educating for citizenship then to succeed as a nation we would need to see the vast majority of our students achieving well in science, not just an elite group. Are the knowledge and skills necessary to be able to engage as an informed citizen in debates about environmental, ecological and bio-ethical challenges facing the world the same as the knowledge and skills needed by our future scientists? (Bull et al., 2010, p. 17)

This question has implications for the types of assessment employed and for how *NZC* is understood and enacted. The science learning area has an overarching Nature of Science strand, which was developed to align with *NZC*'s key competencies (Barker, Hipkins, & Bartholomew, 2004). This Nature of Science component of *NZC* should provide a foundation for the democratic participation and personal decision making envisaged by *NZC* (Hipkins, 2014). However, whether it is understood and effectively used this way depends on what teachers see as the purpose of teaching science (Bull, Joyce, & Hipkins, 2014; Hipkins, 2012).

## Learning about socio-scientific issues

In the papers cited above, learning science by exploring socio-scientific issues is associated with the 'citizenship' purpose for learning science. However, a range of other papers make it clear that this type of learning demands specific types of pedagogy and thinking that may not be a feature of traditional science teaching and learning programmes.

**Evidence from the literature**

- Learning about socio-scientific issues emphasises *critical reasoning* over memorising, and involves value-based, interdisciplinary and holistic approaches. Socio-scientific issues approaches connect science teaching and curricula to students' world views and promote a high level of student engagement. They involve the use of ethical frameworks, breaking down competing interests from personal, societal and global perspectives. The intention is to develop character traits such as empathy, caring, responsibility and willingness to take action. Carefully sequenced socio-scientific issues, with appropriate teaching strategies, can induce cognitive and moral dissonance. Such a curriculum shows promise for developing changes in reflective judgement. However, while there is evidence that properly implemented teaching of socio-scientific issues can facilitate a more robust understanding of the nature of science, it cannot be assumed that this will occur without explicit connections and examples (Zeidler, 2014).
- The chief science adviser to the Prime Minister recently discussed a range of aspects of 'science literacy' for engaging with science as a citizen. These include: understanding the nature of the scientific process; knowing how to evaluate the validity of claims; understanding the difference between causation and correlation; being alert for the possibility of confounding evidence; knowing key concepts of statistics and measurement; distinguishing between absolute and relative effects; recognising when the science is settled and when it is not; seeing applicability of science to the real world; weighing the plausibility and track record of scientists; checking for possible conflicts of interest; knowing about the role of peer-reviewed publication in validating claims; and being aware of values-based influences on scientific work (Gluckman, 2013).
- Students need to develop the ability to *ask appropriate questions* in the context of a scientific issue. Being a question asker is an unfamiliar role for many students, because traditional assessments expect students to answer questions posed by others. Asking students to develop, or even simply identify, the next questions appropriate to a specific situation can be unsettling, and for many students appears to be an unpractised skill. Students need to learn to be comfortable with this different role, but also to have access to different sorts of questions

and to know when to deploy them. This skill is important for the transfer of scientific ideas to contexts where they might help resolve a dilemma or make a decision about what to do next (Joyce & Hipkins, 2009).

- One research project provided an example of how *narrative* was used to engage Year 13 biology students in, and support their thinking about, socio-scientific issues. Storytelling potentially engages students in thoughtful, respectful discussions about socio-scientific issues. Narratives can be used to situate an issue within a context to which students can relate, or to focus on how individuals use personal perspectives to frame their responses to an issue. Narratives recognise the value of students' own perspectives and history when considering controversial issues and so provide a vehicle for Māori, Pasifika and other cultural perspectives to be acknowledged and integrated (Buntting, 2012).
- Examples of pseudoscience offer a lens for exploring the nature of science. Students can learn how to check, analyse and verify the information presented in scientific claims. This could help to equip them for making informed decisions about the conflicting information available to them (Campbell, 2011).
- In one study of 95 Year 10 students in a New Zealand secondary school, a matrix was developed to analyse students' expressions of scientific literacy, as defined by the OECD (2000) for analysing PISA data. The teacher/researcher in the team used two selected Assessment Resource Bank (ARB) items that probed different socio-scientific issues (cost-effective lighting; hygiene and health). Using a pedagogy derived from basic literacy (reading on, between and beyond the lines), as applied to responses in the various categories of the OECD PISA 2000 framework, she found that students can express multiple levels of scientific literacy simultaneously, varying both within and between contexts. The researchers suggest that their matrix has potential for use as an analytical tool for curriculum development in different contexts (Garthwaite, France, & Ward, 2013).
- Surveys commissioned by MORST suggested that improving communications between scientists and the public may not necessarily boost public engagement with science. While about three-quarters of the (adult) respondents agreed that science provides them with benefits and that it is important to keep up to date with science, about half were unmotivated or lacked the confidence to find out more about science. The paper suggests that the disposition to engage should be fostered when people are young (i.e., at school). The science community can support teachers to achieve the science for citizenship aim of *NZC* by engaging with conversations about the 'big ideas' necessary for developing a foundation for responsible citizenship, and contributing to materials that are engaging for and accessible to students that provide examples of science in progress (Hipkins, 2010a).

## Specific types of thinking required to explore socio-scientific issues

*Thinking* is one of five key competencies in *NZC*. Recent research on key competencies and effective pedagogy, commissioned by the Ministry of Education, revealed the need to be more specific about the range of different types of thinking that might be developed through the learning areas.[6] The small collection of teacher stories (across learning areas) developed in that project identified the following, many of which are relevant to socio-scientific issues:

- **cause and effect thinking:** shaping explanations that employ relevant (theoretical) ideas to explicitly link events to their causes
- **evidence-based thinking:** constructing reasoned arguments where the warrants for the assertions made are clear, and the reasons for accepting the evidence presented are articulated (and convincing)
- **embodied thinking:** the contribution made to the expression of meaning and 'knowing' by parts of the body, such as the hands (as, for example, when working between a manual and a piece of equipment to figure out how it works), or different ways of moving (as, for example, when communicating/evoking an emotion in an audience during a dance performance)
- **lateral thinking:** looking for non-obvious connections, or thinking differently about something familiar
- **systems thinking:** recognising the inherent complexity and unpredictability of non-linear, non-mechanistic structures, events and issues
- **values clarification:** thinking about the ways that values and attitudes tacitly shape our thoughts and actions
- **epistemic thinking**: thinking more deliberately about the features of knowledge-construction processes that render the claims being made more, or less, trustworthy (for example, thinking about the nature of science or practising historical thinking).

The papers collected for the RAMP review endorse and add even more types of thinking to this collection.

**Evidence from the literature**

- One New Zealand thesis study investigated the use of pedagogical frameworks to support *ethical thinking*, and recommended that pluralism be included as a new framework dimension so that students come to understand that there can be cultural, religious, ethnic and gender perspectives to socio-scientific issues (Saunders & Rennie, 2011).
- Exploration of socio-scientific issues offers scope for including *futures thinking* within science education. Futures thinking increases student engagement, develops their values discourse, fosters analytical and critical thinking skills, and empowers individuals and communities to envisage, value and work towards alternative futures. The conceptual framework developed in this study has several components: understanding the current situation; analysing relevant trends; identifying drivers; exploring possible and probable

[6] http://nzcurriculum.tki.org.nz/Key-competencies/Key-competencies-and-effective-pedagogy/Insights-into-the-key-competencies

futures; and selecting preferable futures. Each component is explored at a personal, local, national and global level (Jones et al., 2012).

## Examples of future-focused teaching

Science teaching that explores socio-scientific issues has a dual focus on learning for now and for students' futures (Hipkins, 2014). One recently published handbook designed for use in primary schools features advice about pedagogy that is relevant across the school years. Features associated with a future-oriented science curriculum include:

- engages students intellectually and emotionally
- fosters the development of science capabilities
- builds understanding of powerful ideas of and about science
- provides opportunities for creativity and knowledge building
- carefully balances depth and breadth
- provides opportunities for students to engage with complexity and uncertainty in real world issues.

The handbook further notes that pedagogical conditions that encourage innovation include: opportunities for thoughtful risk taking, trial and error, exploration, pushing boundaries; opportunities to create or to produce new things; intrinsic motivation—"passionate play with a purpose"; and valuing difference and unconventionality (Bull et al., 2014). The following examples show that some teachers of the senior-level sciences are successfully designing rich learning experiences that meet these demanding specifications.

**Evidence from the literature**

- In one school a teacher designed an 'issues' course for Level 2 biology. Intended outcomes included that students would be able to research and think critically about biological issues of relevance to their lives beyond school (Farrant, 2014). The assessment plan for this course made strategic use of achievement standards from across the science disciplines. Challenges included the small number of available NCEA achievement standards that reflect future-focused learning goals, and university entrance regulations that (at the time) impeded the development of cross-disciplinary courses (Hipkins & Spiller, 2012).
- In a self-study of this innovative issues course, the teacher concluded that teachers' and students' perceptions of the purpose of science education do not always match. There is significant value in talking to students about more than the content to ensure that they become aware of wider purposes and develop competencies that are useful in other contexts (Farrant, 2014).
- A study of problem-based learning highlighted the potential of co-operative approaches to learning and assessment. Years 9, 10 and 11 (NCEA Level 1) students worked on rich contextual problems in teams. Benefits included: increasing the perceived relevance of

scientific conceptual knowledge; enhancing self-directed and collaborative approaches to learning; and developing key competencies described in *NZC*. Challenges included: resourcing; alignment with the rest of the school programme; shifting the focus from content coverage to a context-driven inquiry model of learning; and different views of the aims and purposes of science education (Lowe, Taylor, & Buntting, 2011).

- One study of how the key competency *thinking* can be more explicitly woven into science learning outlines a specific approach to teaching systems thinking in a Year 13 biology class. The teacher used the flexibility of internal assessment to design a unit of work with a strong emphasis on systems thinking in the context of maintaining human body systems within healthy functioning limits (Hipkins, 2013b).
- As a Youth Guarantee initiative, Year 12 chemistry students at Otaki College worked with the Clean Technology Centre New Zealand to develop ideas for energy, fuels, materials and technologies that have lower impacts on earth systems (which they describe as being "Pāpatuanuku friendly"). The students valued being involved in real-life projects and developing career options, and their learning was assessed against Level 2 NCEA standards (Ministry of Education, 2014).
- One science education provider has noted that doing well in traditional assessments and being knowledgeable about the discoveries of the past does not equip students to be able to make the discoveries of the future. Mind Lab develops experiences to support the development of the next generation of innovators. Rather than structured experiments focused on investigating simple situations featuring two variables, students are given complex challenges designed to allow them to experience science as a dynamic process of discovery. Because students can take a variety of approaches, they come up with different ideas, which are then discussed and critiqued by others (Clay, 2014).

## Creating curriculum coherence: integration of science with other learning areas

As the above examples show, innovative learning programmes can be developed, despite the perceived limitations of NCEA. We now turn to a different type of challenge that has implications for achieving curriculum *coherence* (one of the *NZC* principles). The study of socio-scientific issues is challenging because it will usually need to be spread across several learning areas. We found a number of papers that argue that teachers whose expertise is complementary need to work together, or that discuss the benefits and challenges where this has already been attempted.

**Evidence from the literature**

- A biology teacher and a geography teacher teamed up to teach a Level 2 sustainability course, designed for students who were not succeeding in the more traditional subjects. Students found the chosen issues engaging, successfully gained NCEA credits, and developed skills required in the workplace (Birdsall & Glascow, 2014).

- One collaboration between students, teachers and environmental scientists raised awareness of the issues and risks relating to, and considered adaptation strategies for, change in a coastal environment. The local area school was involved, with students working together to produce a solution to a complex, real-world problem. Strategies were devised to help students organise their learning materials across the different curriculum areas, including science. Assessment included a geography achievement standard that gave students the opportunity to demonstrate high levels of critical thinking (Hume, Scott, Murgatroyd, Hume, & Bell, 2011).
- One study analysed Year 13 biology students' scientific reports for their NCEA biology assessment and their statistical thinking levels. Students with higher levels of achievement in biology investigation tended to also employ higher levels of statistical thinking. Misconceptions about aspects of statistical thinking were revealed. Using sophisticated statistical analytical tools may result in students taking a black box approach, thus hindering statistical thinking. The researcher suggests that teachers should actively facilitate the transfer of statistical thinking skills, and that collaboration between biology and statistics teachers could enable this (Jowsey, 2007).
- A large UK project funded by the Welcome Trust consulted 26 individuals with specific areas of expertise in science communication (science journalists, scientists who do a lot of media work, science educators with expertise in this area, media experts) and then developed approaches to make better use of the media in science lessons. The researchers identified the following knowledge, skills and attitudinal dimensions as necessary to engage critically with science in the news: science knowledge; literacy skills; enquiring habits of mind; and media awareness. They identified media awareness as an area of expertise where science teachers have little knowledge and suggested teaming up with media studies colleagues when developing units of work that draw on media sources. They noted that science-in-the-news is a distinct genre, with different features from other types of science writing. Science teachers in their study successfully developed their own media literacy when working in cross-curriculum collaborations with media studies teachers (Jarman & McClune, 2010).
- Lack of attention to sustainability and the environment is a major challenge in the secondary curriculum, even though *NZC* places ecological sustainability as a core value and identifies it as an important area of study for future-focused learning. Teachers of English have considerable freedom to choose texts for study, and NCEA allows freedom in designing assessment tasks for English. Therefore schools could choose texts that develop a critical awareness of ecoliteracies and that illuminate our dependent relationship with our environments and each other, reflecting the Māori emphasis on nature and sustainability to equip New Zealand young people to be guardians of the earth (Matthewman, 2014).

While not directly related to teaching about socio-scientific issues, one recent American commentary draws on a range of research to argue that the arts add value to the pursuit of science. The researchers advocate for the integration of arts and science, and for arts and science education to sit alongside each other. Participation in arts and crafts enhances the investigative abilities required by scientists (and specifically physicists). Arts and crafts develop skills such as observation, visual thinking, the ability to recognise and form patterns, and manipulative ability. They also develop habits of thought, such as practising, persevering and trial-and-error problem-solving. They provide novel structures, methods and analogies that can stimulate scientific innovation. "The more arts and crafts that scientists, engineers, and entrepreneurs engage in *across their lifetimes*, the greater their likelihood of achieving important results in the workplace" (Root-Bernstein & Root-Bernstein, 2013, p. 19).

## Partnerships between schools and scientists

Some of the examples of innovation outlined above involve partnerships between schools and community organisations. Building effective partnerships for science learning has been a recent focus of research commissioned by the Ministry of Education (Bolstad et al., 2013). Key findings of this research programme included the following.

- Students' science learning should be situated in real contexts of genuine relevance to the community, and students should be connected with community partners and supported to achieve and share the real outcomes of their learning work.
- Making school–community connections has implications for the way the curriculum is planned and organised, how science learning interconnects with other learning, and what kinds of relationships, time frames and resources are needed to support this interconnection, including resources from the science community and wider community.
- A whole-system approach to future engagements between the science community, schools and the wider community is needed. This approach would:
  - provide strategic leadership to support knowledge development, and the sharing and co-ordination of school–science community engagement initiatives
  - strengthen networks of science-connected teachers
  - strengthen networks of people working in intermediary roles across existing school–science community engagement initiatives
  - ensure equity of opportunity for all learners across all New Zealand schools
  - identify a number of key socio-scientific issues that have relevance to whole communities across New Zealand.
- With adequate and secure funding, specialist science educators and scientists could work together to develop high-quality resources that could be adapted to suit specific communities. In addition they could commit to, and resource, well-designed longitudinal research to evaluate the effectiveness of initiatives.

Some pioneering organisations working in this area have come to similar conclusions. Following are some examples.

**Evidence from the literature**

- LENScience programmes involve schools working in partnership with the Liggins Institute and scientists. They engage students through contexts of relevance to their lives and provide opportunities for science–community engagement. These programmes prioritise resource access for low socioeconomic communities with high Māori and Pasifika populations with the intention of raising the profile of science in schools and communities. In choosing a "context of relevance" LENScience asks three questions: is this context going to be meaningful to adolescents?; is this context relevant to the schools' communities?; and is this context important to the science community? Students access age-appropriate data and experience the process of science through student-led, open-ended investigations. They learn about the process of communication in science through sharing their learning with their community (Bay et. al., 2012).
- When Year 13 biology students met two scientists from a biomedical clinical research unit to ask prepared and spontaneous questions, their areas of interest shifted to a more personal perspective about scientific practice. As they engaged with the practice of science in the LenScience laboratory, the students learned more about how science knowledge was developed, and they began to identify with the science and scientists. The shift in students' questions showed that they had developed a broader understanding of scientific literacy by the end of the experience (France & Bay, 2010).
- Citizen Science initiatives give students the opportunity to participate in scientific research to learn scientific information, gain understanding of the nature of science and/or develop their skills in the methods of science. Marine Metre Squared (Mm2), a national citizen science initiative for long-term monitoring of the New Zealand seashore, aims to facilitate partnerships that lead to improved coastal management. Key to the success of this project is community groups and schools going beyond simply submitting data, to using it as a tool to facilitate engagement in wider environmental issues to enable community-engaged science. Local examples of how Mm2 is being used illustrate that school science education can be enriched by involving whānau, community members and scientists in the learning process, and that community knowledge and concerns can contribute to the science. The Mm2 project builds science capabilities among students and teachers and addresses science learning issues of relevance to citizenship (Carson & Rock, 2014.)

# 4. E-learning and e-assessment

A report to the Ministry of Education at the conclusion of a 2-year study of the potential for e-learning in science stated that links with the science community (via e-technologies) can have a hugely formative impact on students' interest and engagement in science. Participants' ideas about the future of e-in-science were interconnected with their ideas about the future of education and e-learning. The researchers concluded that there is value in thoughtfully playing with digital technologies to discover how they might support science teaching and learning (Buntting & Bolstad, 2013). The following sub-sections elaborate on these ideas.

## Curriculum opportunities that e-learning opens up

In his report to the Prime Minster, Sir Peter Gluckman identified keeping up with modern technologies as a challenge for teaching science. He suggested that we need to develop a new form of science education that will depend on both students and teachers having a closer relationship with the science community. He further noted that the use of new technologies is one way to reduce inequities between schools when doing so (Gluckman, 2011). A number of papers outline ways to use e-learning to create new types of learning experiences and/or overcome specific potential barriers to innovation.

**Evidence from the literature**

- In 2008 LENScience developed and trialled the use of a learning platform utilising broadcast technologies (satellite TV and/or high-speed Internet multicast), along with Web 2.0 tools (wiki and chat-room), to enable the development of a learning community for Year 13 secondary school biology students. Students from a range of different geographical locations were able to interact in real time with scientists. The programme was extended in 2009 to cover the full range of concepts from Level 8 Science (Living World) of *NZC*. Students developed their thinking skills and concept understanding, while early career scientists appreciated the opportunity to develop scientific communication skills in a supported environment (Bay, 2009).
- Teachers can bring scientists into their classrooms through the use of videos of New Zealand scientists talking about themselves and their research. Data from nine different classrooms across a range of year levels up to Year 11 uncovered four major functions for the use of videos of scientists talking about their work: bringing scientists into the classroom; scientists talking about science with local relevance; scientists explaining concepts using a multitude of modes; and scientists as authentic alternative authorities within the classroom. Taken

together, the findings demonstrated that the use of video clips of scientists talking about their work can be an effective and efficient way of engaging students in learning about science and scientists (Chen & Cowie, 2014).

- Simple computer simulations can build understanding of concepts and empirical relationships that can be difficult to grasp from traditional descriptive texts (e.g., that the half life of radioactive material remains the same regardless of the volume you have to begin with). This is a new way of 'seeing' ideas and relationships (Burchill, 2014).
- Online laboratories can assist student understanding at least as well as physical hands-on experiments. They have the potential to improve students' learning outcomes, including higher-order thinking skills, and to expand the range of learning opportunities available to students (Karkkainen & Vincent-Lancrin, 2013).
- There are an increasing number of science blogs, and some authors use them as a means of testing their ideas and evaluating data. Exploring such blogs, and the responses of other scientists, provides an opportunity for students to see that science ideas are socially constructed. Students can also learn from writing their own blogs by using them to initiate discussion and critique from others. Some students who are not inclined to speak up in class are more motivated to do so via a blog. There is also the potential for interactions beyond the class. Teacher blogging can have a positive impact on student engagement (Campbell, 2012).
- RIGEL, a mobile technology consisting of a hand-held computer, sensors and associated software, is suitable for teaching science at Years 7 and 8, and for teaching calculus at Year 13. RIGEL is essentially a data logging tool, but it also allows students to explore electronics and electrical circuits they have designed (Fenton, 2008).
- Three-dimensional printing can support the teaching of biology, specifically human evolution, by building models of bones and skulls from our early ancestors. Programmes for such printing are freely available on the Internet if teachers have the IT skills to apply them and access to a 3-D printer (Wilson, 2014).
- Gifted and talented Year 10 students from eight schools in the Coromandel area took part in a project combining co-operative group learning and problem-based learning (PBL) in science. Face-to-face interactions did take place, but day-to-day contact was through extensive use of IT (e.g., video conferencing). PBL aims to foster critical thinking and problem-solving skills, and the relevance of the problems being explored increased the motivation of the students. The opportunity to mix with like students was also a strong motivating factor (Lowe, n.d.).
- A New Zealand teacher working in Abu Dhabi has supported local teachers to design and implement a science investigation based on the use of Geographic Information Services (GIS) and a range of other digital technologies. The students will be involved in an actual inquiry that generates real data as they kayak through a mangrove area to identify nesting sites of an endangered bird species (Lowe & Al Ahmadi, 2014).

## Working effectively with e-learning technologies

Some of the papers just cited make the case for ways to use e-technologies to support learning and/or describe pioneering support materials that have been developed. In a few cases, details of accompanying evaluations were also provided.

**Evidence from the literature**

- Evaluation of LENScience Year 13 symposia reported that communication of concepts to students was most effective when pre-seminar readings were written by teachers in consultation with the scientists, and seminar presentation was shared by teachers and the scientist. Furthermore, satellite television technology provided effective communication for participant schools from a wide range of geographical locations, both rural and urban, independent of the level of broadband capability in the school (Bay et al., 2009).
- The Science Learning Hub (http://www.sciencelearn.org.nz) gives science teachers access to up-to-date insights into science contexts and new scientific knowledge, with the intention that these contexts will be used to strengthen science classroom programmes and enhance student engagement and achievement in science. Teachers who participated in professional learning and development (PLD) related to the use of the hub subsequently used it more frequently and for a greater number of purposes. They also reported changes in their approaches to science teaching. In many cases the Science Learning Hub PLD was the only science-specific PLD that schools accessed, or were able to access (Buntting, Peter, & Cowie, 2014).
- An evaluation of the RIGEL project noted that using this technology increased student engagement (both physical and cognitive) and supported higher-level thinking. Students gained a greater understanding of the nature of science (interpreted here as gaining understanding about what scientists do), and the technology supported authentic learning by enabling students to carry out their own research and problem solving. However, professional learning was needed to raise teacher confidence and technical competence in the technology (Fenton, 2008).

## How widespread is the innovative use of e-learning?

There are some indications that the types of learning experiences just outlined are not yet being widely adopted in New Zealand science classrooms.

**Evidence from the literature**

- Using digital technologies to support students to work like scientists, work with scientists and/or work with each other is happening in small pockets rather than being widespread. Teachers are more likely to use ICT for retrieving and sharing scientific information than for collaborating or creating knowledge (Buntting & Bolstad, 2013).

- Just under half the teachers who responded to an online survey about their science teaching said students often or sometimes collected and analysed scientific data using ICT. However, e-tools such as data loggers and science databases were the lowest-ranked science resources for overall ease of access: more than half the primary and secondary teachers said they had no access, or limited access, to such tools (Hipkins & Hodgen, 2012).

## E-assessment opportunities

In a 2013 speech to secondary school principals, the chief executive of the New Zealand Qualifications Authority (NZQA) noted that the assessment work stream of the Future State project has a focus on providing online and on-demand assessment mechanisms for NCEA and New Zealand Scholarship, for both internal and external assessments. Given the direction of Youth Guarantee, the work stream may eventually cross over into the tertiary sector (Poutasi, 2013). The e-assessment element outlined in this speech appears to envisage students making electronic responses to assessments they might otherwise have completed on paper. The advantages are that assessment can be "anywhere, anytime" and hence "personalised" to meet individual students' needs. A recent *Gazette* article[7] noted that one online assessment is being trialled in 20 schools in 2014.

It is clear that teachers are going to need to support students to complete at least some NCEA assessment activities online in the near future. However, this speech, like other more recent discussion of NZQA's current assessment work stream, does not make explicit reference to designing types of assessment that open up opportunities to assess different types of learning outcomes—with a specific focus on those that might not be possible to assess with paper-based tasks. Some researchers are thinking about these possibilities.

**Evidence from the literature**

- Blogs can be used as an alternative means of assessment to hard copy reports, or for assessing such things as critiquing others' work. A caution is that it is essential for a teacher to decide why you might want students to blog or to access the blogs of others. This activity can fail if there is a lack of focus (Campbell, 2012).
- Real-time formative assessments and skills-based assessments can lead to better student interaction, engagement and motivation, and increase opportunities for collaboration across cultures and between locations. Real-time formative assessment provides the means for different types of activities and skills such as problem solving and creativity (Karkkainen & Vincent-Lancrin, 2013).
- Virtual performance assessments (VPAs) show promise for measuring higher-order skills in science and for evaluating students' progress on sophisticated intellectual and psychosocial tasks. VPAs ensure standardisation by delivering identical instructions to students via

[7] http://www.edgazette.govt.nz/Articles/Article.aspx?ArticleId=8991

technology, as well as cost benefits (fewer materials to deliver). Scoring by technology also reduces costs, training and human error, and there are fewer problems with task and occasion variability (Clarke-Midura, Dede, & Norton, 2011).

## E-assessment issues and challenges

NZQA's discussion points out the need to proceed carefully so that innovations are understood and accepted (Poutasi, 2013). One small-scale New Zealand study illustrates what could happen when alternative forms of assessment make parents anxious. Gifted and talented students in Lowe's problem-based learning study were assessed in their teams through IT-based testing strategies. This created anxiety among some students and parents about whether the students were being equipped to individually pass exams—which they still saw as the main purpose of learning. In some cases students actually sat their class end-of-unit tests in addition to their PBL assessments. Although they performed well in both assessment modes, unnecessary extra work was created and students experienced unnecessary stress (Lowe, n.d.).

One recent major review noted that since *reasoning* is central to science itself, it should also be central to the assessment of science learning (Osborne, 2013). However, most current assessment is too limited in scope to be able to report on how well reasoning is being developed. It is not easy to address this issue at the school or classroom level because research shows that teachers find it hard to design good tasks to assess reasoning. Osborne makes several recommendations for addressing this challenge.

- Teachers need access to a bank of items prepared by those with the necessary expertise.
- Change at both local and national levels needs to begin with clarity about the multiple aspects of reasoning that can (and should) be taught and assessed.
- Given this clarity, interactive computer-based assessments open up many new possibilities while also addressing equity issues (because linguistic limitations are less likely to hamper students' ability to demonstrate their reasoning processes) (Osborne, 2013).

# 5. Making the alignment between NCEA and *NZC* more explicit

High-stakes assessments convey messages about valued outcomes, which means that ensuring appropriate alignment between NCEA achievement standards and *NZC* is really important. It appears that many teachers do not yet see the positive potential in using the flexibility of NCEA and *NZC* to build a local programme to meet their students' learning needs. The innovative studies described in earlier sections do not appear to be common practice. Indications that NCEA can be a barrier to change when alignment is not apparent include the following.

**Evidence from the literature**

- In the NZCER National Survey of Secondary Schools in 2012, 1,266 secondary teachers responded to questions about NCEA. Mathematics & statistics and science teachers were less likely than those of other subjects to agree that the alignment of *NZC* and NCEA represented the "intent of the curriculum" in their subject. They were more likely to disagree that NCEA gives them freedom to design courses/programmes how they want and more likely to identify NCEA as a barrier to curriculum change. Mathematics & statistics and science teachers were also more likely to disagree that NCEA helps with the inclusion of special needs students, or that it motivates underachieving students to do their best (Hipkins, 2013a).
- A 2012 online survey of science teachers revealed that NCEA science exemplars and senior secondary subject guides were the most frequently accessed resources by secondary teachers. For some secondary teachers, NCEA resources appeared to be the only curriculum resources accessed (Hipkins & Hodgen, 2012). However, an accompanying audit of resources revealed that neither of these resources has more than a minor focus on the nature of science, or provides support for rethinking purposes for learning science to any great degree (Hipkins & Bull, with McGrail, 2012).

A related theme concerns avoiding perverse consequences when standards are too narrowly focused and do not fully align with *NZC*'s signals about what is important in science learning.

**Evidence from the literature**

- One study found that NCEA standard 1.1: "Carrying out a practical investigation with direction" exerted a strong influence over the nature of student learning. The emphasis on fair testing limited students' exposure to the range of methods that scientists use in practice. The structured teaching programme encouraged mechanistic and superficial learning rather than fostering creativity and higher-order thinking skills (Hume, 2006).

- Another study identified a mismatch between the way that *NZC* positions science investigations and the NCEA assessment focus. In response to the internal assessment requirements associated with science investigation for NCEA, teachers narrowed the focus of practical investigations and these became more formulaic. The nature of this change raises validity and reliability issues for the assessment of student learning of scientific investigation (Moeed, 2010; Moeed & Hall, 2011).

# 6. NCEA and pathways beyond school

## An overview of STEM-related research

A recent comprehensive review of international research contrasts attitudes to science and "scientific attitudes". The review has a specific focus on challenges such as ensuring a future supply of scientists (Tytler, 2014). Attitudes to science and scientific attitudes are related because they share a focus on the nature of science, but they are not the same thing. Developing scientific attitudes is a necessary outcome for engaged citizenship, but potential future scientists also need to hold positive views of their personal science learning abilities and of their school learning experiences.

The review points to the recent and growing body of research that takes an 'identity' approach to STEM research. This type of approach integrates individual/psychological choices of study and career pathways with sociocultural/contextual theoretical framings of the influence of other people, life experiences, contexts for science learning including school, and so on. Such research can explicitly address changing youth identities in rapidly changing social conditions collectively known as late modernity[8] and provides an informative and productive way of addressing cultural and gender differences in young people's STEM attitudes and choices (and hence equity issues). From an identity perspective, learning in school science is experienced quite differently by different groups of students, which suggests that multiple ways of approaching teaching and learning are preferable to a more uniform curriculum and pedagogy.

Tytler summarises evidence for four key determinants of student engagement with science.

- **Gender:** boys have a more positive attitude to school science than girls. More boys are involved with physical sciences and engineering than girls. Context, purpose and implications of science matter for girls, and the traditional presentation of science as objective and value-free is likely to reduce their engagement.
- **Early experiences:** by age 14, for most students, interest in pursuing further science studies is largely determined. Initiatives to engage students with science would be helped by understanding the formative influences on student and career aspirations before the age of 14 and aiming to foster the interest of younger students, particularly girls, in STEM-related work.
- **Family and cultural influences:** encouragement by families plays an important role in developing children's interest in particular aspects of science, and in science generally.

[8] The term usually encompasses young people's access to and use of many different communication technologies, the influence of globalisation on how they see themselves and their life choices, the changing nature of employment and how young people understand the notion of a 'career', and so on.

Parents are an untapped resource for increasing STEM motivation in adolescents. Students with university-educated parents decide earlier about their career directions and are more likely to choose science subjects.

- **Quality of teaching:** students complain that school science is not relevant to their lives and interests, there is too much content that is dealt with superficially and is repetitive across schooling, there is a lack of opportunity to discuss content or its implications, or to express an opinion, it becomes too difficult too soon, and there is too much copying of notes.

Although this review covers a wide spectrum of international publications, it will be evident that some of the above themes have already arisen in earlier sections (e.g., the quality of the learning that students experience in science, and its perceived relevance to their lives).

## Choosing a STEM pathway

STEM issues tend to crop up cyclically, typically when there is a perception that there may be an insufficient number of students entering the STEM pipeline to ensure future work force needs are met. However, the *NZC* emphasis on science for citizenship implies that the focus of the debate needs to encompass much more than simply how many students choose STEM pathways beyond school. All students need to engage with science and its implications for their lives if the citizenship purpose is to be met. Furthermore it is important that a diverse group of young people choose STEM careers and this is an area of concern:

> If the main aim of science education is to provide a supply of future scientists then we can be relatively happy with the how well New Zealand's top students are performing but perhaps less comfortable with how well informed our students are about career choices and their ambivalence about taking up science related careers. The strong link between students' socio-economic background and achievement in science, and the over-representation of some groups among the low achievers means that some groups are more excluded from science than others and this has implications both for the diversity of our science workforce and for issues of social justice. (Bull, et al., 2010, p. 24)

With these caveats in mind, a number of other papers make points that are relevant to this review's focus on building pathways to further education, training and employment.

**Evidence from the literature**

- Prior academic achievement at school is the strongest predictor of university performance, especially in the first year of tertiary study, irrespective of what subjects are studied at school. Factors that influence university performance include motivation, self-discipline, confidence, study habits, time management skills, family/peer support, attending an institution of choice, and studying preferred courses or subjects. These factors are independent of what is being studied, and these traits will stand students in good stead at university. The author contends that NCEA Level 3 could be regarded as a proxy for some or all of the factors listed above. An implication for universities is that perhaps they should re-examine their admissions criteria to focus on overall achievement rather than requiring achievement in a particular school subject (Engler, 2010).

- Students lose motivation and disengage when they cannot see the relevance of their learning. Of five vocational pathways developed through a partnership between educators and industry representatives, three have a STEM focus (construction and infrastructure, manufacturing and technology, and primary industries). However, the author cautions that the distinction between academic and vocational pathways is not useful. Countries that do not stigmatise vocational education currently experience lower levels of youth unemployment (Williams, 2012).
- A Norwegian study reported in *NZ Science Teacher* noted the following important motivational factors for choosing science in post-compulsory education: believing the subject would be interesting and would provide an opportunity for students to realise themselves, and admission to university. Some students opted out of science because it was perceived by them to be difficult. Science students placed more importance on having a future job involving research or technology development. About half the science students aimed for jobs that involve research or creating new knowledge. More boys than girls were interested in technology, and more girls than boys were interested in science topics related to human health and concerns in society (Boe, 2012).
- One recent UK study explored individual and school factors that influence the uptake of chemistry and physics in post-compulsory study. School factors influencing subject choice relate to school management, student support and guidance, and student empowerment. Students in high-uptake schools appear to make a proactive choice in relation to career aspirations, rather than a reactive choice on the basis of past experience. Schools with a high uptake offer a diverse science curriculum in the final 2 years of compulsory study, set higher examination entry requirements for further study, and, crucially, provide a range of opportunities for students to interact with the world of work and to gain knowledge and experience of science-related careers (Bennet, Lubben, & Hampden-Thompson, 2011).

## Career guidance in New Zealand schools

The last paper in the immediately preceding set draws attention to the importance of career guidance. This is another area where recent cutting-edge curriculum thinking implies challenging changes for science teachers. For New Zealand students from Year 8 upwards, a set of three overarching career management competencies were introduced in 2009. These are related to the *NZC* key competencies and are called: developing self-awareness; exploring opportunities; and deciding and acting. Career management competencies acknowledge changed conditions for life, career and work in the 21st century knowledge society, and stress the need for people to learn, obtain and maintain a clear sense of intent as they make their work and education choices. They shift responsibility from career advisors to teachers of all learning areas. Science teachers could play a more active role in helping young people develop the career management competencies, particularly given that *NZC*'s statement about purposes for learning science connects with the goals of career education (Vaughan, 2012).

Vaughan's advice from the perspective of career management competencies research is in potential conflict with science teachers' beliefs. While students identify teachers as the most useful source of career information, science teachers tend to regard that as the responsibility of careers advisors, most of whom have a non-science background. This implies a need to develop effective approaches, either through a curriculum content focus and/or a more coherent approach to information dissemination (Tytler, 2014).

## Links between STEM concerns and effective pedagogy

A major convocation was recently held for different groups offering STEM learning opportunities in the USA (National Research Council, 2014). One outcome was a proposal to build community "learning ecosystems" that provide diverse and multiple STEM learning opportunities. Creating such ecosystems requires strong leadership to build collaborative vision and practice that attends to the "enlightened self interest of all partners" (p.18). Strategies to do this include:

- focusing on inquiry, project-based learning, and real-world connections to increase the relevance of young people's science learning experiences
- creating learning progressions that connect and deepen STEM experiences over time
- changing the types of assessments used to reflect shift in types of outcomes sought for 21st century STEM education.

As earlier sections have shown, some local examples already exist that provide a flavour of what these strategies might look like in practice. The following additional example included an evaluation with an explicit focus on careers awareness.

**Evidence from the literature**

- Students from several secondary schools collaborated with Massey University scientists to carry out an investigation involving DNA sequencing and analysis. The Level 3 NCEA achievement standard "Describe applications of biotechnological techniques" was used to assess their work. The investigation was designed to make the nature of science visible, including modelling aspects of a scientist's work. Survey evaluation showed that most students found the experience both enjoyable and interesting. Most said they had a better understanding of scientists' work and they were keen to have other similar experiences. More students showed increased interest in a career in science, and the majority were motivated to work harder in science (O'Sullivan, Scott, & Hipkins, 2012).

# 7. Areas where teachers need more support

## Evidence of the need for support

A clear theme in the research literature is the *complexity* of the curriculum and assessment thinking that is now being asked of teachers. The challenges they experience imply a need for ongoing learning and support as they try out new ideas and make changes in their practice.

**Evidence from the literature**

- One paper that illustrates this complexity made the case that epistemic thinking[9] is pivotal to interpreting the Nature of Science strand of the Science learning area in ways that support learning outcomes related to informed participation in society. However, before teachers can support students to practise epistemic thinking as part of their science learning, they need exemplars of how to develop this thinking that show why it matters (Hipkins, 2013b).
- Two small case studies provided support for volunteer teachers to rethink the citizenship intent of the Science learning area, with a focus on effective integration of the Nature of Science strand with more traditional curriculum content. Teacher 1 wanted new ideas to increase student engagement, but supporting students to pass NCEA was her driving purpose for science learning and there was little evidence of change to refocus on the Nature of Science. Teacher 2 made changes with the support of the researcher, but they were not sustained despite positive feedback from students about the changes made. This teacher was uncertain about some aspects of the purpose, look and feel of the changes she had been supported to make. The research concluded that a sincere desire to change, even if followed up with strategic and purposeful experimentation, may not be sufficient to generate sustainable change (Spiller & Hipkins, 2013).
- Another small-scale study supported a group of Year 9 and 10 science teachers to foreground 'thinking' in science, with the aim of realising the vision of a thinking curriculum for the 21st century. The teachers valued: the opportunity to talk with other teachers face to face (none participated in a suggested online forum); taking small steps towards changing practice rather than trying to change everything at once; the acknowledgement that content is still important; and trying out a number of suggested teaching strategies. They considered the following to be barriers to including thinking in science: behaviour management; preparation time; insufficient time in class for students to be able to reflect on what they are doing; high-stakes assessment; their own assumptions about what teaching and learning science is about; and students' perceived reluctance or inability to think about their learning. The intervention revealed several areas for consideration for PDL in the area of thinking: clearly defining

[9] Thinking about the nature of knowledge and knowing

what thinking in science might look like; providing opportunities for teachers to examine their deeply held beliefs about what is important in education and learning; identifying "threshold concepts" teachers need in order to see things in new ways; and the need to work in partnership with teachers for an extended period of time (Bull, Joyce, & Spiller, 2011).

- Teachers in the study just described also felt that their schools' current focus on more generic, school-wide professional development had a negative impact on developing subject-specific expertise (Bull et al., 2011).
- An analysis of the meaning and implications of 'assessment literacy', with particular reference to the context of NCEA, highlighted the complexity required of teachers' curriculum/assessment thinking and decision making. Teachers need support to link science learning to everyday contexts; to integrate the Nature of Science into the curriculum; to plan assessment tasks that intersect with the interests of their students; and to design tasks that allow students to better show their learning. A focus on the potential impacts that assessment can have on students helps teachers to be more aware of the diversity in their classes and to be responsive to this (Edwards, 2013).

## Support needs may be different in different contexts

There is some evidence that well-grounded support is 'patchy' and differs across school contexts.

**Evidence from the literature**

- An analysis of variance in 2007 NCEA results in English, maths and science was carried out in 41 Auckland secondary schools. This study found greater within-school variance between the three departments in the school (when compared with national data for their subject/decile) than across the deciles. Some departments appeared to provide very good support for achievement, while others provided poor support. The study concluded that attention needs to be given to departmental leadership of teaching and learning (Highfield, 2010).
- In the NZCER 2012 National Survey, mathematics & statistics and science teachers were more likely than teachers of other subjects to disagree that feedback from NZQA had helped clarify the intent of the new achievement standards, or that national moderators' reports are helpful. They were more likely to strongly agree that they had sent optional teacher-selected evidence for moderation. They were more likely to be unsure or to disagree that best practice workshops gave them more confidence to answer students' assessment questions, that they had gained a better understanding of how to make holistic judgements, or that they now have more achievement-focused conversations with students (Hipkins, 2013a).
- In the NZCER 2009 National Survey of secondary schools, science and mathematics & statistics teachers were less likely than teachers of other subjects to see pedagogies that integrate the key competencies into the curriculum as important, or to say that students could often experience these types of learning in their classes. They were less likely to say that exploring the vision and values part of *NZC* would be important to implementation.

However, taking part in whole-school exploration of *NZC*, as well as within-department exploration, was not common across secondary schools in general. The report suggests that the opportunity could have been missed to explore beliefs shared within subject-based teams (e.g., about the purposes for learning the subject) in the wider school context and from the high-level perspective of *NZC*'s future-focused front section (Hipkins, 2010b).

- The ERO report on science teaching in Years 5–8 noted that the disbanding of science advisers based in the universities had led to fewer opportunities for effective science programmes to be developed. Those schools that did provide an effective science programme (judged against ERO indicators) had leaders with a strong commitment to science. These leaders were able to motivate and support teaching staff. By implication, leadership needs to be provided from elsewhere when it is lacking inside the school.

## Support strategies that have been evaluated

In some of the studies included in this review, the support strategies described had been evaluated to demonstrate their impact on teaching and learning.

**Evidence from the literature**

- Beginning teachers need support to develop their pedagogical content knowledge (PCK). A conceptual tool known as 'content representations', or CoRes, provides one model for doing this. In one study, science and technology experts in content and pedagogy, early career secondary teachers and researchers worked together to design a CoRe, then researched the early career teachers' use of the CoRe in their planning and delivery of a unit in their classrooms. The early career teachers felt that participating in the design of the CoRe with the experts and then using the CoRe to inform their teaching helped them establish the fundamental ideas of the topic they were teaching. Being involved in the process of designing the CoRe with the experts was as important as the product of the CoRe itself. Using the CoRe developed their confidence and supported them to try new pedagogical approaches (Eames, Williams, Hume, & Lockley, 2011).
- Several papers present pedagogical frameworks to support specific types of thinking; for example, futures thinking (Jones et al., 2012) and ethical thinking (Saunders & Rennie, 2011). Evaluations of these frameworks point to the importance of support for teacher professional learning if they are to be used effectively.
- One study tracked understanding of the nature of science among a cohort of primary and early childhood practising teachers over a semester-long course as part of a Bachelor of Education degree. Pre-instruction, teachers' understanding was fragmented, lacking in depth, inconsistent, fluid and revealed many myths about the nature of science. Over the duration of the course shifts in understanding occurred. Factors that contributed to these shifts included the use of an explicit approach, consistency between explicit and implicit instruction, reflection, a conceptual change approach, and the use of generic science-content-free nature

of science activities throughout the course. The research indicated that an explicit, reflective teaching approach is pedagogically effective for changing teachers' understanding of the nature of science (Heap, 2007).

Anecdotal feedback from the science advisers appointed to recently-formed professional learning consortia suggests that the new science capabilities resources can provide an effective way to support teachers to think differently about the purposes for science learning, and to modify existing approaches and materials. However the NZCER science education team who created the capabilities resources are concerned when they see and hear the current set of five capabilities being spoken of as if they are 'things' that layer onto the existing curriculum.[10] It is important for advisers to model the treatment of the capabilities resources as *ideas to think with* if this misunderstanding is to be averted.

The NZCER team are aware of gaps that need to be debated and addressed. For example, *pattern recognition* has cropped up as an important capability in primary school science explorations.[11] Interestingly, section 6 notes that strengthening this capability is the justification made for the strong link between being an effective science investigator and having a deep involvement in an art or craft (Root-Bernstein & Root-Bernstein, 2013). Capabilities in moving between cultures and world views also need to be addressed, but a different process will be needed to do this appropriately and inclusively.

## Comments on the role and impact of advisory services

Advisers tend to be doers rather than writers of research papers, which perhaps explains why evaluative accounts of the impact of their own work were largely absent from the papers we found. The next commentary was adapted from a PowerPoint presentation given at a recent NZCER science education conference.

With advisory support to carry out inquiries into their own practice, teachers of senior secondary sciences can look past apparent limitations of current NCEA assessments to design and teach innovative learning programmes that are highly engaging for students. In one case, five teachers from four different schools worked together to inquire into ways to better support lower achieving students to achieve Level 1 NCEA in science. Working with a small group of students in each school, common findings across the schools were: these students were disengaged with science to a large extent and had not experienced success in the past; they did not have expected levels of vocabulary, some in the 2000 word test (particularly ELLs) and many in the academic word list;

[10] For example, one provider announces on their website front page that their materials include "the five science capabilities", although there is no evidence of any substantive change to existing resources that might justify this claim.

[11] Ally Bull, personal communication.

and support was needed to understand the content, but also to unpick assessments and with writing answers. The group responded by collaboratively designing a unit of work to be assessed with Level 1 achievement standard AS90946: “Investigate the implications of the properties of metals for their use in society”. Assessment was via a poster rather than a written account. Most students were more engaged and more successful than in the past, but the teachers identified a need to foster better self-management skills and also realised they should not try to change too many things at once (Cleary, 2014). Cleary concluded that with advisory support it is more likely that teachers will:

- keep the vision of a critical, informed and responsible citizen in focus
- experiment with their pedagogy through reflective inquiry cycles
- collaborate with others in and out of their own school (including people in the science community and education research community)
- continue conversations to clarify their thinking, support needs and challenges, and demonstrate the sustained commitment required to change their practice.

# Appendix: Methodology for searching and constructing the Endnote file

To support the Review and Maintenance Programme (RAMP) for the Science learning area we undertook to gather evidence about current curriculum content, pedagogical and assessment practices, and student achievement in the context of the Science learning area in *The New Zealand Curriculum* (*NZC*) and NCEA at Levels 6–8. We used the literature we found to build an Endnote file that provides summaries of the research papers, commentaries and other relevant documents we found.

## Search parameters

We searched for papers published since around 2010 (when the *NZC*/NCEA alignment was being undertaken) unless we judged a piece of work completed before then to be substantive and relevant to matters raised in the more recent papers.

We focused on New Zealand-based publications with an explicit focus on NCEA and/or *NZC* and learning science in the senior secondary school years. However, seminal international research and summaries were included where they addressed significant gaps, had something of real interest to say in terms of the review questions, or represented significant meta-analyses of a large body of relevant international research. (In the latter category, for example, we included three chapters from the most recent handbook of research in science education—all of them chosen because they directly addressed one of the review areas.) Some research about the science learning of younger students was also included when it addressed a theme of continuing relevance as students go through their schooling.

We began our search with a range of sources that included Google Scholar, the New Zealand Educational Theses Database, the New Zealand Council for Educational Research's research papers, Ministry of Education research reports, the *Handbook of Research on Science Education*, Volume II (2014), various journals for science researchers and teachers (e.g., *New Zealand Journal of Educational Studies*, *Assessment Matters*, *Curriculum Matters*, *International Journal of Science Education*, *Research in Science Education*, *New Zealand Science Teacher*). We used a snowballing process to build lateral connections from the papers we found, checking citation links in Google Scholar for the most recent work and visiting the personal Research Gate pages of known New Zealand science educators. Where we were aware of interesting in-progress or unpublished research, particularly in schools, we contacted researchers, educators and/or teachers directly to check for papers written or presentations given. Although unpublished, a recent science Special Interest Group (SIG) symposium provided some examples of interesting support programmes for science educators, as did the NZCER one-day science conference held in October 2014.

## Search terms and keywords

As well as using key search terms to locate papers, we needed to build a typology of key words to enter into the Endnote file so that it can function as a searchable data base. First-tier search terms were derived from the description of the overall RAMP review. Some second-tier search terms were added to cover issues we predicted might arise, based on our understanding of the future-focused literature, and from our knowledge of NZCER's ongoing programme of research on *NZC* and NCEA.

1. **NZC alignment:**
    - teachers' professional learning
    - curriculum integration
    - dispositions (motivation, engagement, agency).
2. **Innovative programmes:**
    - non-traditional outcomes (Nature of Science [NOS], action competence, inquiry competencies, literacies, etc.)
    - future focused
    - technology (online teaching).
3. **NCEA:**
    - assessment
    - online assessment.
4. **Priority learners:**
    - Māori, Pasifika, special learning needs
    - equity
    - diversity.
5. **Pathways:**
    - vocational
    - STEM.

Three other key words further categorise collected sources as:

- research
- evaluation, or
- commentary.

## The Endnote file

For each entry a short summary of the research, evaluation or commentary was entered in the Notes section. The summaries focus on areas of interest for the RAMP review, so they do not necessarily include all of the findings or recommendations from a particular piece of work.

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