# The Future of Science Education in New Zealand

## Introduction

The Royal Society of New Zealand (RSNZ) has a leadership role in supporting and promoting quality science and science education in New Zealand. This paper looks to identify how RSNZ can use its influence in the education and science system in order to develop more students having a strong and positive interest in science and more students following pathways that will see them become the scientists of tomorrow.

The purpose of this paper is to draw together current research and thinking on science education in the compulsory years of schooling to: (i) argue that changes in thinking and practice are required; (ii) identify the key shifts needed; and (iii) suggest some strategies to develop the system-wide support needed to facilitate this change.

RSNZ believes that strengthening science education in New Zealand schools requires a much clearer view of the student outcomes at different stages of a student's education process that would see New Zealand producing more students having a strong and positive interest in science and more students interested in becoming the scientists of tomorrow.

As recommended by leading system-level school reformers, this will require identifying and then relentlessly pursuing a small number of key principles and practices.[1] In doing this we also believe that the responsibility for strengthening science education should not be seen as entirely lying in the education sector: it needs to draw on the thinking of educators *in collaboration with* scientists, parents, policy makers and politicians. The RSNZ can use its influence to shape what matters in the classroom and how the science system can better align to, and support, much more effective teaching of science in New Zealand schools.

This paper sets out key issues from today's educational debates that apply to science education. It is designed to stimulate and focus debate that has the imprimatur of RSNZ and its work, and influence, with key decision makers.

Thinking strategically about science education in New Zealand is particularly important at this point in time, 11 years into the 21st century. Despite many reform attempts, current science education practices continue to be framed by 20th century understandings of science, of education and learning, and of the needs of young people and society. Earlier this year, the Prime Minister's Chief Science Advisor, Sir Peter

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1 See Fullan (2010, p. 59).

Gluckman, argued, in his paper *Looking Ahead: Science Education in the 21st Century*, that "a forward-looking science education system is fundamental to our future success in an increasingly knowledge-based world".[2] But what exactly *is* a forward-looking science education system? What ideas need to underpin its development? What would it look like? How might it be implemented in practice? These are hard questions. Equally challenging are the questions that follow from these. What new infrastructure is needed to support the shift to a forward-looking science education system? How can we develop the kind of dynamic, innovative, learning-oriented system needed to engage today's young people in the science of today?

This paper argues that it will not be enough to speed up, provide more support for or develop better measures of today's processes: something new and different is needed. It sets out the ideas that underpin this claim, explains why change will be difficult and proposes four strategies for moving forward.

## Background—why now?

Recently we have seen an increasing acknowledgment, at government level, of the importance of science and innovation to New Zealand's economic and social future.[3] Alongside this there is increasing public concern about how we are building our ability to address the "wicked problems"[4] of the future.

The release of the Prime Minister's Chief Science Advisor's paper on science education signals a high-level interest in how our science education system might be strengthened to contribute to New Zealand's development as a "smart", knowledge- and innovation-oriented country that is capable of addressing the serious questions it will face in the future.[5] As the Prime Minister's Chief Science Advisor's paper points out, this is a complex issue. Addressing it requires change in a number of areas—new teaching and assessment practices, and better linkages between science and education, for example. However, the present paper argues that change is required at a deeper level—at the level at which we think about what science education is *for*, *who* it is for and what we would like it to achieve. It argues that science education, as it is currently practised, does little to prepare young people for the "knowledge societies" of the future, but, worse, it contributes to reproducing some ways of thinking that most need to change.[6]

Change is needed in two key areas: (i) the preprofessional education we offer to those who will be the scientists of the future; and (ii) the way we build the nonscientist population's capacity to engage in public

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2 Gluckman (2011, p. vi).

3 The new (February 2011) Ministry of Science and Innovation was established to support a "broader government focus on boosting science and innovation's contribution to economic growth" (www.msi.govt.nz) and the Prime Minister has appointed a Chief Science Advisor.

4 The term "wicked problem" is widely used to refer to very complex problems that are difficult or impossible to solve—or even define—using the tools and techniques of one organisation or discipline. Because they have multiple causes and complex interdependencies, efforts to solve one aspect of a wicked problem often reveal or create other problems. They are common in public planning and policy, where any solution is likely to require large numbers of people to change their mindset and/or behaviours. The standard examples of wicked problems include climate change, natural hazards, public healthcare, nuclear energy and waste, but the term is also widely used in design and business contexts. "Tame" problems, in contrast, while they can be highly complex, are definable and solvable from within current paradigms.

5 See, for example, *Looking Ahead: Science Education for the Twenty-first Century—a report from the Prime Minister's Chief Science Advisor* (Gluckman, 2011).

6 This argument is made in Hodson (2003, 2011) and in Gilbert (2005).

discussions of science-related issues. A “smart”, knowledge- and innovation-oriented country needs professional scientists, engineers, technologists and mathematicians who can think and work in today’s organisations, but it also needs the support of an engaged and scientifically-literate public.

Can a science education system produce both of these? If so, what would it look like? Why is the present system not good at producing either? This paper attempts to answer these questions.

## Why change is needed

For much of the last century, there was a good “fit” between the education we provided and the education that was needed—by individuals, society and the economy. We used the best means possible (modern schools, professional teachers and formal exams) to deliver the kind of education (being disciplined into the disciplines) needed in a relatively stable economy made up of large hierarchical organisations. However, two key developments over the past three decades have changed things; so much so that there is no longer a good fit between the education we provide and the education we need.

The first development, largely the result of the 20th century goal of making formal education accessible to all, is that we now know a great deal about how people learn. Ironically, this knowledge doesn’t fit very well at all with the education system as it now is. Moreover, this knowledge has developed alongside an increasing sense of doubt that continuing to improve what we do now will be enough to equip our young people for life and work in the 21st century.

The second development is that there has been a shift in the way knowledge is thought about and used. Because the kind of knowledge that underpins the new “knowledge societies” is something quite different from the kinds of knowledge that are the basis of our education system, this shift is highly significant for education. Education systems are supposed to foster the development of the knowledge, skills and dispositions people need to participate—economically, socially and politically—in the society they live in. If this society changes, then the education system needs to change with it—if it is to continue to meet people’s needs. So: what exactly has changed?

## The knowledge society—what is it?

The late 20th century–early 21st century was a period of major social and economic change across the “developed” world. In the new post-industrial, “knowledge societies”, knowledge has replaced the exploitation of natural resources as the main driver of economic growth. This has produced a number of important changes. In the business world, innovation and “niche” markets have replaced the Industrial Age’s focus on standardised products for mass markets. To compete in this context, 21st century businesses have developed new management models, which in turn require new kinds of workers. Businesses routinely now need problem solvers, team players and good communicators. They need people who are flexible and adaptable, who see themselves as learners and who can take responsibility for all parts of a project. These changes have not been confined to the business world: 21st century government organisations (including universities) and not-for-profit organisations are now run very differently.[7] One result of this is that workers—at *all* levels—now need skills, attributes and knowledge that they did not need in the past. This is the case in virtually all sectors—*including* science.[8]

Alongside this, there has been a shift in the way knowledge is thought about and used. According to one commentator, knowledge is now being thought of, not as a "thing" you can get, but instead as being like energy, something that *does* things.[9] Or, put another way, knowledge is now thought of as a verb rather than a noun, something we *do* rather than something we have.[10]

These shifts—in the way knowledge is understood and in the way workplaces are organised—are now well established: however, their impact on education has, so far, been limited. The New Zealand education system (along with others in comparable countries) has responded to 21st century demands by instituting interventions designed to raise overall educational attainment and increase participation in tertiary education. In addition, we have added and emphasised certain core "competencies" to be achieved by all to the school curriculum, and tried to provide more flexible "pathways" from school to work and/or further education. Supporting the development of a "smart", knowledge- and innovation-oriented country, however, does *not* simply mean producing more "knowledgeable" people—more people who have been "filled up with" existing knowledge. It means producing people who have a different *orientation* to knowledge, people who have enough knowledge to be able to do things with it (that is, to innovate).

Schooling needs to equip people to *do things with knowledge*, to use knowledge in inventive ways, in new contexts and combinations. Rather than providing access to a fixed stock of knowledge, the task now is to equip people to enter and navigate the constantly shifting networks and flows of knowledge that are a feature of 21st century life.[11] An individual's stock of knowledge is important as a foundation for their personal cognitive development: however, for it to be useful as a foundation for their participation in social and economic life, the individual must be able to connect and collaborate with other individuals holding complementary knowledge and ideas.

These high-level changes are significant. However, at the same time there have been other, more "on-the-ground" changes that also need to be taken account of. These, broadly, have to do with meeting the needs of today's young people.

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[7] See, for example, Drucker (1993), Gee, Hull and Lankshear (1996), Lash and Urry (1994), Neef (1998), Peters (2010), Prichard, Hull, Chumer and Willmott (2000), Stehr (1994), Thurow (1996).

[8] Ziman uses the term "post-academic science" to draw attention to the coming together of the "two parallel cultures" of 20th century science (academic scientists working alone or in small teams, in universities or publicly funded research organisations, largely following their own interests, and industrial scientists working in large teams on commercially driven projects). Today's post-academic science largely involves large, networked teams working on large-scale, multidisciplinary, multimethod projects. These projects routinely deal with highly complex, interconnecting systems, many involve ethical issues and some are subject to business and/or political influence. This work is all taking place in the context of an increasingly complex science–society relationship, and the now sizeable body of work challenging science's traditional status as universal, objective and value-free knowledge—i.e., "above" and apart from other forms of knowledge.

[9] See, for example, Castells (2000).

[10] See Gilbert (2005).

[11] The idea of knowledge as a system of "networks and flows" is taken from Castells (2000).

## Today's young people, knowledge and learning

Recent research, in a variety of different contexts, tells us that today's young people have a view of themselves and their futures, a view of science and an orientation to learning and knowledge that is quite at odds with the assumptions underpinning today's schools. Many do not find school science engaging, and most do not learn enough science to allow them to usefully participate in discussions of science-related issues.

While it is, of course, nothing new for the older generation to point out the younger generation's differences from themselves,[12] there is quite a bit of evidence that today's young people *are* qualitatively different from those of the previous generation, and that these differences are the product of the Industrial Age–Knowledge Age shift outlined above.

Researchers who follow cohorts of young people as they leave school report that these young people have ideas about work, careers and personal identity that are very different from those of their parents' generation. Uncertainty and change—not stability and predictability—influence their values and choices. Many see their work life, not in terms of one "career", to be "followed" and "built" over time, but as a series of areas they might "get into" (and learn about) for a while, before moving on to something else. This view is framed in terms of personal "choices"—middle-class youth expect to be able to choose their areas of interest, while young people from poorer areas see themselves as having fewer choices. Neither group expects to have to "jump through hoops" set by others as they make their choices—they expect to be able to find out what they need to know on a "just-in-time" basis, using their own resources. The young people participating in these studies value autonomy, flexibility, nimbleness and choice. To them, it is important to be able to take up opportunities as they occur, to have several skill sets and to be able to combine and work across these skill sets as necessary.[13]

Related to this is a very different orientation to knowledge. Because today's "digital natives" do not see teachers, books and adults as their main source of information or authority, school lessons are too often experienced as irrelevant, slow-moving and boring, as something to be endured, not engaged with. As one young research subject put it, going to class involves having to "power down" from real life.[14] These young people are routinely connected to a wide range of information sources: what they need is not more information, but strategies and skills for selecting, processing, assessing and making sense of (that is, *thinking* about) what they already have access to. While these ideas are promoted within school curriculum areas, it is difficult for teachers of all subjects, including science, to implement these strategies in practice.[15]

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[12] Aristotle and Socrates wrote a great deal on how the "dangerous age" of youth should be moulded to develop responsible citizens.

[13] For recent research in this area, see Wynn (2004), Vaughan (2008) or Vaughan et al. (2006). See also Lewis (2001) for an account of how young people are subverting the "hoops".

[14] The term "digital native" and the "power down" reference are taken from Prensky (2001).

[15] The new national curriculum document emphasises *thinking* as one of five "key competencies" to be acquired across all of the different learning areas: however, it seems that science teachers are not finding it easy to incorporate this into their practice—see Bull et al. (2011) for some preliminary research on this.

International studies of student achievement tell us that, comparatively speaking, the performance of New Zealand's top students is very good, but that we have a very broad spectrum of achievement.[16] However, interest in science declines as students move through their schooling, until middle secondary school when it is one of the least enjoyed subjects.[17] Many of the students studying science at senior secondary level appear to be doing so for utilitarian reasons (it is needed for the university course of their choice), rather than for interest or enjoyment. Many are not well informed about the career choices available to them, and relatively few see themselves going on to study "advanced science".[18] Three recent New Zealand studies[19] confirm that here, as in other countries, students are making up their minds about science (and science careers) well before age 15, when they can choose not to study it. There are obvious issues here if we are concerned about the "selection pressures" that determine who enters our future science workforce, on the one hand, and the general population's level of knowledge, interest and engagement with science on the other.

Several research studies attempting to understand these trends—long a concern in New Zealand and many other countries—attribute the decline in student interest in science to the way science is taught in schools, arguing that school science has not adapted to the interests, orientations and needs of the new generation of young people. Three recent studies, for example, found that students resented the lack of opportunity to discuss, reflect, offer opinions, ask questions or "be creative" in science classes.[20] As one group of researchers points out, these views are likely to be the result of teachers feeling pressured to "cover" an over-full curriculum. As they put it, students are "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".[21] Students in all three studies thought science was "important", but boring, difficult, unrelated to the real world and/or their lives and therefore as "not for them". Interestingly, "difficult" 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. A third group used the term to mean intellectual challenge: however, this was seen negatively only where it was not accompanied by appropriate teaching methods. These findings are interesting and significant in the light of current knowledge of how people learn.

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16 See Telford and Caygill (2007).
17 See Wylie et al. (2006, 2009).
18 See Telford and Caygill (2007).
19 The three studies are the National Education Monitoring Project (see Crooks et al. [2008]); the Competent Children, Competent Learners study (see Wylie et al. [2006, 2009]) and the Staying in Science project (see Hipkins et al. [2006]). For Australian data, see Tytler (2007).
20 These studies, carried out in Australia, the UK and Sweden, are: Lyons (2005), Lindahl (2003) and Osborne and Collins (2001).
21 Osborne and Collins (2001, p. 450).

## What we know about learning

There is a vast body of research on learning—how people learn in general, how young people learn and how young people learn science. From this work, a consensus is emerging that, if it was reduced to a list of key principles, it would suggest that:[22]

- Learning is much *more* than simply adding new concepts (or knowledge) to one's existing repertoire.
- Learning involves *thinking*. Knowledge is important to learning, and learning and knowledge are linked, but learning isn't just "getting" knowledge. Learners need knowledge to think *with*. They need to think *about* knowledge to remember it. Knowing things makes it easier to learn new things.
- *Experiences* are critical to learning. Just as learners need knowledge to think with, they also need experiences to "think with". Children's thinking and learning processes are similar to those of adults, but their learning and knowledge have less depth because they have fewer experiences to draw on when processing new ideas or situations.
- Learners need to develop *in-depth* knowledge in some areas if they are to go on learning. Experts in a particular knowledge area think in terms of the deep structures or underlying principles of that knowledge, whereas novices tend to focus on the surface features. Seeing the deep structures allows experts to transfer what they know to new situations more easily than novices. They are also able to appreciate how a knowledge system "works" and what it can do, whereas novices are likely to think it just "is". Learners need to be encouraged to search not for the "right" answer (this produces a focus on surface features), but for the right *approach* to solving a problem.
- To learn, people need to be *actively engaged*—they need to be *doing* something, *thinking* something and/or *saying* something that requires them to actively process, interpret and adapt an experience to a new context or use. This sometimes involves finding a way to integrate existing knowledge with new knowledge, but sometimes it involves jettisoning existing knowledge, something that rarely happens in the science curriculum.
- Learners have to *want* to learn the material. They have to be able to see a *purpose* to learning it—both in the short term, and in the longer term sense of seeing how learning this material will allow them to contribute to something beyond themselves.
- Learning has to be a *personalised*—not a standardised—experience. Learners have to feel "in charge" of their own learning. They need to feel that they know what they are doing, and that they can control the pace of their learning. They need to "get into it" enough to get a sense of "flow" and progress; they need the right amount of challenge (not so much that it is beyond them, but not so little that it is boring); and they need feedback along the way (not just at the end of the course). Young children need help to do this, but to learn more (and become better learners) they need to be able to regulate their own learning and become less and less reliant on the teacher to regulate the pace and goals of learning.
- Learning (usually) needs *structure*. Adults play an important role in young children's development by structuring their experiences and directing their attention to certain aspects of those experiences.

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[22] For fuller accounts of the research underpinning these principles, see Bransford et al. (2000), Perkins (1995, 2009), Hattie (2009), Willingham (2009), Zull (2002, 2011), Duncan (2010). See also Bereiter (2002), Christensen (2008), Claxton (1999, 2002, 2004), Egan (2008), Fullan (2010), Wagner (2008), Pink (2009).

Older children and adults need some sort of "map" to orient themselves and find out where they are up to. In educational contexts the subject areas usually provide this map.

- Learning involves *interaction*—trying out and testing ideas with others. Some or all of it takes place in the context of relationships with other human beings. Sometimes these are people who know more than the learner, sometimes they know less and sometimes they are learning together. A precondition for learning, then, is that the learner feels acknowledged and valued by their co-learners, that they feel that they belong to, or are part of, the "culture" of the learning context.
- Learning needs to take place in a wide *variety of settings*—not just at school, in a classroom—if learners are to be able to transfer and use their learning in new contexts.
- "Intelligence"—or intellectual capacity—is not fixed, but is expandable (through the right kinds of experiences and engaging in practice purposefully using all the cultural tools that add to our biological capacity to think and learn). Expanding people's intellectual capacity should be *the* key function of an education system.

In other words, people do *not* learn well as spectators—having prepackaged knowledge "delivered" *to* them—they need to be actively engaged in the "game". The more people learn, the more they are *able* to learn, and everyone can develop their learning "fitness".[23]

Although some of these principles are understood by many teachers, they are *not* the basis of current science teaching practice, and they are not well understood by the wider public. If we are serious about building a science education system that is capable of preparing young people for the "knowledge societies" of the future, we need to reconfigure it in new, more *learning-centred* ways. However, it will only be possible to do this when there is wider public awareness of the growing gap between the kind of learning our young people are getting and the kind of learning they need. There will also need to be wider public support for teachers as they attempt what is effectively a paradigm shift in practice.

Why is science education not well aligned with current knowledge about learning? What ideas have driven the development of science education? Why? Why are these ideas not a good fit with today's world?

The next section of the paper attempts to answer these questions by looking at science education's development, focusing in particular on what it was supposed to achieve, and at how this plays out in today's official school science curriculum.

## School science—what is it *for*?

In the century or so since science became part of the school curriculum, it has had many different, often conflicting, purposes. Some of these have been explicit, some not. Some lead practice in one direction, others in another. While this muddle of purposes has long been a problem, in today's context it is a major stumbling block to change of the kind discussed in this paper. These purposes can be summarised as follows:

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[23] The British educationist Guy Claxton argues that we need to replace the 20th century model of schooling as the filling of empty vessels with knowledge with a model in which schools are like gymnasia—their aim is to develop "fitter" minds, to build students' learning "muscles" (see Claxton, 1999, 2002).

1. The *preprofessional training* purpose: preparing students for entry to university courses that will lead to science-related careers. This is usually done via programmes organised around key concepts and structures of science.

2. The *utilitarian* purpose: providing students with science knowledge that will allow them to make better personal choices (e.g., about health), and to have some understanding of how the natural world and/or various everyday devices work.

3. The *citizenship* purpose: preparing students to participate in public debate on the major issues of the time, many of which are science-related. This requires some knowledge of the science behind these issues, but it also requires some understanding of how scientific knowledge is developed and tested, skills in critical and ethical thinking, the ability to work with science ideas in nonscience contexts and so on. This kind of knowledge is often referred to as "science literacy".

4. The *intellectual development* purpose: expanding and strengthening students' intellectual "muscles"—their ability to *think*, to *organise* their thinking and to think in increasingly *complex* ways as they become more educated, through being exposed to the scientific ways of doing these things. This is the most "educational" of the four purposes.[24]

The first and second of these four purposes are *knowledge*-centred: that is, the knowledge comes first, it is the goal of the teaching and the teaching is designed to reproduce the existing structures of that knowledge. The third and fourth purposes are *learner*-centred: that is, the learner comes first, the learner's development is the goal and the teaching is designed to provide the learner with the skills and ways of thinking they need to participate fully in economic, social and public life.

Research study after research study shows that the first of these four purposes predominates at secondary school level (although in theory it is not supposed to). The second purpose is usually the focus of primary and/or "nonacademic" secondary science education. The third purpose is supposed to be important, but in practice is underdeveloped, as is the fourth.

Why does science education have so many purposes? Why are some purposes advocated (and officially acknowledged) but not implemented in practice? The answers to these questions lie at the intersection of various ideas about what science is, and what education is for, and how these have played out as our current, Industrial Age education system has developed.

## The context—Industrial Age education

This pattern—a mixture of knowledge-centred and learner-centred goals—is a feature of 20th century education systems. These systems were set up to serve Industrial Age societies. They are supposed to produce equal opportunity for all, but at the same time they are also supposed to provide the kind of workforce the economy needs. This is a problem, because Industrial Age economies are not egalitarian: they are hierarchical, bureaucratic and highly segmented. This problem is resolved by combining two key ideas—the Industrial Age production line, and the academic curriculum. Students are organised into batches (or year groups). They progress together through a series of stages, following a standardised

[24] And the oldest—it goes back 3,000 years or so to Plato's model of the educational needs of a democracy.

curriculum, organised as a linear progression in a preset order. Knowledge, broken down into bite-sized pieces, is "bolted on" in sequence along the production line. The system's quality control checks assess the extent to which this knowledge has "stuck" and, on the basis of this assessment, the system's products are sorted according to their likely employment destinations (i.e., a professional/managerial role, or one of the Industrial Age's many low-skill jobs). This model, characterised by a former Director General of Education as "bread for all and jam for the deserving",[25] gives everyone the "basics", while rationing higher education to those who "have what it takes" to benefit from it. Because the traditional academic curriculum is the basis of the system's sorting mechanism, some knowledge areas "matter" more than others, acting as *de facto* gatekeepers of higher education.

In this system, learner-centred teaching approaches are associated with primary and nonacademic education—that is, with the egalitarian function of education and "the basics". Traditionally, knowledge-centred approaches are introduced further along the production line, where the system's sorting function—and the "real game"—begins. At first glance, this seems a sensible way of allocating scarce resources, and in the Industrial Age context, perhaps it was: however, in today's world it is not. It does *not* produce equal opportunity and its quality control system is based on a set of highly questionable assumptions. But, more importantly in the present context, this system is designed to foster dispositions, skills and orientations to knowledge that are more or less the opposite of those that are needed in today's world.

In the first decade of the 21st century we have made little progress in moving from this model to one more aligned with the needs of the world today. In fact, some changes have moved us in the opposite direction. For example, the shift, over the last 10–15 years or so, has been towards a "seamless" school curriculum: that is, one in which there is no differentiation between primary and secondary schooling, so that primary age students are now required to acquire knowledge of science content and processes in much the same way as secondary students—just at a lower level. The knowledge-centredness of secondary science has thus trickled down to primary level, rather than, as might have been more appropriate, importing the learner-centredness of traditional primary education up into the secondary school. This emphasis is challenging for the many primary school teachers who have little background in science and, when it is set alongside the recent focus on basic literacy and numeracy skills, is likely to result in primary school students learning a great deal less—not more—science.

So, what does New Zealand's current official national curriculum document[26] have to say about the learning of science?

## Science in The New Zealand Curriculum

The New Zealand national curriculum document sets out to provide a "framework" for learning, not a detailed plan.[27] It "sets the direction for teaching and learning" in all English-medium state and integrated schools from Years 1–13. Schools must provide teaching and learning in eight "learning areas", of which Science is one, for all students from Year 1 to Year 10 (age 5–14). Through the eight learning areas,

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[25] See Renwick (1986, p. 26).
[26] *The New Zealand Curriculum for English-medium Teaching and Learning in Years 1–13* (Ministry of Education, 2007).
[27] Ministry of Education (2007, p. 37).

students should develop five "key competencies"—*thinking*, *using language, symbols and text*, *participating and contributing*, *managing self* and *relating to others*.

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.[28]
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> Science is a way of investigating, understanding, and explaining our natural physical world and the wider universe. It involves generating and testing ideas, gathering evidence—including by making observations, carrying out investigations and modelling, communicating and debating with others—in order to develop scientific knowledge, understanding, and explanations. Scientific progress comes from logical, systematic work and from creative insight, built on a foundation of respect for evidence. Different cultures and periods of history have contributed to the development of science.[29]
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> By studying science, students:
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> - develop an understanding of the world, built on current scientific theories;
> - learn that science involves particular processes and ways of developing and organising knowledge, and that these continue to evolve;
> - use their current scientific knowledge and skills for problem solving and developing further knowledge;
> - use scientific knowledge and skills to make informed decisions about the communication, application, and implications of science as these relate to their own lives and cultures and to the sustainability of the environment.[30]

Science in the national curriculum document has five "strands"—Living World, Planet Earth and Beyond, Material World, Physical World and Nature of Science (NOS). This fifth strand is the core and is compulsory: the intention is that through this strand students learn what science is and how it works, while the other strands provide the contexts for learning this. The four "contextual"[31] strands represent revisions of the 1990s science curriculum and so were already familiar to most science teachers. The NOS strand was developed with the key competencies of the overall curriculum framework in mind. One of the five key competencies, *participating and contributing*, is directly referenced as the title of one of the four NOS substrands. A second key competency, *using language, symbols and texts*, clearly underpins the "communicating in science" substrand but the other three key competencies (*thinking*, *relating to others* and *managing self*) are implied rather than explicitly developed. This is a problem because the way teachers interpret the role that competencies should play in teaching and learning depends on the depth of understanding of the *nature* of competencies and their curriculum *purpose*.[32] In practice, many teachers have drawn on surface-level understandings to claim that their current practice is already reinforcing and developing students' competencies, and they do not perceive a need for the sorts of changes signalled by the principles of learning outlined above. However, a deeper reading of the intent of

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28 Ministry of Education (2007, p. 17).

29 Ministry of Education (2007, p. 28).

30 Ministry of Education (2007, p. 28).

31 The title reflects an intention that the nominated concepts will provide contexts for developing the sorts of thinking and insights signaled in the NOS strand—i.e., these strands support the overarching NOS strand.

32 In the Australian national curriculum, currently in development, they are called "capabilities", but curriculum commentators there are also concerned that this term is vulnerable to trivial, surface-level readings.

key competencies would support changes in teaching and learning that align with these principles, so this is obviously an important challenge to address.

## The more things change, the more they risk staying the same…?

The challenge with interpreting key competencies reflects the considerable freedom schools have within this general "framework" to decide how to organise their science learning programme. In theory, any secondary school could now choose to create a more "learner-centred" science programme, along the lines of the principles outlined above. *The New Zealand Curriculum*'s (*NZC*'s) own vision and principles point strongly in this direction. However, the Science learning area part of *NZC* gives more mixed signals by including all four of the purposes outlined earlier in this paper: that is, through the Science learning area, students are supposed to get useful knowledge (about how the natural world *and* science work), this knowledge is supposed to enable them to participate as citizens and their intellectual capacity will be developed via a focus on the *thinking* key competency. If the relationship between the four purposes is carefully developed, the document could be seen as signalling the appropriateness of knowledge- *and* learner-centred teaching approaches. However, these two approaches are usually seen as either/or alternatives, and as long as such thinking continues, more traditional knowledge-centred approaches are likely to continue to dominate secondary school curriculum decision making.

*NZC* is favourably regarded by teachers and others in the education sector—mainly for the permission it gives for a range of different approaches, but also for the emphasis it gives to future-focused issues and so-called "21st century learning". It *is* potentially enabling. Nothing in *NZC* itself hinders the possible implementation of science programmes that take account of what we know about learning and of the interests of today's young people.[33] However, this document on its own will not produce the paradigm shift in educational thinking we need if we are to become a "smart", knowledge- and innovation-oriented country—for two key reasons:

1. Many teachers continue to see school science's primary purpose as being to provide students with knowledge.[34]
2. Because other stakeholders—parents, the wider public, education policy makers and the science community—do not appreciate the extent to which innovation is needed in our education infrastructure, they are unlikely to support—and demand—the development of new models. If our goal is to be a knowledge- and innovation-oriented country, then the current policy focus—on assessment and raising basic achievement levels *within the current paradigm*—is, at best, misplaced.

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[33] The modular structure of assessment for secondary-school leaving qualifications (NCEA) also provides for considerable flexibility in curriculum design, if schools are willing to take this up (Bolstad & Gilbert, 2008)

[34] In a recent NZCER survey (unpublished), designed to investigate how teachers were "reading" the signals given in the new curriculum document, teachers were asked what they thought the purpose of school science was. Most mentioned developing an understanding of how the world works and/or investigating, enquiry, thinking and/or questioning skills. Many said that its purpose is to prepare students for high school (if primary) or science careers (if secondary), that it was "part of the curriculum", or that science is "important facts to learn". A few said that it "develops the mind". None mentioned socioscientific issues, citizenship or scientific literacy and none, apart from the references to "investigating", mentioned anything about how scientific knowledge is developed or justified. A few said things like "Wow, what a question" or "I've never thought about it".

To summarise so far then: the main “inhibitors” to our thinking and actions as we try to develop a 21st century science education system are as follows:

1. The wider intellectual context—people, ideas and thinking:

    - Because the public’s understanding of the kind of learning needed to successfully participate in 21st century society is limited, there is currently little public—particularly parental—support for innovation in the public education system.
    - The science education community’s[35] ideas about the purposes of learning science at school are, in general, outdated and in need of reworking for 21st century needs.
    - Most secondary school science teachers do not have a good knowledge of recent developments in learning theory. This, combined with the pressure they are under to “cover” the material needed by students sitting high-stakes assessments, means that the teaching methods that are commonly used are not always appropriate for 21st century needs.
    - Many primary school teachers do not have enough background in science to design the kind of programmes emphasised in the current curriculum document. This, along with the current focus on basic literacy and numeracy, effectively means that very little time is allocated to science in primary schools.

2. The current infrastructure:

    - The “seamlessness” of the current national curriculum document for schools has led some to view the purpose(s) for learning science at school to be the same all the way through school.
    - There is currently a smorgasbord of nonschool science education experiences available (science outreach centres, museums, enterprise education programmes, local experts and so on). These are provided by a wide range of very different groups—including government agencies, education–industry partnerships and research organisations—for very different purposes. There is limited communication and/or knowledge sharing between these groups, no systematic co-ordination of their collective activities and too few links with school science activities.

3. The lack of a systemic “innovation culture” in education:

    - References to “21st century learning”, “future focus” and so on appear frequently in education policy discussions: however, the development of a genuinely 21st century education system will require us to confront and dismantle some “old” assumptions—about learning, knowledge and what is needed to support them. New organisational models are needed and new “building blocks”. While this work will have to be done inside the education sector, it will not happen without support from outside. Innovation only develops where there is demand and, in this case, the demand will only be generated when there is wider public understanding of the qualitatively different cognitive requirements of 21st century life.[36]

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[35] This term is used here in its widest sense to include anyone interested in science education: that is, policy makers and scientists as well as teachers and researchers.

[36] See Kegan (1994).

## Overcoming the "inhibitors"—where to next?

Moving beyond the inhibitors outlined above requires innovation—thinking and exploring "outside the square" of existing ideologies and systems. However, explorers need maps: they need a shared framework for moving forward. Some commentators have suggested that the "new" view of learning—as an engaged, participative activity that builds cognitive capacity—should be the basis of this map.[37] A learning-oriented education system should be something that everyone—including teachers, parents, students, policy makers, politicians, business people and scientists—can sign up to. However, these commentators argue that these groups will have to do more than just sign up: they will have to talk to—and work with—each other. Redrawing the "old" map will require new collaborations, new social networks, new organisations and new practices.

All this will, of course, take time. In the meantime, what can we do to continue flying the plane while we're still building it?

## What could we do right now in school science programmes?

School science education programmes designed to support New Zealand's development as a "smart" country need to produce: (i) a supply of tertiary graduates who have the knowledge, skills and dispositions needed by *today's* science workforce (not those needed in the past); and (ii) a wider population that is *engaged* in science—that is, a population that is interested in science, has some understanding of the "big ideas" and is ready, willing and able to participate in public discussions of science-related issues.

To do this, the main—and explicit—purpose of science education needs to be to *engage* as many students as possible in learning science at school, and in wanting to *go on* learning science after they have left school. Offering students abstract knowledge, and then using the extent to which they seem to have absorbed this knowledge to filter those headed for further education from the rest, does not do this. Rather, school science education needs to be organised so that it provides students with experiences designed to build the dispositions and knowledge that make long-term learning possible. This *learning*—rather than knowledge—centred science education prioritises the last of the four traditional purposes of science education outlined above: however, the other three would also be achieved.

We could easily do this. We know *how* to do it and the science curriculum can provide the support for providing learning-centred programmes.

The central aim of primary science education should be to nurture children's interest and curiosity in the world around them and to develop positive attitudes towards science. This would mean building on the experiences children bring to school and providing a broad range of engaging experiences designed to help children explore the natural world[38].

Years 7–10 (intermediate and early secondary) programmes could continue to focus on providing a wide range of experiences while also ensuring students have the opportunity to study some topics in depth. At

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[37] See, for example, Claxton (1999, 2002) and Leadbeater (2011).

[38] For a detailed argument, refer Bull, A. *Primary Science Education for the 21st Century: How, what, why? (2011).*http://www.nzcer.org.nz/research/publications/primary-science-education-21st-century-how-what-why

the same time, students could be encouraged to explore and debate socioscientific issues at increasing levels of complexity and, as part of this, to develop their research and argumentation skills.

Years 11–13 (senior secondary school) core programmes would continue this focus on “citizenship skills”, while also offering parallel courses in pure and applied science concepts for those heading for university-level science study.[39] At all levels, the focus would be on challenging students to develop deep understanding via strategies emphasising student questioning, and active engagement with science’s “big ideas”. Students at all levels need a wide range of active experiences, and support to use those experiences to build deep knowledge in selected areas.

## What we could do right now—high-level strategies

We could also develop high-level strategies to provide the system-wide support needed to facilitate this change over time. We suggest the following:

### 1. Build community-wide understanding about the role of science education in developing New Zealand as a smart nation

We need to find ways to engage *people* in thinking and talking about *what we know now,* working—and strategising—with others from different sectors with different expertise, in order to develop a collective sense of what needs to be done and why.

***Recommendation***

- There needs to be a community-wide debate, involving leaders in science, education, government and business, about the kind of science education we need for young New Zealanders and for the future of our nation.

### 2. Build professional capabilities

We need to find ways to build professional knowledge about the kind of science education—at primary and secondary—that will be engaging and relevant to young people, their futures and the future of the country.

***Recommendations***

- Drawing on the science curriculum, there needs to be systemic agreement about the knowledge and skills needed by students in the early years, middle years and senior years of schooling and how science programmes can take account of current knowledge of learning, of science and of young people. These decisions then need to frame the kind of education teachers of science—in primary and secondary—require and so the nature of the professional learning support needed in preservice programmes and for classroom teachers.
- There is a need for an investigation into the ways that current enactment of assessment in the senior school assists and/or hinders the implementation of the kind of science programmes we need to

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[39] This would require the development of new NCEA courses: however, the infrastructure for this exists now.

ensure that all students leave school with a high level of scientific literacy and those who plan careers in science have the necessary knowledge and skills to be successful in the future study of science.

### 3. Build a supportive infrastructure

We need to provide *conditions* and *contexts* that can support people to do this in a connected and coherent way.

***Recommendation***

- There are many groups, including a range of government agencies, providing support for school science programmes. This support includes outreach programmes, resources, events and competitions. This collective expertise and interest needs to be harnessed in systemic ways so that the support is targeted to the agreed purposes of science education and enables the sharing and building of knowledge about what constitutes a quality science education in the 21st century.

### 4. Build a dynamic learning system

We will need *new knowledge* to grow the capabilities and infrastructure needed for developing *learning*-oriented science education. This will need to draw on local studies of "what works" here, as well as international thinking on learning, innovation and 21st century science.

**------------------------------------------**

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