Inspired by science

A paper commissioned by the Royal Society and the Prime Minister's Chief Science Advisor

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1 INTRODUCTION

This paper has been commissioned by the Royal Society of New Zealand and the Prime Minister's Chief Science Advisor in conjunction with the Ministry of Research, Science and Technology to encourage debate on how better to engage students with science, with a particular focus on the role of schools. It examines the assumption that there is a problem with engagement in science and reviews research on the dimensions, context and causes of a perceived or actual problem. The paper looks at what we are trying to achieve currently through school science education and whether there is an increasing mismatch between science education of today and the demands of the 21st century.

The focus of this paper is the current provision of science education. Science and technology have some areas of commonality and overlap and for that reason, as well as the fact that much international literature discusses them together, the paper does at some points address both. However, this paper discusses technology only as it relates to science and the application of science ideas, it does not attempt or claim to do justice to the many other dimensions of technology such as the purposeful invention and design of products of the future.

Section 2 looks at the history of science education, discusses how subjects came to be included in the school curriculum and looks at why science was included among them. It explores some of the purposes of school science programmes, in particular, those that have informed the development of New Zealand's school science curriculum. It argues that the actual curriculum delivered in schools tends to be a rather muddled mixture of purposes and, because of this, it doesn't meet any of them particularly well.

Section 3 reviews New Zealand and international evidence on what students think about science and how well they achieve in it, including how well they perform compared with young people in countries similar to ours. Section 4 addresses what has changed in society, in science, and in schooling and why it is that the goals, content and teaching approaches that evolved to meet the needs of a different kind of society may no longer serve the needs and interests of today's young people. Furthermore, it questions whether science teaching approaches actually fit well with the practices of science or with what we now know about learning.

Finally, the paper explores possible ways forward. It does this by presenting a scenario of how school science could be developed and draws on some examples of international current practice that illustrate aspects of the scenario. It suggests that an important first step in engaging more young people in science could be to convene a forum of scientists, educationalists and policy makers to debate the future of science education in New Zealand.

The paper is designed for scientists, educators and policy makers, in fact for anyone who is thinking about how we best educate our students to participate fully and successfully in a world where an understanding of science and technology has become increasingly necessary. It is not a comprehensive review of New Zealand's students' achievements in science, nor is it a critique of our National Curriculum. Its primary intent is to take a strategic look at how science education can best meet the needs of our emerging adults and our country.

2. A BRIEF HISTORY OF SCIENCE EDUCATION

Some studies indicate that many New Zealanders' levels of understanding of and interest in science are not as high as they could be and the number of young people choosing to study science at school once it is no longer compulsory is steadily decreasing. This is a problem for at least two reasons. First, if we are to be able to replace, and even increase, our existing pool of science and technology professionals we need to ensure that we have enough people emerging from the school system with the aptitude for and interest in these jobs. Second, in order to have a healthy democracy we need a population that is able to participate in an informed way in discussions of science-related issues.

New Zealand is not alone in these issues, with similar concerns being expressed in many other countries. As the review of evidence will show, it appears that although some New Zealand students are achieving very well in science there are also large numbers who are not. It also seems that many New Zealand students have formed negative attitudes towards science by the middle years of schooling, a trend that increases through the secondary school years.

Why are students not more positive about science? Is it something to do with school science education? Is it something to do with the way science is represented in the popular media? Or, is it something to do with science itself? This section of the paper addresses the first of these, why and how it is that school science education has contributed to the problem of engaging young people in science. To understand why this is we need to look at how and why science came to be a school subject and what its function should be today, ten years into the 21st century.

2.1 Evolution of the curriculum

Why is science part of the compulsory school curriculum? Why, for that matter, are other subjects such as English, mathematics, history, geography, other languages, the arts and physical education included in the school curriculum? The common-sense answer to this question could be that studying these subjects provides young people with knowledge that will be useful to them when they leave school; and, that these subjects give them basic literacy and numeracy skills as well as some understanding of themselves and the world around them. Another answer might be that knowing about these things is part of becoming an educated person, part of the induction into the society in which we live and provides a framework that young people can use to think for themselves.

What then does learning science contribute to these things? Much of the science taught in schools is not especially useful in everyday life, and many students do not achieve sufficient understanding of it to be able to contribute to scientific debates. The reason why science, along with some subject areas, but not others, came to be included in school curricula requires a brief look at the history of the development of the school curriculum, a story, which goes back thousands of years.

The first important idea in this story is that the primary purpose of the school curriculum has been to develop the intellectual capacities of students and that the content of the school curriculum is chosen for its ability to do this. A second necessary understanding is that the content, or subjects, included in the school curriculum are not the same as the sophisticated disciplinary knowledge (of science, literature, history and so on) from which they are derived. Rather, what appears in the curriculum is knowledge transformed or converted into subjects designed to educate young people for tacit or explicit social, political or economic ends. In other words, curriculum development is a process of selecting and translating knowledge into subjects which can be delivered to students to fulfil society's educational purposes.

Those educational purposes are informed by prevailing ideas of the purpose of schooling and of the proper relationship between schooling and society. Subject matter knowledge is framed to meet educational goals rather than being taken directly from the discipline from which it is drawn. It is packaged and presented to students in ways that take account of learning theory as well as students' ages, interests and abilities. So it is that the purpose of a school curriculum subject is different from its purpose in its original disciplinary context. What this means is that school science or history or maths are different in kind from science, history or maths as practised by professionals, and not just because they have a lower level of complexity or sophistication.

Science began to be part of the curriculum in some schools in the 19th century. Right from the start it was supposed to achieve a range of goals - the *intellectual* goal of developing students' thinking and reasoning skills, the *personal* and *practical* goal of developing students' understanding of how things work (including nature), and the *futuristic* goal of building students' capacity for innovation and creativity. In the 19th century these goals had very different intellectual antecedents: the 'thinking and reasoning' goal, for example, came from Huxley and Spencer's advocacy of science study as a way to build 'mental discipline', truth-seeking, and intellectual autonomy (in opposition to what they saw as the authoritarianism of the traditional emphasis on the Latin and Greek classics). The 'practical' goal on the other hand originated in the work of the radical pedagogical theorists of the 19th century. J.F. Herbart, for example, advocated practical science lessons that would 'fit pupils for life' by giving them 'direct experience of the natural world', in 'real-world, authentic' (i.e. not abstract) contexts.

These goals are the intellectual 'spine' of school science education: however, the way they are perceived, and the extent to which they are realised, is strongly influenced by the ever-changing socio-political context in which public education is developed and delivered. Public education must contribute to national goals and priorities while also offering equal opportunity to all: however, it plays out in a context of deeply entrenched beliefs about what - and who - schools are *for*. In the New Zealand context, our conflicted relationship with egalitarianism has had some interesting consequences for our national school curriculum in general, and for science in particular.

New Zealand's public education system was set up in the late 19th century. The 1877 Education Act made provision for a nation-wide, secular system of compulsory, free primary schooling for everyone (between the ages of 7 and 14). Before this, schooling had been provided by the six Provinces and/or the churches, but its quality was uneven. The 1877 Education Bill was argued for by the parliamentarians of the time on the grounds that universal public education would give everyone a fair chance to succeed (thereby improving social cohesion) on the one hand, and that it would improve economic productivity (by developing both the work ethic and the kinds of skills needed in the economy at that time) on the other. The New Zealand system reproduced the English distinction between primary education (as providing the basics of reading, writing and arithmetic to all) and secondary education (as a preparation – and gatekeeper - for university and the professions). This produced the "bread for all, jam for the deserving" model (that we still have), as well as certain curriculum contradictions (that we also still have).

In the early twentieth century secondary education was not thought to be necessary for most people, and, because until 1914, state secondary schools charged fees, only children from the few families who could afford these fees went to secondary school. However, during the 1920s, uptake increased rapidly (from fewer than ten percent of the population in 1900 to about forty percent in the 1920s). This caused problems because the traditional academic curriculum offered at the secondary schools of the time was not designed to meet the needs of this new population of students. The response to this was to institute a parallel system of technical high schools offering a more 'practical' and 'relevant' curriculum. These schools were not a success: they were resisted because they were perceived as preparing students for working class jobs, and so were considered to have lower status. They were eventually phased out. However, their presence allowed the earlier-established schools to continue offering the traditional academic curriculum, scorning 'practical knowledge', and to position themselves, as one headmaster of the time put it, as "service[ing] the professional, official or business classes". The schools also added weight to the perception of abstract, academic science education as being higher in value than the more practical or 'everyday-oriented' forms of science education.

The unpopularity of the technical high schools forced the government to try a different tack, one which led, in 1944, to the publication of a document known as the Thomas Report. This report set out a new direction for secondary education in New Zealand, one that was to remain in place for the next fifty years. The School Certificate and University Entrance examinations were set up, and a new curriculum, designed to provide "a broad and balanced education for all", was introduced. This new curriculum combined material from the traditional academic subjects with material drawn from the practical subjects to produce a "common core" curriculum for all students, whatever their ability, interests, background, or likely employment destination. 'General science' was invented at this time. The aim of this new subject was to provide a basic course in practical science for everyone, while at the same time *also* laying the foundations for later specialisation and ongoing science study. However, this goal was never fully realised. Schools resisted the intent of the Thomas Report by 'streaming' students into different classes based on their 'ability' (as measured by IQ tests administered on entry to secondary school), and giving these different classes different versions of the core curriculum. The effect of this was to preserve the academic/practical split, and, to some extent, the segregation of pupils by social class.

As well as all this, school science curriculum development is underpinned by another important split, one that, while it may appear to be an esoteric concern of educationists, is important for considering the question of how to engage more young people in science. For the last sixty years or so, the emphasis of the official school science curriculum has oscillated between two different approaches to teaching (with a periodicity of roughly twenty years): 'knowledge-centred' teaching approaches, in which the primary focus is to replicate the structures of the discipline, and 'learner centred' approaches, which are oriented around the learner's needs. However, whatever the official focus might have been, learner-centred approaches have predominated in primary classrooms, and knowledge-centred approaches have prevailed in secondary school classrooms, often for reasons that have little to do with students' needs. In primary classroom, from the 1940s on, 'discovery methods', which involve encouraging students to explore their immediate world, have been the norm. Nature study was the focus, and children's understanding and interest was to be built through a variety of experiences, rather than by learning facts. In secondary schools the emphasis shifts to knowledge, and disciplining students into the discipline. Whenever curriculum reformers have attempted to make secondary school science more 'inclusive', 'relevant' or learner-centred, there has been strong resistance - from scientists and many science teachers, for whom science is a body of objective facts that cannot be diluted - or 'dumbed down' - by teaching approaches designed to meet the needs of learners. This commitment to the 'base discipline' is much more a feature of science education than is the case in other curriculum areas. In addition, secondary school science teaching, despite the recent reforms of the national student assessment system, is still constrained by the requirements of high-stakes assessment at senior level, with the result that it in general continues to be oriented more towards teaching knowledge (content, facts, and principles) than towards meeting the individual learning needs of students (whatever these may be).[1] Recent research in this area, in particular, research on students' perceptions of their school science classes,

[1] For research evidence that this is still the case, see p.12-13 of the notes to this section.

points to this as one possible reason for secondary school science education's limited success in engaging a diverse range of today's young people in studying science for its own sake.

Since the 1990s New Zealand has officially had a 'seamless' curriculum: that is, the national curriculum sets out what all students should learn from Years 1-13 with no differentiation (or 'seams') between primary and secondary. Primary-age students are now required to develop an understanding of science content and science processes in the same discipline areas as secondary students – just at a lower level. The effect of this is to import the knowledge-centeredness of secondary science into the primary school (rather than, as might be more productive in terms of engaging students, importing the learner-centeredness of the primary school into the secondary school). This new emphasis is also likely to be challenging for the many primary teachers who have very little background in science. Coupled with the recent increased emphasis on developing numeracy and literacy in the early years (and the introduction of national standards for assessing children's progress in these), the result is likely to be that science will have a very low profile in today's primary schools.

The next section moves away from the New Zealand context to look in more detail at the range of very different purposes school science programmes are asked to achieve.

2.2 Purposes of science education

Science education academics identify four broad purposes for school science education. These are:

1. Preparing students for a career in science. (Pre-professional training)
2. Equipping students with practical knowledge of how things work. (Utilitarian purpose)
3. Building students' science literacy to enable informed participation in science-related debates and issues. (Democratic/citizenship purpose)
4. Developing students' skills in scientific thinking and their knowledge of science as part of their intellectual enculturation. (Cultural/intellectual purpose)

i. Pre-professional training

Science education to introduce students to and equip them for what are sometimes called 'STEM' careers – jobs in science, technology, engineering and maths – has been an important, although not always explicit, purpose behind science curricula and science teaching. The rationale is that studying science will increase students' awareness of STEM careers and stimulate their interest in them, and that the science knowledge they gain will give them a necessary foundation for the advanced study needed to qualify for such careers. From this perspective, science education at school is, in effect, a pre-professional course of study where associated assessments function as a gate-keeper reserving entry to the STEM professions for the most successful students. Widespread concern in New Zealand and other western countries that we are not producing enough scientists for our current and future needs has kept this purpose at the forefront of science education.

A science education designed to prepare students for STEM careers emphasises the basic components of accepted scientific knowledge. The curriculum is effectively a catalogue of important – often highly abstract – scientific ideas or processes (forces and energy for example). These ideas are often learned and assessed in isolation from contexts which could increase their relevance or their coherence as explanatory stories. In an effort to ensure the fundamentals are clear, science education for intending scientists breaks scientific knowledge into smaller and smaller parts and risks losing sight of the 'big ideas' and explanations of science. *Beyond 2000: Science education for the future,* a seminal report in the development of science education in the UK, says this:

> *To borrow an architectural metaphor, it is impossible to see the whole building if we focus too closely on the bricks. Yet, without a change of focus, it is impossible to see whether you are looking at St Paul's Cathedral or a pile of bricks, or to appreciate what it is that makes St Paul's one of the world's great churches. In the same way, an over concentration on the detailed content of science may prevent students appreciating why Dalton's ideas about atoms, or Darwin's ideas about natural selection, are among the most powerful and significant pieces of knowledge we possess.*
>
> *Consequently, it is perhaps unsurprising that many pupils emerge from their formal science education with the feeling that the knowledge they acquired had as much value as a pile of bricks and that the task of constructing any edifice of note was simply too daunting – the preserve of the boffins of the scientific elite. (Millar & Osborne [eds] 1998: p5)*

Another problem is that a strong focus on science subjects at school is likely to preclude the study of other knowledge areas needed to work effectively as a scientist, and the science knowledge required in most scientific careers is highly specialised and context specific. Furthermore, when preparing students for STEM careers is a central purpose of school science education, and responsible for determining its approach and curriculum, there is a problem in that only a minority of students actually go on to such careers, leaving open the question of school science's value to the rest. Many young people finish their science education at school with a sense that science is hard, irrelevant to everyday life, and best left to the high achievers. They are also likely to see science as a body of recognised knowledge that has no new questions – and no place for them.

Thus organising school science as a preparation for science careers is flawed in a number of ways. It does not provide a balanced, or even particularly effective, education for the minority who do go on to pursue STEM careers; it results in the majority of students seeing themselves as science failures, and science itself as the boring, esoteric preoccupation of a few; and, it seems to engage only a few in wanting to know more science simply for its own sake.

ii. The utilitarian purpose

Providing people with practical knowledge of how things work – the natural world, everyday devices and machines, and their own bodies – has long been a key purpose of school science education. Teaching for this purpose involves a focus on basic science concepts and principles as they apply in the everyday world of things we need and care about, for example how our bodies and those of other animals work, what electricity is and how to use it safely. Science taught for this purpose is likely to emphasise hands-on, practical activities and skills such as wiring a three-pin plug, keeping a record of everything students eat for a week, or looking after laboratory animals and plants.

This approach is designed not to prepare people for science-related careers but to give them everyday life skills and information that will allow them to make better choices. While well-intentioned, it also has a number of flaws. Firstly, research doesn't support the idea that knowledge alone about such things as the effects of cigarettes, alcohol, high speed collisions, good nutrition or physical exercise produces changes in behaviour, and secondly, most everyday appliances and other machines (including cars) are now constructed using electronic control technology that makes them difficult if not impossible for amateurs to fix.

iii. The democratic/citizenship purpose

Questions about the causes and effects of climate change, the potential and ethics of genetic modification, and the safety and sustainability of sources of energy become more pressing all the time as the long-term future of life on earth is no longer taken for granted. People need to be aware of the issues, have some ability to critically evaluate information and be equipped to participate in debates and influence policy on these and other important matters.

Some describe this as essentially a 'democratic' argument in that we are in a time where the increasing complexity of technology puts effective control of these critical issues into the hands of a smaller and smaller group of experts. A scientifically literate population is essential to sustain a healthy democracy, for only if the non-expert population has at least some understanding of the underlying science can the issues be aired in public and discussed in relation to wider, non-scientific concerns.

Teaching for scientific literacy would focus on the nature of scientific knowledge including what makes science 'scientific', how science knowledge develops and how scientists think and work. Critical and ethical thinking, skills in constructing scientific argument and problem-solving would all be emphasised, and because students would do this through in-depth exploration of particular issues, they would also learn some key science concepts.

There have been a number of attempts over recent decades to introduce aspects of this approach but as yet there has not been widespread uptake by teachers, possibly because it requires them to have a different core knowledge base and new skills.

iv. The cultural/intellectual purpose

This purpose of science education goes back to Plato's idea that education should involve being exposed to the best and greatest forms of knowledge one's culture has produced. This, Plato thought, allows the developing mind to be shaped by – or imprinted with – the cognitive processes of the great thinkers who produced that knowledge. Science was included in the traditional 'liberal' curriculum for its capacity to develop rationality; because it is derived from logical reasoning, the argument goes, it should develop logical reasoning in its students.

While scientific thinking is the goal, teaching for this purpose does not generally focus explicitly on developing thinking skills. Students are supposed to pick these up implicitly through exposure to the structures of scientific knowledge, and by emulating the thinking modelled by their teachers who, it is assumed, think like working scientists. However, most students do not acquire these skills in this way, although some do with support from out-of-school contexts. So, this purpose, while it is a foundation of the traditional academic curriculum, is rarely achieved in schools.

These four purposes are all very different. Each has different origins, and each requires a different kind of learning programme if it is to be met. However, school science curricula, now and in the past, have, at least in theory, been required to serve *all* of these purposes. This has resulted in programmes with rather muddled mixtures of purposes, and limited success in achieving them.

Current purposes

New Zealand's current official national curriculum document arguably continues this trend. This document "sets the direction for student learning" in all English medium state schools (including integrated schools). It is a framework for teaching rather than a detailed plan. The relative freedom it gives schools to plan their own curriculum means that it is very important for schools to be clear about what they are trying to achieve in their programmes.

The 'vision' of *The New Zealand Curriculum* is to produce "young people who will be confident, connected, actively involved, life long learners." (p.7). The document sets out a set of 'principles' that are intended to underpin all school decision-making, and a set of 'values' that are to be encouraged, modelled and explored. It also defines five 'key competencies' considered essential for effective participation in society, and eight 'learning areas' (subjects), of which science is one. Each 'learning area' of the curriculum is divided into levels. One 'level' typically covers about two years of learning.

The science 'learning area' is described as follows:

> In science students explore *how both the natural physical world and science itself work* so that they can *participate as critical, informed, and responsible citizens* in a society in which science plays a significant role. (p.17, italics added).

This 'learning area' is organized into five 'strands':- Living World (biology), Planet Earth and Beyond (astronomy and geology), Material World (chemistry), Physical World (physics) and Nature of Science. This last strand is the core strand and is compulsory for all students up to Year 10 (about age 14). The intention is that through this strand students learn what science is and how it works. The other strands are intended to serve as contexts for learning this. As they move through the ten years of the core curriculum from Year 1 (age five) to Year 10 (about age fifteen), students should experience science programmes that include learning in all four of the other strands. Within this overall framework schools have the flexibility to design curricula that meet the needs of their particular communities. They could, for example, decide to organize their learning programmes around themes or projects, rather than around traditional subject areas.

Thus, while schools have considerable freedom as to how they present it, the curriculum document's description of the science 'learning area' clearly signals that school science programmes should be meeting all four of the purposes outlined in this section.

2.3 In summary

For the last century and a half or so since we have had mass education it has been generally agreed that science should be part of the core curriculum of schools. However, there has been less agreement on what aspects of science should be taught, how they should be taught, and why they should be taught. The view of school science's purpose as being primarily to prepare – and select – students for university-level science study and science-related careers has predominated - for reasons that are not necessarily education-related. This has resulted in curricula that foreground the basic concepts of biology, chemistry and physics, taught largely through didactic approaches that assume learners as 'empty vessels' that are able to be filled up with knowledge.

There have been a great many attempts to reform the curriculum, particularly over the last 20 or 30 years. These attempts have mainly focused on making the curriculum more 'learner-centred' – that is, more appealing to - or 'inclusive' of - students from a wider range of backgrounds; more 'relevant' to students' existing experiences, interests and background knowledge; more connected to authentic, 'real world' contexts; and/or more cognisant of what we know about how people actually learn new things. However, while this work (sometimes) resulted in the appearance of new words in official curriculum documents, it has had very little effect on the way science is taught in schools. Secondary school science programmes largely continue to teach conceptual knowledge in discrete disciplines, while in primary schools science has a low profile, appearing mainly as a topic or context for inquiry learning.

The traditional model persists for a number of reasons. Most secondary science teachers support it because their early enculturation through school and undergraduate study has fostered a commitment to and identification with this type of knowledge, and because their existing skills and professional identities are oriented towards the traditional curriculum. It is also maintained by existing resources such as textbooks and laboratories; by school structures such as timetable arrangements and assessment traditions; by many academic scientists and science education academics; and, by the traditional high status conferred on highly differentiated, insulated school subjects like science. The most recent official national curriculum provides a number of signals for change and gives schools considerable freedom to make decisions about how it is best implemented in their community: however, these signals are seldom, as yet, being taken up.

What all this tells us is that understanding what good science education looks like – that is, science education that is educative, that represents science accurately, and that is engaging for students – is very challenging, and that, despite much effort, it continues to be very challenging.

The next section looks at the evidence we have, in New Zealand and international studies, of how well we are engaging young people in science, and how well they are achieving in it.

2.4 Notes to Section 2

A brief history of science education

Page 4:
The study reported in Hipkins, R., Roberts, J., Bolstad, R. and Ferral, H. (2006). *Staying in science 2: Transition to tertiary study from the perspectives of New Zealand Year 13 science students*. *Research carried out for the Ministry of Research, Science and Technology*. Wellington: NZCER http://www.educationcounts.govt.nz/publications/series/2303 investigated New Zealanders' understanding of and interest in science, and their reasons for not choosing not to study science.
However, New Zealand is not alone on this issue. Other studies of students' experiences of school science and their subsequent study choices have come to similar conclusions. See for example, in Australia: Tytler, R. (2007). *Re-imagining science education – engaging students in science for Australia's future*. Camberwell Vic: Australian Council for Educational Research; Lyons, T. (2005). Different countries, same science classes: Students' experiences of school science in their own words. *International Journal of Science Education* 28(6), 591-694; Lyons, T. (2006). The puzzle of falling enrolments in physics and chemistry courses: Putting some pieces together. *Research in Science Education* 36(3), 285-311; Goodrum, D., Hacking, M., & Rennie. L. (2001). *Research report: The status and quality of teaching and learning of science in Australian schools.* Canberra: Department of Education, Training and Youth Affairs www.detya.gov.au/schools/publications/index.htm; Gough, A., Marshall, A., Matthews, R., Milne G., Tytler, R., White, G. (1998). *Science baseline survey research report*. Melbourne: Deakin University; in the UK: Osborne, J., Driver, R. & Simon, S. (1986). *Attitudes to science: A review of research and proposals for studies to inform policy relating to uptake of science*. London: Kings College London; and in Sweden: Lindahl, B. (2003). *Pupils' responses to school science and technology – a longitudinal study of pathways to upper secondary school* www.mna.hkr.se/~ll/summary.pdf

Evolution of the curriculum

Page 5:
A description of the three 19th century goals for school science, and the very different approaches advocated by Huxley, Spencer and Herbart can be found in DeBoer, G. (1991) *A History of Ideas in Science Education: Implications for Practice*. New York: Teachers College Press.

Accounts of how and why New Zealand's public education system was set up in the way it was can be found in: McKenzie, D., Lee. H. and Lee, G. (1986) *Scholars or dollars? Selected historical case studies of opportunity costs in New Zealand education*. Palmerston North: Dunmore Press; Shuker, R. (1987). *The one best system? A* *revisionist history of state schooling in New Zealand*. Palmerston North: Dunmore Press; Harker, R. (1990) Schooling and cultural reproduction. In J. Codd, R. Harker & R. Nash (eds.). Political issues in New Zealand education (2nd ed., pp. 25-42). Palmerston North: Dunmore Press; Openshaw, R. Lee, G. and Lee, H. (1993) Challenging the myths: Rethinking New Zealand's educational history. Palmerston North: Dunmore Press; Openshaw, R. (1995) *Unresolved struggle: Consensus and conflict in New Zealand state post-primary education.* Palmerston North: Dunmore Press.

The "bread for all jam for the deserving" reference is taken from Renwick, W. (1986) *Moving targets: Six essays on educational policy*. Wellington: New Zealand Council for Educational Research (p.26).

Page.6:
For an account of the issues surrounding the development of technical high schools, see: McKenzie, D. (1992). The technical curriculum: Second class knowledge? In G. McCulloch (ed.) *The school curriculum in New Zealand history: History, theory, policy and practice* (pp. 29-39). Palmerston North: Dunmore Press.

The 'Thomas report' - officially Department of Education (1944). The post-primary school curriculum: Report of the committee appointed by the Minister of Education in November 1942. Wellington: Author - took its more widely used name from the name of the committee's convenor.

A detailed description of how and why official school science curricula have oscillated between learner-centered and knowledge-centered approaches can be found in DeBoer, G. (1991) *A History of Ideas in Science Education: Implications for Practice*. New York: Teachers College Press.

Some educational theorists argue that students' intellectual capacities are best developed by knowledge-centered approaches that start with the structures of the discipline, while others argue for starting with the needs of the learner. The case for knowledge-centered approaches is made in Bruner, J. (1966). *Toward a Theory of Instruction*. Cambridge MA: Harvard University Press; and Bruner, J. (1996). *The Process of Education*. Cambridge MA: Harvard University Press [original work published in 1960] and in Shulman, L. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review*, 57(1), 1-22. the argument for learner-centered approaches is made in Schwab, J. (1962). The concept of a discipline. *Educational Record*, 43, 197-205; Schwab, J. (1973). The practical: translation into curriculum. *School Review*, 79, 493-542; Schwab, J. (1978). Education and the structure of the disciplines. In: I. Westbury & N. Wilkof (Eds.) *Science, curriculum and liberal education* (pp. 229-272). Chicago: University of Chicago Press. See also Dewey, J. (1990). *The School and Society & The Child and the Curriculum*. Chicago: University of Chicago Press. [Original work published in 1902] or, for a more recent review, see Deng, Z. (2007). Transforming the subject matter: examining the roots of pedagogical content knowledge. *Curriculum Inquiry* 37(3), 279-295.

The development of the New Zealand primary science curriculum since the 1940s is described in Fletcher, W. (2010). *Spreaders of a vision: natural science education in New Zealand schools.* Wellington: School Science Advisers Association; and Ewing, J. (1970). *Development of the New Zealand primary school curriculum 1877-1970*. Wellington: New Zealand Council for Educational Research.

For example, Matthews, M. (1995). *Challenging NZ Science Education*. Palmerston North: Dunmore Press, argues strongly against the science curriculum reforms of the 1990s (the term "dumbing down" is used in this book).

For research evidence on the extent to which secondary science teaching (in New Zealand and overseas) is knowledge- (rather than learner-) centred, see the following research reports and syntheses.
Goodrum, D., Hackling, M., & Rennie, L. (2001). *The status and quality of teaching and learning of science in Australian schools: A research report*. Canberra: Department of Education, Training and Youth affairs; and Millar, R., & Osborne, J. F. (Eds.) (1998) *Beyond 2000: Science Education for the Future.* London: King's College London explicitly identify didactic teaching and knowledge-centred approaches to science teaching as key issues to be addressed. More recent New Zealand specific evidence can be found in the most recent report from the 2009 NZCER National Survey of Secondary Schools: Hipkins, R. (in press) *Giving effect to the New Zealand Curriculum in Secondary Schools*, Wellington, New Zealand Council for Educational Research.
Research investigating students' perceptions of their science classes consistently shows that, from their point of view, school science is more content-driven than other subjects, that it is not especially relevant to the rest

of their lives, and it provides few opportunities for them to be actively involved in their own learning. Some recent New Zealand examples of this type of research are: Caygill, R., & Sok, S. (2008) *PISA 2006 School context of science achievement. How ready are our 15-year-olds for tomorrow's world?* Wellington: Ministry of Education; and Wylie, C., Hipkins, R., & Hodgen, E. (2008). *On the Edge of Adulthood: Young people's school and out-of-school experiences at 16.* Wellington: New Zealand Council for Educational Research. Some overseas (UK, Australia, and Sweden) examples of research of this type are as follows: Osborne, J. and Collins, S. (2001). Pupils' views of the role and value of the science curriculum: a focus-group study. *International Journal of Science Education*, 23(5), 441-467; Lyons, T. (2005). Different countries, same science classes: Students' experiences of school science in their own words. *International Journal of Science Education, 28(6),* 591-614; and Lindahl, B. (2003). Pupil's responses to school science and technology? A longitudinal study of pathways to higher secondary school. See: http://na-serv.did.gu.se/avhand/lindahl.pdf

Purposes of science education

Page 7-10

The four purpose framework used here is taken from Osborne, J. and Hennessy, S. (2003). *Literature review in science education and the role of ICT: Promise, problems and future directions.* Futurelab Series, Report 6. http://www.futurelab.org.uk/resources/publications-reports-articles/literature-reviews/Literature-Review380.

Pre-professional training

Page 7

The long quote on p.8 comes from Millar & Osborne (eds.) (1998) op.cit.

Coles, M. (1998). *The nature of scientific work: a study of how science is used in work settings and the implications for education and training programmes*. London. Institute of Education argues that knowledge of more than just science is required for successful scientific work.

Osborne & Collins (2001) op.cit. discusses students' negative perceptions of science programmes that are oriented towards preparation for STEM careers.

The utilitarian purpose

Page 8

The source of the statement that the link between knowledge-based interventions and behaviour changes isn't supported by research is the review reported in Jepson. R., Harris, F., MacGillivray, S., Kearney, N. and Rowa-Dewar, N. (2006). *A review of the effectiveness of interventions, approaches and models at individual, community and population level that are aimed at changing health outcomes through changing knowledge attitudes and behaviour.* Cancer Care Research Centre, University of Stirling

The democratic/citizenship purpose

Page 9

Osborne, J. and Hennessy, S. (2003). *Literature review in science education and the role of ICT: Promise, problems and future directions.* Futurelab Series, Report 6. www.futurelab.org.uk/ resources/publications-reports-articles/literature-reviews/Literature-Review380 contains a rationale for the democratic/citizenship purpose of science education.

Discussions of the concept of scientific literacy can be found in Bybee, R. (1997). Towards an understanding of scientific literacy. In W. Graib & C. Bolte (eds.) *Scientific literacy*. Keil Germany: IPN; (pp. 37-68); Hurd, P. (1998). Scientific literacy: new minds for a changing world. *Science Education* 82(3), 407-416; Ryder, J. (2001). Identifying science understanding for functional scientific literacy. *Studies in Science Education* 36; Osborne, J. (2002) Science without literacy – a ship without a sail? *Cambridge Journal of Education, 32(2),* 203-218; Norris, S. & Philips, L. (2003). How literacy in its fundamental sense is central to scientific literacy. *Science Education* 87(2), 224-240; Trefil, J. & O'Brien-Trefil, W. (2009). The science student. *Educational Leadership*, September 2009, 28-33.

Ryder (2001) op.cit.; Trefil & O'Brien-Trefil (2009) op.cit.; Osborne, J., Erduran, S. & Simon, S. (2004) Enhancing the qualiy of argumentation in school science. *Journal of Research in Science Teaching* 41(10, 994-1020; and Osborne, J., Ratcliffe, M., Collins, S., Millar, R. and Duschl, R. (2003). What 'ideas about science' should be taught in school science? A Delphi study of the 'expert community'. *Journal of Research in Science Teaching*, 40(7), 692-720 make the case for the importance of scientific reasoning and argumentation, and critical and ethical thinking in science education.

Tytler, R. (2007). *Re-imagining science education: Engaging students in science for Australia's future*. Camberwell: Australian Council for Educational Research; McGee, C., Jones, A., Cowie, B., Hill, M., Miller, T., Harlow, A. & MacKenzie, K. (2003). *Curriculum Stocktake: National School Sampling Study: Teachers' experiences in curriculum implementation: Science*. Wellington: Ministry of Education; and
Ryder (2001) op. cit. all point out that, while there have been many attempts to introduce such approaches, uptake has been low, probably because teachers lack the necessary knowledge base and/or skills.

The cultural/intellectual purpose

Plato's ideas about education were set out in *The Republic* and *The Laws*. For the standard account of his ideas and the 'liberal ideal' of education that developed from them, see Hirst, P. (1972). Liberal education and the nature of knowledge. In R. Dearden, P. Hirst & R. Peters (Eds). *Education and reason* (pp. 1-24). London: Routledge & Kegan Paul.

For an account of the pedagogical limitations of this model, see: Egan, K. (1997). *The educated mind: How cognitive tools shape our understanding*. Chicago: University of Chicago Press. For evidence of New Zealand teachers reistsance to it, see: Baker, R. & Jones, A. (2005). TIMSS and PISA in science education. *International Journal of Science Education*, 27(2), 145-157.

Current purposes

Pages 9-10
New Zealand's official national curriculum document for English-medium state schools is: Ministry of Education (2007). *The New Zealand Curriculum*. Wellington: Author.

A parallel document, entitled *Te Marautanga o Aotearoa,* serves the same purpose for Māori-medium schools. An English translation of this document can be retrieved from http://nzcurriculum.tki.org.nz/Curriculum-documents/Te-Marautanga-o-Aotearoa.
This document is based on Māori philosophies and is not a translation of *The New Zealand Curriculum.*

Most students work at Curriculum Level 1 during the first couple of years at school, Level 2 during Years 3 and 4, Level 3 during Years 5 and 6 and so on. Each level has a number of learning objectives. The use of the word, "level" is confusing though, because as well as referring to curriculum levels, it is also used in relation to NCEA (the National Certificate of Educational Achievement). Here its meaning is different. NCEA Level 1 refers to the qualification the majority of students attempt at Year 11 (as 15 year olds) while the curriculum level 1 refers to the objectives the majority of students are working on at Year 1 and Year 2 (as 5 or 6 year olds).

In New Zealand when students enter school as 5 year olds they are classified as either Year 1 or Year 0 depending on when their birthday is. They then progress through the Year levels. By age 10 ½ or 11 students are in Year 7 (previously known as Form 1) and they begin high school at Year 9 (previously known as Form 3).

In summary

Pages 10- 11
Some examples of the more 'learner-centred' attempts at reform were the 'science for all' and the 'science, technology and society' approaches of the 1970 and 1980s, and the 'issues-based science', science literacy and inquiry-oriented approaches of the 1980s and 1990s. The key ideas behind the 'science for all' movement are described in Fensham, P. (1986). Science for all. *Educational Leadership*, December 1986, 18-23. See also Stenhouse, D. (1985). *Active philosophy in science and education*. London: Allen & Unwin. See Solomon, J. & Aikenhead, G. (eds.) (1994). *STS education: International perspectives on reform*. New York: Teachers College Press for the main ideas of the 'science, technology and society' reform movement.

For evidence and discussion of the persistence of the traditional model see: Fawns, R. (1985). Negotiating an Australian General Science: The professional dilemma 1939-45. *Research in Science Education* 15, 166-175; Gaskell, P. & Rowell, P. (1993). Teachers and curriculum policy: Contrasting perspectives of a subject specialist and generalist teachers' organisation. *Historical Studies in Education* 5(1), 67-86; Goodrun et al (2000) op.cit;

Fensham, P. (1993). Academic influences on school science curricula. *Journal of Curriculum Studies* 25(1), 53-64; Hart, C. (2001). Examining relations of power in a process of curriculum change: the case of VCE physics. *Research in Science Education* 31(4), 525-54; McGee, C., Jones. A., Cowie, B., Hill, M., Harlow, A., & McKenzie, K. (2003). *Curriculum stocktake national school sampling study: teachers' experiences in curriculum implementation (Science).* Wellington: Ministry of Education.

3 ENGAGEMENT AND ACHIEVEMENT IN SCIENCE

Reviewing how well our students are engaged with and achieving in science now is not as straight forward as it might seem. In order to do this it is necessary to be clear about what is meant by engagement and achievement and to consider how well current assessment tools measure what is valued. This section considers these questions before looking at the assessment data.

3.1 What is engagement?

It is not long in any discussion of teaching and learning before someone mentions 'student engagement', heads nod in agreement that engagement is a critical precondition for students' learning and achievement and the conversation turns to how to increase this precious prerequisite. Less often do we deconstruct the concept of engagement in search of a better understanding of what it looks like and how it works. So what does this term actually mean? One meaning can be seen on the Ministry of Education's website, where there is a page called 'student engagement'. This page has links to reports and other documents that:

> provide information on how New Zealand students are engaged in their learning using the key indicators of *stand-downs, suspensions, expulsions, exclusions and early leaving exemptions analysis'.*

Here 'engagement' means that the student is *physically present* in the classroom, or at least at school.

At the other end of the spectrum a typical researcher definition is as follows:

> Student engagement occurs when students make a psychological investment in learning. They try hard to learn what school offers. They take pride not simply in earning the formal indicators of success (grades), but in understanding the material and incorporating or internalizing it in their lives (Newman, 1992: p.2-3).

Here student engagement is understood as a psychological investment by the student in meaningful learning.

One widely cited comprehensive review of research on student engagement identifies three 'dimensions' used in research: behavioural engagement, emotional engagement and cognitive engagement - any of which can be present on its own or in conjunction with others.

- Behavioural engagement. Students who are behaviourally engaged are involved and participating. They are likely to be on task and following instructions.
- Emotional engagement. Evident interest and enjoyment are the signs of emotional engagement. Students find the learning sufficiently worthwhile or challenging to give it their attention and effort.
- Cognitive engagement. A student who can describe what they have learned or complete an assessment task accurately demonstrates a surface level of cognitive engagement. A deeper level is likely to manifest as self-directed further investigation or perhaps setting and solving related problems and challenges.

But what does good engagement in *science* look like? Does it mean that students keep studying science: participating, and progressing through levels of achievement, or is it real intellectual curiosity about the questions science asks and can sometimes answer? Is it an interest in the natural environment, new technologies, museums or science-related media? Is it an aspiration to develop a career in science, or is it a belief in the value of science to the individual and to society?

3.2 What is achievement?

Achievement, just like engagement, can be defined in a variety of ways. However, before it is possible to define either, we need to be clear about the *purpose* of science education - what it is students should learn, and why? Is it more important for students to explore, or to explain? Should science be limited to matters of fact or should it also address matters of concern? Should science teaching focus on the nature of science, or should it focus on scientific knowledge and principles?

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?

Regardless of what we decide is important for students to learn, and for whom it is important, it is questionable whether we can consider that we are succeeding as a nation if our students can ‘do the science’ but they don’t *want* to. Thus engagement and achievement are closely linked.

3.3 Assessment tools

When we consider the evidence about students’ engagement and achievement in science we also need to consider the nature of the assessment tools that generated the data. It is possible that the assessment tools on which we currently rely may not measure the knowledge and skills needed for the future; tools which assess recall of scientific content may not accurately predict students' suitability for a career in science or indeed their ability to participate as active citizens in today's society. Assessments that provide a measure of mastery of scientific content may provide little information about how well a student can apply that knowledge in a range of situations.

The nature of the assessment tools available is important for other reasons too. In any situation where students' good performance in assessments becomes their ticket to future opportunities, or where teachers are judged by their students’ results on tests, there is a risk that what the assessment tools measure will become the 'taught curriculum', regardless of the intended curriculum. Curriculum purpose, pedagogy, assessment practice, and the resources available to teachers need to be aligned if curriculum change is really to make a difference. Some recently designed assessment tools, for example PISA and NZCER’s *Science: Thinking with evidence* test, do attempt to assess how well students can *use* their knowledge and skills. However, other assessment tools still have a more traditional focus and so when results are being analysed questions need to be asked about exactly what is being measured in the various tests.

With these caveats in mind, this section reviews the evidence we have on how well New Zealand students are achieving in science; how effectively the current system is developing students' interest in science; and, finally, whether sufficient opportunities exist to learn science. It draws mainly on data from the *Programme for International Student Assessment* (PISA), the *Trends in International Mathematics and Science Study* (TIMSS) and New Zealand's *National Education Monitoring Project* (NEMP).

3.4 Achievement

In brief, many New Zealand students are achieving well in science, but there are large numbers who are not. New Zealand students have relative strengths in applying knowledge rather than in knowing scientific content, and there is a stronger relationship between socio-economic background and achievement in New Zealand than there is in many other countries.

The Programme for International Student Assessment (PISA), commissioned by the OECD assesses the ability of students at age 15 in the principal industrialised countries to use their knowledge and skills in reading, mathematics and science to meet real life challenges. The 2006 PISA survey of science completed the first cycle of assessment in the major subject areas – reading (2000), mathematics (2003) and science.
PISA is unusual in that, unlike many traditional assessments of student performance in science, it has a focus on whether young adults have the ability to *use* their knowledge and skills to meet real life challenges rather than whether they have mastered a specific school curriculum. This approach was taken to reflect the nature of competencies valued in modern society. (OECD 2007)

The mean score of New Zealand's 15 year olds in PISA 2006 was well above the OECD mean, and New Zealand had a higher proportion of top performers than any other country except Finland. Furthermore, these top performers were spread across a wide range of schools.[2] In PISA, New Zealand students generally performed very well on identifying scientific issues and using scientific evidence but were less strong on explaining phenomena scientifically.[3] New Zealand students scored well in biology and earth science but were relatively weak in chemistry and physics.

However, evidence from PISA also tells us that although our top students do very well, New Zealand also has a large group of students who do poorly at science; in fact we have one of the greatest spreads of achievement of all the participating nations.[4] Mäori and Pasifika students are over-represented among these low achieving students with Mäori also more likely to be among those who discontinue their science education early.

TIMSS (see text box on next page) assesses students' performance midway through their primary education and early in their secondary schooling. The most recent results show that New Zealand Year 5 students' achievement in science which had improved from 1994/95 to 1998/99 and again to 2002/03, dropped back in 2006/07 to levels similar to those of 1994. In 2006/07, New Zealand Year 5 students had significantly lower science achievement on average than those in England, the United States and Australia. On this evidence we would have to say that we were not, at that point, laying a strong knowledge foundation for a broad range of our student population.

[2] See Appendix 1 *Achievement data* No 1 for more detail on this point.
[3] See Appendix 1 *Achievement data* No 2 for more detail on this point
[4] See Appendix 1 *Achievement data* No 4 for more detail on this point

TIMSS data show that 13% of New Zealand Year 5 students who participated in the 2006 data collection did not reach the low benchmark of *'some elementary knowledge of life science and physical science*'.

Although most countries participating in TIMSS had some students in this group, countries with similar proportions of students reaching the advanced benchmark generally had fewer students unable to reach the low benchmark than New Zealand.

Analysis of TIMSS results shows that New Zealand students perform better on questions that involve demonstrating knowledge than on questions that assess reasoning or applying knowledge.[5]

While both PISA and TIMSS allow us to compare New Zealand students' performance with that of students in other countries, NEMP tracks performance as students move through primary school. NEMP's analysis of students' performance in science in 2007 shows clear improvement from Year 4 to Year 8 in most aspects of science performance assessed, with particularly large gains in providing satisfactory explanations of scientific phenomena. There was little change in science performance overall for either Year 4 or Year 8 students during the 12 years from 1995 to 2007, although the 2007 report does raise a concern that some decline has been detected in Year 4 students' mastery of the physical science strands over the years of the survey. As with TIMSS, we see some evidence of a recent decline in content acquisition.

Ministry of Education data show that while overall participation (as a percentage) of New Zealand students in secondary school science has increased slightly since the mid 1990s, average achievement in Year 11 science has gone down slightly in the same time.

In New Zealand there is a strong relationship between socio-economic background and achievement which PISA found to be stronger than in most OECD countries. TIMSS too found a clear relationship between socio-economic background and

Trends in International Mathematics and Science Study (TIMSS) is a research study of student achievement in mathematics and science around the world. It measures and interprets differences in approaches to teaching mathematics and science in order to help improve the teaching and learning of these subjects worldwide. TIMSS is designed to link with the current school curriculum of each country and has assessed achievement in mathematics and science at middle primary (Year 5) and lower secondary (Year 9) levels every four years since 1994. TIMSS also collects background information on students, and classroom and school contexts through questionnaires. New Zealand's Year 5 and Year 9 students have participated in TIMSS since its inception, with the exception of Year 9 students in 2006/07.
TIMSS assessment are organised around two dimensions, a content or subject matter dimension and a cognitive dimension which assesses thinking processes.
(Caygill 2008)

New Zealand's National Education Monitoring Project (NEMP) has been conducting annual assessments of student achievement, values and attitudes at Year 4 (aged 8-9) and Year 8 (aged 12-13) since 1995. Based in the Education Assessment Research Unit at the University of Otago, NEMP has a four year cycle of assessments across the curriculum with student achievement in science being assessed in 1995, 1999, 2003 and 2007. Students are assessed on a variety of tasks and their responses are recorded orally, by demonstration or in writing.

5 NB: In the international data sets for all countries the results for the Knowing and Applying cognitive scores were inadvertently mislabelled so all data labelled 'Knowing' actually pertained to 'Applying' and vice versa. The data in this report draws on the corrected data.

achievement, while NEMP found statistically significant differences in performance in students from low, medium and high decile schools on many tasks.

Neither PISA nor TIMSS found any significant difference in overall science achievement between boys and girls in New Zealand although boys were slightly more likely than girls to be at the top or bottom of the achievement distribution.

Other factors identified by these studies as being linked with achievement in science are ethnicity, immigration status and language spoken in the home. While there were high and low performers in all ethnic groups, the average score of Päkehä and Asian students was higher than that of Mäori and Pasifika students. TIMSS found that students born in New Zealand had higher science achievement on average than those who were not. PISA, however, found students born overseas with parents also born out of New Zealand (first generation immigrants) performed almost as well as students with a New Zealand born parent, but 'second generation immigrants', New Zealand born students of parents born overseas, performed significantly less well overall. PISA also found students who changed school frequently were less likely to perform well.

3.5 Engagement

Producing students who can use skills and knowledge in a range of situations is in itself not sufficient either for ensuring a future workforce or for preparing citizens who can understand and debate socio-scientific issues. For both of these, students need not only have knowledge of and about science but to be interested in science and able to see its relevance to their world.

Interest in science

Positive attitudes are important. At age 15, the point at which students in New Zealand begin to exercise more choice in the subjects they study, PISA results show that the proportion of students reporting high or medium interest in science topics is similar to that of other OECD countries.
Although New Zealand's students were generally positive about science they were less likely than their OECD counterparts to believe they are good at science. They agreed that science helps us understand the world and is of value to society but were less convinced that science was important to them personally; and, while they were concerned about environmental issues they were not very optimistic about the possibility of improvement.[6]

A measure of students' interest in science is the extent to which they choose to participate in science-related activities in their leisure time. PISA 2006 shows that fewer New Zealand students regularly engaged in any leisure time science-related activities than those in most other countries. Students who did engage in science-related activities in their own time were more likely to have high science literacy scores than those who did not. This was also true for other countries. Boys, Asian students and students from higher socio-economic backgrounds were more likely to engage in science related leisure activities than others.

PISA also found that in New Zealand boys were more likely than girls to report that they enjoyed science. Boys were also more likely to have higher self-belief in their ability in science and to place a high value on science both to society and to them personally. TIMSS, however found at Year 5 levels of confidence and attitudes toward science were similar for boys and girls.

TIMSS and NEMP both provide evidence that students in their middle primary years have positive attitudes towards science. Eight out of 10 Year 5 students in the most recent TIMSS research

[6] See Appendix 1. *Achievement data* No 3 for more details

indicated they would like to do more science at school. However, this interest declines as students move through school and in the *Competent Learners* study science was one of the least enjoyed school subject for students at both age 14 and 16.

Career aspirations

According to some measures New Zealand is performing relatively well in producing students with the ability and achievement to go on to STEM careers and it seems that the careers are available to them. PISA developed a tool to measure 'research intensity' which correlates the proportion of top performing school students with the number of full-time science researchers per 1000 employees. Only Finland outperformed New Zealand, suggesting that we have both a better supply of students equipped for scientific careers and more career opportunities for them than most other OECD nations.

However, even our successful students are not well-informed about career options and relatively few of them see themselves moving into advanced science careers. PISA found that just 39% of top performers said they would like to spend their life doing 'advanced science' and on this dimension New Zealand students scored below even the OECD average. Asian students were more likely to be positive about advanced science than other students, and Mäori students less likely than their peers to express this interest, important information if we aspire to a diverse scientific workforce that reflects New Zealand's population.

Recent New Zealand research surveyed students studying science in Year 13, their final year of schooling. Four clusters of students were identified based on the combinations of subjects they were taking and with some distinct differences in career aspirations. 'Serious science' students who were taking more than one traditional science subject tended to have their sights set on medicine, dentistry or veterinary science; 'business/science' students who may have chosen physics and calculus in combination with some form of computer science were sceptical that science offered a sufficiently rewarding career and were looking towards the business sector; the other two clusters who were for different reasons taking a more diverse selection of subjects including some science, were keeping options open and were more undecided about their future study and career plans.

NEMP, *Competent Children, Competent Learners* and *Staying in Science* all confirm that here, as in other countries, children are making up their mind about their interest in science and in science careers well before age 14 when they are approaching the point of having more choice in the subjects they study.

3.6 Opportunities to learn science

In New Zealand the school-based curriculum makes it difficult to judge the opportunities students have to learn science. The New Zealand Curriculum (NZC) is strongly focused on the skills and qualities our education system is trying to develop in learners, and while schools must offer students opportunities in each of the eight learning areas, schools have a large degree of freedom in what, when and how they teach. There can be enormous variation in the amount of time given to teaching science as well as in the teaching approaches, the organisation and the content of the programmes.
The data about the actual implementation of science in schools are not comprehensive but what follows gives some useful insights.

Time

Evidence suggests that New Zealand's students in primary school do not spend as much time learning science as their counterparts in other countries. TIMSS reports that in 2006 Year 5 students in New Zealand spent an average of 45 hours a year on science (down from 66 hours in 2002) and that only six participating countries reported spending less time on science.

NEMP data show that in 2007 more students at both Year 4 and Year 8 indicated that their class 'never' did experiments with everyday things, experiments with science equipment, or visited science activities than in 1999. Science may be getting less attention because of increased demands from other curriculum areas, but it also appears that there has been a particular decline in the science activities that students find most stimulating. The percentages of students who said they think they learn 'little' about science at school also almost doubled between 1999 and 2007 (from 8 to 16% for Year 4 students and 6 to 11% for Year 8 students) with even more of an increase in the percentages saying that their class 'never' does really good things in science (from 5 to 15% for Year 4 students and 8 to 16% for Year 8 students). However, it is important that primary school students' perceptions of time spent on science are put in the context of the cross-curricular approach taken in many primary school classrooms. It is for example possible that primary students may not actually recognise how much science they are doing as primary schools commonly call science learning “topic” or “inquiry”, rather than science. Conversely, primary teachers’ lack of confidence in science teaching could mean that even when an integrated topic has a significant opportunity for learning science, this may not be realised.

At Years 9 and 10 science is commonly taught for three or four 50-60 minute lessons a week, but the amount of time students spend in science lessons becomes more variable after Year 10 when students have greater subject choice.

In PISA 2006 almost two-thirds of New Zealand students indicated they spent four hours a week or more on school science lessons, a figure comparable to the UK but more than double that of Finland and the OECD average. One in six New Zealand students said they spent less than two hours a week on regular lessons. Across all OECD countries students spending more than four hours a week studying science generally scored higher than those studying science for two or less hours a week. However, PISA cautions that there is a range of ways 15 year-old students are exposed to science both within and beyond school with in-school lessons being just one context for learning science.

Quality

The level of primary teachers' knowledge and confidence in teaching science is often cited as an obstacle to quality science teaching in primary schools. TIMSS reports that compared with their international colleagues, New Zealand primary teachers had relatively low levels of pre-service specialisation in science and received less on-going professional development.

The 2010 Education Review Office report *Science in Years 5-8: Capable and Competent Teaching* found that most schools in their study faced some challenges in developing high quality science education, that most primary teachers did not have a science background and that low levels of science knowledge and science teaching expertise contributed to the variation in quality of science teaching across schools. The report also noted that many teachers had not learned about science in their pre-service teacher training.

A recent, unpublished report into the sustainability of school development in 10 New Zealand primary schools found that there has been very little systemic support for science teaching for many years, that once teachers have completed pre-service training which may or may not have included much science content, there was minimal support to continue their professional learning in science. Furthermore, there has been virtually no policy attention given to the teaching of science.

The current level of supply of quality secondary science teachers is difficult to judge. In NZCER's 2006 National Survey of Secondary School's approximately one third of principals reported difficulty in recruiting suitable applicants for teaching vacancies in science. Teach NZ Scholarships, which target areas of highest need, in 2010, as in other recent years, include scholarships in chemistry and physics. However, the 2010 Ministry of Education survey monitoring teacher supply, indicates that teaching vacancies in New Zealand have decreased over recent years. Only 9.3 percent of secondary teaching vacancies were in science in 2010 (compared with 11.6 percent in 2009). According to this source at the beginning of 2010 there were no vacancies in physics or chemistry.

Organisation

The New Zealand Curriculum is often described as 'seamless' which means that students in Year 1 study in the same learning areas as secondary students but with simplified learning objectives. This means, for example, that both five year-olds and 15 year-olds will study earth systems with the learning objective for five year-olds being 'to explore and describe natural features and resources', and for the 15 year-olds it is to 'investigate the external and internal processes that shape and change the surface features of New Zealand'. Primary science is seen as a simplified version of secondary science.

In New Zealand primary schools science is rarely taught by subject specialists nor is it timetabled into the school week in the same ways that language or maths usually is. Commonly, schools have a topic or a theme that spans several weeks and which may, or may not, have a science focus. Even if the topic or theme lends itself to developing scientific ideas or thinking there is no guarantee that this will be explored. For these reasons it is very difficult to get any accurate measure of just how much science is taught in primary classrooms.

Science is a compulsory subject till the end of Year 10. Many schools also require students to study science in Year 11. In PISA 2006 over 90% of 15 year olds in New Zealand were involved in some type of science course. Of these 90% of students, over 70% were enrolled in compulsory courses and about 40% in an optional course. (Some were involved in both.)

Most schools continue to offer an integrated science programme in Year 11 but a small number offer discipline specific courses at this level. In some schools some students are offered an 'alternative' course as they are considered unlikely to be successful within a more traditional science course. Years 12 and 13 are characterised by huge variety in science courses taught from integrated courses, to mixes of two disciplines (such as chemistry and physics) to traditional, discipline-specific courses. Scholarship examinations at Year 13 are discipline-specific so the most able students are likely to be taking traditional courses at this level.

A snapshot survey of secondary schools taken in 2007 found a higher level of self-reported course innovation in science than in any other curriculum area with 46% of responding schools reporting innovative changes to science courses. The most common reason for the innovations was that they wanted to create 'a more coherent focus for the chosen context'.

Teaching approaches

PISA provides some contextual information about school activities designed to promote the learning of science. The percentage of NZ students in schools (that according to principals) promoted engagement through excursions and field trips, science competitions, extra-curricular science projects and science fairs was above the OECD mean for each category.
PISA also collected information on teaching from students. New Zealand 15 year olds reported greater use of interactive teaching approaches (activities that are designed to stimulate discussion)

compared with either the use of models and applications, or hands on activities. This pattern was similar across the OECD countries.

TIMSS 98/99 created an index of teachers emphasis on scientific reasoning and problem solving based on teachers' reports of how often they asked students to explain the reasoning behind an idea, represent and analyse relationships using tables and graphs, work on problems for which no immediate solution was obvious, write an explanation of an observation and describe why it happened, and put events or objects in order and give a reason for the organisation. On average, internationally 16% of Year 9 teachers placed a high value on these scientific reasoning and problem solving skills whereas just 4% of New Zealand's teachers did so. This may have changed in the past decade but we are unaware of evidence that suggests that it has.

The age-16 phase of the longitudinal Competent Children, Competent Learners study found 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.

There are a number of recent New Zealand PhD theses that address issues related to how science is taught and these may be able to add useful insights especially given the somewhat patchy evidence currently available.

3.7 In summary

The evidence we have available about achievement and engagement is mixed. If we accept that an important outcome of science education is that nearly everyone engages positively with science, then the high proportion of NZ students who do not want to continue with science beyond the point when it is no longer compulsory is cause for concern. Although we have a higher proportion of top performers in science than in many other countries our achievement data also reveal too many students leave formal education having gained little from their science education.

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.

On the other hand New Zealand students' relative strengths in identifying scientific issues and using scientific evidence (as identified in PISA) could be seen as a positive sign that we are equipping students well for a future where many of the issues they will face are as yet unknown.

Science education as currently delivered does not seem to be preparing students as well as it could either for careers in science or as citizens who can confidently engage with science related issues.

However, even if students were doing extremely well on current measures the question remains whether doing more of the same (or even doing it better) meets the needs of our changing world. In the next chapter we review changes in society, work and young people, changes in the purpose of schooling and in science itself.

3.8 Notes to Section 3

Page 16
The Ministry of Education website referred to is: www.educationcounts.govt.nz/publications/series/2303

The 'researcher definition' on p.15 is taken from Newman, F. (1992). *Student Engagement and Achievement in American Secondary Schools*. New York: Teachers College Press (p.2-3).

The comprehensive review of research on student engagement referred to on p.15 is: Fredericks, J., Blumenfeld, P. & Paris, A. (2004). School engagement: Potential of the concept, state of evidence. *Review of Educational Research*, 74(1), 59-105.

Achievement

Page 17
For more information on the sources for the statements made on this page, see Appendix 1.

See Telford, M. (2010) *PISA 2006 Scientific literacy: How ready are our 15 year olds for tomorrow's world?* Wellington: Ministry of Education for more information on New Zealand's large spread in achievement.

Page 18
For the data on Year 5 science achievement see: Caygill, R. (2008a). *Science: trends in year 5 science achievement 1994 to 20*06. Wellington: Ministry of Education.

Page 19
The source of the Ministry of Education data on participation and achievement in science at Year 11 is: Ministry of Education (2007) *Boys' achievement: A synthesis of the data.* Wellington: Ministry of Education.

Page 20
The source of the data on socio-economic background and achievement are Caygill (2008a) op. cit. and Crooks, T., Smith, J., & Flockton, L. (2008) *Science assessment results 2007: NEMP report 44.* Wellington: Ministry of Education
See Telford (2010) op. cit for the data on gender differences, Caygill (2008a) op. cit. for the data on the differences between immigrants and New Zealand born students, and Telford (2010) op. cit. for the data on the links between frequent school movement and achievement.
See also Appendix 1 *Achievement data* 5 for more information.

Engagement

The sources of the information on student attitudes to and interest in science were Caygill (2008a) op. cit., Telford (2010) op. cit. and Caygill, R. (2008b). *PISA 2006: Student attitudes to and engagement with science*. Wellington: Ministry of Education. See also Appendix 1 *Achievement data* no 3 for more information.
For the *Competent Learners* study see Wylie, C., & Hipkins, R. (2006). *Growing Independence: Competent Learners @14.* Wellington: New Zealand Council for Educational Research; and Wylie, et al (2008) op.cit.
See also Appendix 1 *Achievement data 6* for more information about students' attitudes to science.

Career aspirations

Page 21
The information on the extent to which students aspire to science-related careers comes from
OECD (2009) *Top of the class: High performers in science in PISA 2006* http://www.oecd.org/dataoecd/44/17/42645389.pdf.

The recent New Zealand research on school subject combinations and career aspirations in Year 13 is: Hipkins, R., Roberts, J., Bolstad, R. and Ferral, H. (2006). *Staying in science 2: Transition to tertiary study from the perspectives of New Zealand Year 13 science students*. *Research carried out for the Ministry of Research, Science and Technology*. Wellington: NZCER http://www.educationcounts.govt.nz/publications/series/2303
The New Zealand information on children's attitudes to and interest in science comes from the *NEMP*, *Competent Learners* and *Staying in Science* studies (op. cit.). For Australian data see: Tytler, R. (2007). *Re-imagining science education: Engaging students in science for Australia's future*. Camberwell: Australian Council for Educational Research http://www.acer.edu.au/documents/AER51_ReimaginingSciEdu.pdf

Time

See Caygill (2008a) op. cit.

Page 22
The NEMP (op. cit.) study is the source for the comments on students' perceptions of the 'interestingness' of school science. For the relationship between time studying science and achievement see: Telford (op. cit.), p46.

The reminder that schools are not the only context in which students learn science comes from OECD (2007) PISA *2006: Science competencies for tomorrow's world. Volume 1: Analysis*
http://www.oecd.org/document/2/0,3343,en_32252351_32236191_39718850_1111,00.html#Vol_1_and_2 .

Quality

The sources for the comments on primary teacher knowledge are: Trends in International Mathematics and Science Study (2007) http://www.iea.nl/timss2007.html; and Education Review Office (2010). *Science in Years 5-8: Capable and Competent Teaching.* Wellington: Author.
The comment about New Zealand primary teachers' relative lack of specialisation and professional development in science come from Caygill, R., Lang, K., & Cowles, S. (2010) *The school context for Year 5 students' mathematics and science achievement in 2006: New Zealand results from TIMSS.* Wellington: Ministry of Education.
The source of the comment on the lack of policy attention to the teaching of science is Wylie, C., Cameron, M., McDowall, S., Twist, J., and Fisher, J. (forthcoming) Sustaining School Development in New Zealand Primary Schools.
The comments about supply of secondary science teachers come from Schagen, S., & Wylie, C. (2009) *School resources, culture and connections: NZCER National Survey Thematic Report.* Wellington: New Zealand Council for Educational Research.
Lee, M. (2010) *Monitoring teacher supply: Survey of staffing in New Zealand schools at the beginning of the 2010 school year.* Ministry of Education: Wellington.
Retrieved from www.educationcounts.govt.nz/publications/series/2519

Organisation

Page 23
For information on the types of science courses students are enrolled in see: Caygill & Sok (2008) op.cit.
Ministry of Education data from 2009 "roll returns" show approximately 48,000 Year 11 students were enrolled in science; approximately 4,000 students in biology; 3,000 in physics; 2,700 in chemistry
Retrieved from www.educationcounts.govt.nz/statistics/schooling
For more information about the range of science courses available in senior secondary school see
Hipkins et al (2006) op. cit.
The 'snapshot' survey of secondary schools in 2007 is: Hipkins, R. (2007). *Course innovation in the senior secondary curriculum: A snapshot taken in July 2007*. Wellington: New Zealand Council for Educational Research.

Teaching approaches

The source of the information on the low value given by New Zealand teachers to scientific reasoning and problem solving skills is: Baker, R. & Jones, A. (2005). TIMSS and PISA in science education. *International Journal of Science Education*, 27(2), 145-157.
The reference to the age-16 phase of Competent Children, Competent Learners study is Wylie et al (2008) op. cit.

4 YOUNG PEOPLE, SCHOOLING AND SCIENCE IN THE 21ST CENTURY

4.1 Changes in society, work and young people

The shift from the industrial age to the post-industrial age, sometimes called the knowledge age, in developed countries has involved major social and economic changes. Knowledge, rather than tangible assets such as land, labour, capital, or natural resources, is now the main driver of economic growth. Innovation, 'fast' capitalism and niche markets have replaced the earlier emphasis on mass-producing goods for traditional markets. There has been a decline in unskilled and semi-skilled jobs, and an increase in jobs in the creative, technological and service-based industries with an associated shift in the skills and aptitudes required.

The hierarchical, bureaucratic management styles that characterised industrial age enterprises are being replaced by flatter, more distributed management systems in which all employees are expected to play a role in understanding and improving the organisation's products or performance. Where industrial age organisations required workers who were diligent, respected authority and took direction, today's organisations need people who are adaptable and autonomous and can quickly learn new skills. They need people who can communicate their knowledge to others, build relationships and work in teams. They need people who can solve problems and who can take responsibility for all parts of a project. These skills, formerly only required of managers are now required of all workers.

These changes are producing new sorts of workers. For example, many of the new knowledge workers are highly mobile, contracting their services to different organisations simultaneously, sometimes in several countries. The primary professional identities and connections of these workers are not with workmates and local communities but rather, through widespread use of the internet, they identify and are connected with a diversity of other individuals and communities who may share similar knowledge portfolios or other interests. All of this means that that the expectations, values and life patterns of today's young people are very different from those of the previous generation.

Researchers currently following cohorts of young people as they move from school to the early years of work report that uncertainty and change are the primary shapers of these young people's values and choices. They value autonomy, flexibility and choices far more than predictability. They see their work life as being a series of potentially, but not necessarily, intersecting pathways rather than aspiring to the job for life that was likely to have been their parents' aim. The skills these young people value and promote are flexibility, the ability to take up and maximise opportunities that are presented and the ability to work across and between different skill sets.

In addition, today's young people have a very different orientation to knowledge from that of previous generations. For today's 'digital natives', teachers, books and adults are not their main sources of information or authority and school classes are often seen as irrelevant, slow-moving, and something to be endured. According to one young research subject, going to class involves having to 'power down'. For these young people, the range of information sources to which they are routinely connected means that they need to be provided, not with new information, but with strategies and skills for selecting, processing, assessing, and making sense of what they already have access to. This is an obvious function for schools, and while some curriculum areas emphasise these skills, science, in general, does not.

Young people's orientation to work and knowledge is not one that is encouraged or supported in schools as they currently exist. Schools, and school curricula, are still very much organised to serve the needs and values of industrial age society.

There is evidence that the drop-off in student interest in science in the late primary and early adolescent years can be attributed at least in part to the failure of school science to adapt to the interests, orientations and needs of this new generation of young people. Three recent studies carried out in Australia, the UK and Sweden which investigated why the numbers of students choosing to study science once it is no longer compulsory continues to decrease, found that students resented the lack of opportunity to discuss, reflect, offer opinions or be creative in science classes. One group of researchers found the students' experiences were the result of an over-full curriculum and didactic teaching methods. When teachers feel pressured to cover every aspect of the curriculum, students are, as one group of researchers puts it, *"frogmarched across the scientific landscape from one feature to another, with no time to stand and stare, or to absorb what it was they had just learned*." Students in all three studies, while recognising the importance of science content, saw science as boring, irrelevant, unrelated to the real world, difficult and, as a result, not for them. In all the studies, the persistence of students who did go on in science was attributed to out of school factors – mainly family members who were strong advocates for science or education along with the students' own motivation and ability to persist with independent learning.

The studies found that students perceive science as difficult, but difficulty meant different things. To some students, it meant passive, rote learning of material that, because it was not well understood, was not interesting. To others, it meant unfamiliar terminology and concepts, while a third group used it to refer to intellectual challenge – however, this was only seen as a negative where it was unsupported by the teaching methods. These are interesting and important findings in the light of recent research on how adolescents learn, some of which is reviewed below.

4.2 Changes in the purposes of schooling

Given the changes outlined above, many educationists are now arguing that schooling needs a major change in emphasis if it is to prepare students for life and work in the 21st century.

Today's schools need to prepare all students, rather than just a few, to participate in some form of tertiary education. To do this, programmes of learning need to be more customised and personalised rather than offering the one-size-fits-all model that many schools now offer. Schools need to focus on building students' learning power or capacity to learn, and their ability to do things with knowledge rather than rewarding them for acquiring and storing bits of knowledge for possible future use. Schools need to focus on helping students develop certain basic competencies that are required in all areas of life, competencies such as thinking and working with others, rather than helping them to accumulate knowledge-based credentials.

Young people need to understand processes, systems and relationships, to appreciate the connections between knowledge systems rather than the details of the systems themselves. The ability to communicate one's learning and to work collaboratively have become paramount and need to be developed more effectively through school. As part of this there needs to be much greater educationally appropriate use of information and communications technologies and digital media including the ability to work in multiple modes.

Educationalists who think this way are strongly critical of the traditional academic curriculum, the view of knowledge that underpins it and the role it has played in sorting students for future employment. However, they do *not* devalue knowledge: rather they are advocating a different *view* of knowledge. In this literature, knowledge is seen not as 'stuff you get' but rather as a context or domain for building students' capacity for thinking and learning through using a range of modes such as text-based, visual, oral, musical and so on. This work is also influenced by recent developments in cognitive science, in particular on how people learn. The next section looks briefly at some of this work.

4.3 New theories of learning

Questions about how people think and learn are the domain of learning theory. Learning theorists are interested in how people come to know things (and what helps them to do this), as well as how people come to *want* to know things (and what helps them to do that). Designing effective learning programmes, which engage students' interest in something and support them to understand it, requires a coherent theory of learning. However, contemporary learning theory is not yet evident in teaching practice in schools and universities.

The learning theory that has had most influence on science learning is the conceptual change/ personal constructivism model. Early work in this area set out to explain why it is that very few students, even very high achievers, actually understand the science concepts taught at school and so cannot apply what they have learned to situations outside school assessments. Drawing on the constructivist view of learning as an active process that uses prior experiences to make sense of new experiences, science education researchers developed a model of science teaching that involves exposing the limitations of students' naïve science ideas, and helping students abandon and replace these ideas with concepts that more closely match those a scientist would hold. In this model, coming to know involves replacing old, 'imperfect' concepts with new, 'better' ones. However the model is not clear about how students might be encouraged to do this. While this approach was widely advocated, later research has demonstrated limited success in actually changing students' concepts, possibly because its focus on abstract conceptual knowledge and individual learners' mental processes make it insensitive to the social, cultural and emotional contexts in which the learning takes place.

A second body of work, broadly known as socio-cultural theories of learning, was designed to address this. Researchers influenced by this approach argue that learning is much more than conceptual change, that it is situated in and inextricably bound up with the context in which it takes place. In this theory, learning is not the acquisition of specified knowledge but the developing ability to 'speak the language' of a particular knowledge community – in this case science. Learning is a process of coming to know things in, and linking them with, specific contexts. Teaching informed by this approach encourages discussion of ideas, their implications and how they relate to and affect each other; effectively, to model the ways scientists think, talk and argue with each other about science ideas. The strength of this approach is that it can take account of the embedded nature of learning and of differences between learners as well as to create the conditions under which students are likely to engage productively with a learning activity. However, it is less helpful as a basis for developing teaching that can support students to really engage with science concepts.

In a third, emerging, body of work in science learning, researchers argue that people think and learn primarily through stories. While they may later be able to talk about and link concepts to build logical arguments, they have to have the story straight first. This approach has its origins in work done in the 1980s by cognitive psychologist Jerome Bruner who argued that all human beings, in all cultures, learnt through stories and that the 'narrative' mode of thought could be used as a bridge, or way into, other modes of thought (such as the scientific). This idea has been taken up by some science educators. Others have taken this further, focusing on affective as well as cognitive aspects of learning to argue that narrative approaches make it possible for students to imagine themselves participating in science. Thus, for socio-cultural and narrative oriented learning theorists, learning is not simply concept building. Rather it is a complex process of interaction between concepts and stories embedded in particular socio-cultural contexts.

Because this body of work calls into question the traditional understanding of knowledge, learning and ability it challenges most current science teaching practice. However, it provides a useful basis for developing the kind of "thinking curriculum" that is needed if we are to engage more young people in science.

In summary, while the aim of an education in science is to develop the ability to work with scientific concepts, recent developments in learning theory tell us that effective science learning must take account of the values, aesthetics, feelings and personal stories through which individuals make meaning. While learning concepts is obviously important, for this to occur, considerable 'translation' is needed, and this is best done through activities and tasks designed to help students make explicit links between science concepts and stories or contexts that can allow them to talk their knowledge into place.

There have been some attempts to set out what these theories might look like in practice. One example is the (Australian) Middle Years Research and Development project. This project came up with five principles for designing programmes that engage today's young adolescents in learning.

1. Students are *challenged* to develop *deep* understanding through strategies that emphasise student questioning, exploration, and engaging with significant ideas and practices.
2. The learning environment is *supportive* and *productive* with classroom environments that allow students to take responsibility for their own learning, take risks and express themselves.
3. Teaching strategies cater for *individual interests* and *learning needs.*
4. Assessment is an *integral* part of teaching and learning.
5. Teaching practice meets the *developmental needs* of adolescent learners –it emphasises students' active engagement in their own learning, student involvement in decision-making, linking of classroom learning with local and broader communities.

The learning theories outlined above focus specifically on young people's learning. Other work has explored the thinking processes of working scientists, concluding that they too do not actually work exclusively with resolved concepts. This leads some science educators to argue that science education which aims to produce this in students is misrepresenting science.

4.4 Changes in science

While the practice of scientific research has changed significantly over the last century or so this is not evident in how science is taught in schools. The 18th and 19th century model of the individual scientist pursuing their own interests was largely replaced in the 20th century by two parallel cultures – academic scientists working alone or in small teams, largely following their own interests, and industrial scientists working in large teams on commercially driven projects. More recently, however, these two cultures have come together into what Ziman calls 'post-academic' science (largely as a result of changes to the funding arrangements of universities). Post-academic scientific work takes place in large teams that are often networked over a number of institutions and countries, and involves a succession of projects that have to be justified in advance in order to attract funding. These projects are usually large in scale, multi-disciplinary, and multi-method. They commonly deal with highly complex systems with many interconnecting effects. Some projects are likely to involve ethical issues, some will be of interest to local communities and some will be subject to business and political influence. Post-academic science of this kind is not currently reflected in schools.

Similarly, the now sizeable body of work known as the social studies of science and the many challenges to science's status as universal, objective knowledge of reality are not reflected in school science education. Research involving focus groups of leading scientists has consistently highlighted this as a concern with scientists seeing school science as presenting an outdated, narrow and excessively discipline-bound view of science.

Engaging young people in science requires us to take these changes into account, and doing this requires us to think differently about the purpose of school science education. In this section, we have argued that current science education and the demands of the 21st century are out of step. Traditional science education, designed to prepare science-able students for science careers, is in fact turning many students away from science and it may not be serving any of our students particularly well – even those who are high achievers on current measures.

4.5 Notes to Section 4

Changes in society, work and young people

Page 28
See Gilbert, J. (2005) *Catching the Knowledge Wave? The Knowledge Society and the future of education*. Wellington: NZCER Press; or Gee, J-P., Hull, G. and Lankshear, C. (1996). *The new work order: Behind the language of the new capitalism.* Sydney: Allen & Unwin for more detailed accounts of the implications of the 'knowledge age' and/or the 'new work order' for education.

For recent research following cohorts of young people as they transition through school to tertiary education and/or the early years of work, see Wynn J. (2004). *The Transition of young people to adulthood in changing times and contexts*, in R. Galbally (Ed), *Healthy Minds, Healthy Bodies, Healthy Nation: Connecting Education and Health*, College Yearbook 2004, Canberra: Australian College of Education; Vaughan, K. (2008). *Student Perspectives on Leaving School, Pathways and Careers* (Report no.4 from the age 16 stage of the Competent Children, Competent Learners project). Wellington: Ministry of Education; and Vaughan, K., Roberts, J., & Gardiner, B. (2006). *Young people producing careers and identities: The first report from the Pathways and Prospects project.* Wellington: New Zealand Council for Educational Research.

The "power down" quote is taken from Prensky, M. (2001).*Digital natives digital immigrants*. From *On the Horizon* MCB University Press, 9(5). Available at www.marcprensky.com/writing/Prensky.

Page 29
The "frogmarched across the landscape" quote is taken from Osborne, J. and Collins, S. (2001). Pupils' views of the role and value of the science curriculum: a focus-group study. *International Journal of Science Education*, 23(5), 441-467 (p.450).

Changes in the purposes of schooling

Page 29
For a fuller discussion of how schools need to be different now, to meet the needs of 21st century learners, see: Warner T. (2008). *The global achievement gap: Why even our best schools don't teach the new survival skills our children need – and what we can do about it*. New York: Basic Books; Warner D. (2006) *Schooling for the Knowledge Era*. Victoria: ACER Press; Gilbert, J. (2005) *Catching the Knowledge Wave? The Knowledge Society and the future of education*. Wellington: NZCER Press; and Beare, H. (2001). *Creating the future school*. London: Routledge.

For a discussion of the 'new' understanding of knowledge that defines the 'knowledge age', see: Castells, M. (2000). *The Rise of the Network Society* (2nd ed.). Oxford: Blackwell. For a discussion of the implications of this for schooling and leaning see: Claxton, G. (2002). *Building learning power: how to help young people become better learners*. Bristol TLO Ltd; and Kress, G. (2003). *Literacy in the new media age*. London: Routledge.

New theories of learning

Page 30
In New Zealand the constructivist-influenced approach to learning was exemplified in the University of Waikato-based *Learning in Science* Projects of the 1980s and 90s. See Bell (2005) for a review of this work.

For discussions of the socio-cultural approach to learning, see: Lave, J. & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge: Cambridge University Press; Wertsch, J. (1991). *Voices of the mind: A socio-cultural approach to mediated action*. Cambridge MA: Harvard University Press; Hennessy, S. (1993). Situated cognition and cognitive apprenticeship: implications for classroom learning. *Studies in Science Education* 22, 1-14: Driver, R., Asoko, H., Leach, J., Mortimer, E. & Scott, P. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher* 23(7), 5-12.

See Bruner (1986) for the case for two distinct 'modes of thought' – the narrative and the logic-scientific.

More recently, the view that people develop a sense of self and their place in the world though stories – the stories told to them by others, and the stories they are encouraged to tell about themselves to people who are important to them – is 'mainstream' in psychology. See, for example: Sarbin, T. (ed.) (1986). *Narrative psychology: the storied nature of human conduct*. New York: Praeger; Polkinghorne, D. (1988). *Narrative knowing and the human sciences*. Albany NY: State University of New York Press; Connelly, F. & Clandinin, J. (2000). *Narrative enquiry: experience and story in qualitative research*. San Francisco: Jossey Bass.

For discussions of the use of narrative-based teaching approaches in science education see: Millar, R. & Osborne, J. (eds.) (1998) *Beyond 2000: Science education for the future.* London: Kings College London; Gilbert, J. (2001). Developing narrative-based approaches to science education: Re-thinking an 'old' discipline for the 'knowledge society'. In: B. Cope & M. Kalantsis (eds.) Learning for the future: Proceedings of the Learning Conference 2001. Melbourne: Common Ground; Solomon, J. (2002). Science stories and science texts: What can they do for our students? *Studies in Science Education* 37, 85-106; Norris, S. & Philips, L. (2003). How literacy in its fundamental sense is central to scientific literacy. *Science Education* 87(2), 224-240; Barker, M. (2004). Spirals, shame and sainthood: More ripping yarns from science. *New Zealand Science Teacher* 106, 6-14.

Page 31
See Resnick, L. (2010). Nested learning systems for the thinking curriculum. *Educational Researcher*, 39(3), 183-197 for a explanation of the "thinking curriculum" idea. For her, a "thinking curriculum" is one that is (i) cognitively demanding with conceptual learning, reasoning, explaining and problem-solving engaged in daily; (ii) embedded in specific, challenging subject matter such as science; and, (iii) capable of engaging *all* students.

The five principles for designing programmes to engage today's young adolescents in learning come from the (Australian) Middle Years Research and Development project – see Victorian Department of Education & Training (DE&T) (2003). *Middle Years Pedagogy Research and Development Project* (Victoria Australia). http://www.education.vic.gov.au/studentlearning/teachingprinciples/principles/unpacked.htm for details.

Changes in science

The term 'post-academic science' comes from Ziman, J. (2000). *Real science: What it is and what it means*. New York: Cambridge University Press.

Page 32
For a review of research work on how the 'doing' of science is portrayed in schools, see Haigh, M., France, B., and Forret, M. (2005). Is 'doing science' in New Zealand classrooms an expression of scientific inquiry? *International Journal of Science Education*, 27(2) 215-226.

Osborne, J., Ratcliffe, M., Collins, S., Millar, R. and Duschl, R. (2003). What ‘ideas about science’ should be taught in school science? A Delphi study of the 'expert community’. *Journal of Research in Science Teaching*, 40(7), 692-720; and Tytler, R. and Symington, D. (2006). Science in school and society. *Teaching Science: The Journal of the Australian Science Teachers Association*, 52(3), 10-15 report on research with scientists, highlighting their concern that science is portrayed inaccurately in school science education.

The claim that traditional school science education is turning science-able students away from science is made in Tytler, R. (2007). *Re-imagining science education: Engaging students in science for Australia’s future*. Camberwell: Australian Council for Educational Research
http://www.acer.edu.au/documents/AER51_ReimaginingSciEdu.pdf

5 CONSIDERING THE OPTIONS

Changes in society, schooling and science itself, coupled with a lack of clarity of the purpose of science education, have produced school science programmes that are not optimally meeting the needs of *any* of our students – neither high achievers headed for science related careers nor the majority who need science for citizenship. Solving this problem requires a long term strategy that takes into account purposes, pedagogies, assessment practices, teacher beliefs and values, resources and the wider community.

In this section we provide one possible scenario of how science education could look different in the future. The purpose of providing this scenario is two-fold. Firstly, we aim to *stimulate debate* about what really matters in science education. Any curriculum decision involves trade-offs: thus our aim in including this scenario is to bring to the surface deeply-held - but often tacit - beliefs about what "good" science education should do. What can be given up, and what needs to be retained? The second purpose is to 'concretise' some of the ideas discussed in this paper, and provide some *practical ideas* about possible first steps.

5.1 Scenario:

This scenario assumes that the purpose of science education is different for students at different stages of the school system.

Years 1-6 (Primary)	The emphasis in these years would be on stimulating students' interest and curiosity, and in developing literacy skills.
Years 7-10 (Middle school)	The emphasis in these years would be on socio-scientific issues. There would also be a focus on increasing students' awareness of the possibilities of future careers in science.
Years 11-13 (Senior secondary)	At the upper secondary level students could continue to study an issues focused programme but they could also take courses in either pure or applied science that are more focused on preparation for careers in science.
At all levels	Students are *challenged* to develop *deep* understanding through strategies that emphasise student questioning, exploration, and engaging with significant ideas and practices. There would be much greater interaction between schools and the science community and more emphasis placed on students' active engagement in their own learning.

The different stages of this model are described in more detail below.

Primary years (up until about age 10 or 11)

According to Osborne, *"reading, writing and argument are central to any conception of science as it is currently constituted."* The development of these skills would be the major contribution that the primary school years make to science education. Classroom teachers would be responsible for the development of reading, writing and argumentation skills, as currently covered in the *Communicating in Science* strand of the New Zealand Curriculum. Stories would also play an important role in science teaching. This focus on oral language, and interacting with a range of texts, could be complemented with hands-on activities specifically designed to stimulate children's interest in the world around them and in science itself. These could be regular, one-off activities or they could be intensive blocks of activity perhaps provided in collaboration with, or by, community partners. (For example, monitoring and looking after a local waterway, field trips etc) This approach recognises the expertise primary teachers have in teaching 'everyday' literacies, while providing support for hands-on science. By encouraging working in collaboration with community experts it recognises the importance of deep knowledge, passion, and enthusiasm for a subject in motivating learners.

Middle years (from about age 11 until 14 or 15)

These programmes, as in the primary years, would be aimed at all students. They would encourage a strong focus on the science literacy approach signalled in the most recent national curriculum document: that is, science teaching that aims to:

(i) build students' understanding of what is known as 'the nature of science' – that is, how science works, how scientific knowledge is built up, its special features and so on, and
(ii) develop students' ability to participate in an informed way in current debates of socio-scientific issues.

The main emphasis of teaching programmes would be on exploration, critical thinking and discussion of socio-scientific issues. The content would be determined by how central any particular knowledge is to students' understanding of contemporary issues. Science literacy could be developed through new learning programmes and resources put together by cross-disciplinary teams made up of experts in such areas as critical thinking and ethics working with scientists and with teachers who have pedagogical and programme development expertise. Community expertise would also be needed in some cases to help define the problem or issue as it applies in the local area.

In addition to this focus on socio-scientific issues, these programmes would also develop students' awareness of the wide range of science-related careers. This aspect of the programme could also involve schools and the science community working closely together.

Senior secondary (from about age 15 until 17 or 18)

At this level some students would choose a programme with a stronger focus on preparation for university and a science-related career. Such a programme would include courses clearly directed at providing the foundational knowledge and experiences these students need, but students could also choose to continue on with science literacy focused courses as well.

Working within the existing school system, such career-oriented programmes would probably involve some form of ability streaming of interested and able students which would require decisions to be made about when and how to stream. Alternatively, career-oriented programmes could be offered through science academies or specialised schools with good facilities for teaching science and specialist science teachers. Another option for achieving this purpose could involve a major emphasis on well-resourced, well-designed, extracurricular or out-of-school science programmes.

Regardless of how it was organised and delivered, the science curriculum would need to emphasise deep understanding of key science knowledge as well as a focus on scientific thinking and some exploration of socio-scientific issues. As the needs of students headed for careers as working research scientists are different from those headed for science-related professions such as medicine and other health professions, different modules might need to be offered. For example, science for future scientists would put more emphasis on scientific thinking, research design and problem-solving, would offer interaction with and mentoring by working scientists, at least some history, philosophy and even sociology of science and scientific knowledge development. Science for health professionals might focus more on essential science knowledge taught in the context of its likely uses in everyday human and social situations.

Advantages and disadvantages

This scenario encompasses multiple purposes for science education, but focuses clearly on different purposes at different stages. There are several advantages of this approach. Focusing on different purposes at different stages allows for targeted, developmentally appropriate programmes for all students. The different focus of programmes at each stage also means students have the opportunity to re-engage with science at each new stage, regardless of their experiences of science at the previous stage. The focus in the primary school on the development of every-day literacies, with support for "hands on" activities from science experts, allows primary teachers to work from their areas of expertise. Furthermore, everything within this scenario would be possible within the current New Zealand Curriculum framework.

The challenges would be that aspects of this programme (especially the focus on socio-scientific issues in the middle years of schooling, and the increased participation of community experts) would require many teachers to make changes to both teaching and assessment practices. For instance a focus on socio-scientific issues would require many teachers to find a different balance between teaching knowledge and skills and providing the opportunities for students to work with complex situations so that they can practise identifying what is important in a particular context. This science for citizenship approach brings issues rather than content into the foreground of science teaching and although it has the potential to encourage integrated learning programmes across school disciplines as well as to encourage community involvement, both would require flexibility of school operation and timetabling. Considerable investment would need to be put into professional learning for teachers and the development of new resources for both teaching and assessment. These challenges however are not insurmountable and there are examples of such innovative practice in some New Zealand schools now.

The scenario described attempts to reconfigure school science education in ways that are designed to build the kinds of knowledge and thinking skills needed for the future by New Zealanders, both scientists and non-scientists. A curriculum of this type would achieve all the traditional purposes of science education, in particular, preparing students for science careers, creating a more informed citizenship and exposing students to traditional science knowledge. However, and importantly for the purposes of this report, because it would take into account the interests, orientations and future needs of today's young people it is likely to engage them in the study of science for its own sake, not just because it is a hurdle to be jumped to achieve a career goal.

5.2 A way forward

The scenario described above is aligned with the ideas in recent reviews in science education internationally. There are several international examples where some aspects of this scenario are already being put into practice, supported by professional development and new teaching and assessment resources. There are also many New Zealand examples of community and/or school based innovations in science education.

These New Zealand initiatives, like the overseas examples, address different aspects of engaging students in science and many appear successful in what they set out to do. Despite this enthusiasm and energy from a wide range of stakeholders it seems unlikely we will make much progress in engaging more students with science without a coherent overarching strategy. An important first step in engaging more young people in science could be to convene a forum of scientists, educationalists and policy makers to debate the future of science education in New Zealand. The forum would consider the purposes of science education discussed in this paper - pre-professional training, utilitarian, democratic or cultural purposes; and the changing demands of students, society and science itself. The forum would debate both how education can best serve science and how science can best serve education. This is important as a string of recent government and policy documents have pointed out, New Zealand's size, its resources and its geographical location mean that our main option for keeping pace with developments in the global economy is to focus on developing our knowledge-based resource – the quality and capacity for innovation of our people.

5.3 Notes to Section 5

Page 35
The quote re the importance of reading writing and argument in science comes from: Osborne, J. (2002) Science without literacy – a ship without a sail? *Cambridge Journal of Education, 32(2),* 203-218

Page 37
For UK evidence of the need for teachers to change their pedagogy to meet the demands of new curricula see for example Osborne, J. (2007) Science Education for the Twenty First Century. *Eurasia Journal of Mathematics, Science and Technology Education, 2007,3(3),* 173-184
For NZ evidence of teachers' need for support to make changes in pedagogies for issues-based science teaching, see for example Saunders, K. J. (2009). 'Engaging with controversial science issues – a professional learning programme for secondary science teachers in New Zealand'. Doctoral thesis, Curtin University of Technology, Australia.
One example of innovative practice in New Zealand schools is Paul Lowe's work at Morrinsville College. Paul Lowe, who is the 2009 winner of the Prime Minister's Science Teacher Prize, has developed programmes for teaching science that involve students working together in teams solving real life problems. Students are encouraged to find their own resources, to use a range of new technologies and to work closely with scientists. There is an emphasis on self-assessment and each team member gains the team's mark for projects. Teams of talented students from several different schools have been using this problem-based learning in teams for some years. Students are brought together both face-to-face at camps http://gallery.me.com/jpaullowe and through extensive use of technology such as video conferencing. More recently a similar programme has been rolled out to mixed-ability classes. Data collected from 320 students showed improved engagement and achievement levels and 75% of students ranked science as their favourite subject. www.pmscienceprizes.org.nz/about/winners_2009/teacher.html

For recent international reviews of science education, see: Osborne, J. and Dillon, J. (2008) *Science Education in Europe: Critical Reflections.* A report to the Nuffield Foundation. http://www.pollen- europa.net/ Pollen.dev/Images_Editor/Nuffield%20report.pdf (in particular, their recommendations to the Nuffield Foundation on Science Education in Europe); and Tytler, R. (2007). *Re-imagining science education: Engaging students in science for Australia's future*. Camberwell: Australian Council for Educational Research.

A way forward

Two examples of recent reports advocating increasing our capacity for innovation by focusing on our knowledge-based resources are: MoRST (2010) *Igniting Potential*: *New Zealand's Science and Innovation Pathway*. Available at http://www.morst.govt.nz/Documents/publications/Igniting-Potential.pdf ; and The NZI (2009) discussion paper, *Standing on the Shoulders of Science: Getting more value form the innovation ecosystem.* Available at http://www.nzinstitute.org/Images/uploads/Standing_on_the_shoulders_of_science_-_Full_report.pdf

Appendix 1 Achievement data

1. The international PISA assessments of 15 year olds use a six-point scale to identify 'top performers', those who achieve at levels 5 and 6 on the scale; 'strong performers' proficient at level 4; 'moderate performers', operating at levels 2 and 3; and, those at risk who perform at level 1 or below. In the 2006 PISA assessment 9% of students overall were identified as top performers in science but encouragingly, 18% of New Zealand students fell into the top performer category, second only to Finland with 20%. Further investigation of the top performers group reveals that they were far more likely than other students to want a future career involving science, to go on to further study in science and to see themselves working on science projects in the future. Furthermore, the top performers in science reported being significantly better prepared for science-related careers than students in other performance groups, although not always well informed about the careers available. Thus it seems that, by comparative international standards, we are doing very well at educating our top students in the sciences.

2. The PISA framework for scientific literacy identified the competencies, knowledge and attitudes students need to be scientifically literate. The competencies required are to 'identify scientific issues', to 'explain phenomena scientifically' and to 'use scientific evidence'. New Zealand students performed very strongly on 'identifying scientific issues' and 'using scientific evidence', with only Finland achieving a significantly better result in these areas, and showed a slightly weaker performance in 'explaining scientific phenomena'. PISA assessed students on two knowledge domains – knowledge *of* science which explores scientific concepts and knowledge of living systems, earth and space and physical systems, and knowledge *about* science which is the understanding of the nature of science, scientific enquiry and scientific explanations. While New Zealand's students performed well in both areas, only two countries' students did better in their knowledge *about* science[7]

3. In the 2006 assessment cycle New Zealand students expressed most interest in biology, chemistry, astronomy and physics. [8] Just 66% of New Zealand's students agreed that science can bring social benefits, compared with an OECD average of 75%, although on other attitudinal indicators New Zealand students were around the OECD average. Our students also scored below the average on the dimension of 'self-efficacy', a scale which probed students' perceptions of their ability to use science as a tool to think with. The proportion of students who reported enjoying learning about science was also similar to other OECD countries although fewer New Zealand students than those in other countries liked reading about science preferring instead to tackle science problems. The PISA analysis shows a clear link between interest in and enjoyment of science, and achievement.

4. Student performance on various aspects of scientific literacy measured in PISA 2006 was amalgamated to give the combined scientific literacy scale. Of the 57 countries participating in PISA 2006 only Finland and Hong Kong-China achieved a better performance than New Zealand putting New Zealand in a group along with eight other countries which achieved a similar performance. New Zealand had one of the widest spreads of achievement scores with the top

[7] Telford M and Caygill R (2007) *PISA 2006: How ready are our 15 year olds for tomorrow's world?* Wellington, Ministry of Education

[8] Results from the 2009 cycle will be available in December 2010

five percent of our students outperforming other high-performing countries and the bottom five percent achieving scores significantly lower than low achievers in those countries.

5. Analysis of PISA 2006 showed that there was no significant difference in overall science literacy between boys and girls in New Zealand although boys were slightly more likely to be at the top or bottom of the achievement distribution. Päkehä students obtained the highest scores followed by Asian, Mäori and Pasifika students. Students born overseas with parents also born out of New Zealand (first generation immigrants) performed almost as well as students with a New Zealand born parent, but 'second generation immigrants', New Zealand born students of parent born overseas performed significantly weaker overall. Other factors linked with high science literacy included a high level of parental education, speaking English at home and having access to educational resources. Students who changed school frequently were less likely to perform well.[9] TIMSS found a very similar patterns in relation to Year 5 students' achievement in science – there was little difference between boys and girls, there was a clear relationship between socio-economic background and achievement, and that while there were high and low performers in all ethnic groups, the average score of Päkehä and Asian students was higher than that of Mäori and Pasifika students. TIMSS found that students born in New Zealand had higher science achievement than those who were not. [10]

6. A recent update on international research into school students' attitudes towards science identified problems in measuring attitudes because of an assumption that science is a homogenous entity whereas the reality is that there is a diversity of sciences.[11] However, despite the measurement issue, there is convincing evidence that by the age of 14 the majority of students have decided whether or not they are interested in pursuing further study in science. Girls' attitudes to science emerged as of particular concern with the authors suggesting that this was a result of an attempt to present science as decontextualised and value free. The authors offer this explanation about why such a presentation may not be helpful to today's young people of either gender:

   The decision-making landscape that young people negotiate as they select their school subjects, decide who they want to be, and aspire to fulfilling futures is a complex terrain making it difficult to define who they are and where subject choice becomes one important marker for defining who they are to others.(Osborne et al, 2009, p9).

   The Relevance of Science Education (ROSE) Project is a co-operative research project involving about 40 countries exploring students' attitudes and motivations towards science and technology. ROSE focuses on students' at age 15 who are in the formal schooling system. ROSE has developed an instrument that can be used for both genders and across cultures to examine students' attitudes. New Zealand does not currently participate in the ROSE project.
   ROSE provides a rich data set which, summarised at a very high level, indicates that:

   - children in most countries agree strongly that science and technology are important for society

   - attitudes to science and technology among adults and young people are mainly positive

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9 Telford M (2010) *PISA 2006: Scientific literacy: How ready are our 15 year-olds for tomorrow's world*? Ministry of Education: Wellington

10 Caygill R (2008) *Science: trends in year 5 science achievement 1994 to 2006.* Ministry of Education: Wellington.

11 Osborne J, Simon S and Tytler R. (2009) *Attitudes towards science: An update*. Paper presented at the Annual Meeting of the American Educational Research Association, San Diego, California, April 13-17 2009.

- in the richest countries (Northern Europe, Japan) young people are more ambivalent and sceptical than the adult population

- there is growing gender difference, with girls, particularly in the richest countries, being more negative (or sceptical, ambivalent) than boys.[12]

[12] Sjøberg s and Schreiner C. (2010) *The ROSE project: An overview and key findings.* University of Oslo. http://folk.uio.no/sveinsj/ROSE-overview_Sjoberg_Schreiner_2010.pdf