

Essential Learning Prep to Year 10 Science Curriculum Area

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Section 1: Vision

The driving purpose of science education in Victoria is **to enable scientific capability** for all. Embedded within the multi-dimensional notion of scientific capability are *dispositional facets*, such as interest and curiosity, *operational facets*, such as creativity and problem solving, and *cognitive facets*, such as reasoning and critical thinking.

Through learning scientific ideas, practices, language and values, it is intended that students will choose to engage with and use science as future learning citizens, innovative science professionals and informed critics. All students will learn the ways in which science interacts with our physical, constructed and social worlds, and how it interacts with their personal lives and the communities within which they interact. In teaching science, we need to be invitational, beginning in students' worlds, seeking ways to engage students in thinking and working through science.

Teachers see themselves equally as teachers of science and as teachers of students. At the heart of the implemented curriculum is pedagogy and assessment. An enabling pedagogy is student-centred, socially interactive, builds on direct explorations of our world, and is language-focused. An enabling pedagogy provides ways for students to be creative, critical and reflective in their thinking. Through learning science in school, students will become metacognitive, sceptical and ethical in their ways of working, thinking and being. Assessment must support the complete notion of scientific capability and not focus on a narrow set of aspects within it.

Students' worlds, their spheres of concern – what they perceive as relevant to their personal lives – are prioritised when planning science experiences. The spheres of concern that are used as sources of science experiences may differ across the levels of schooling and in particular community contexts.

As future learning citizens and/or science professionals, young people will participate in experiences across the full spectrum of scientific capabilities by the end of Year 10. The essence of science is multi-dimensional. To highlight the **major dimensions of scientific capability** we have separated them here, even though it is recognised that they interact and sometimes overlap.

- Exploring science @ work

Experiencing and researching how people work with and through science; understanding and valuing how science generates and evaluates new knowledge and science-based technologies; and how science relates to community and environmental needs and issues.

- Doing science

Working collaboratively and thinking scientifically: being curious and pursuing questions; engaging in particular forms of reasoning in science; measuring with precision; undertaking investigative practices; and operating with the underlying values, skills and attributes of science, such as seeking verifiability of evidence.

- Constructing science understandings

Building deep understanding of the overarching conceptual ideas of science: wondering why; seeing how science can be used to think through contemporary challenges and issues; and knowing how and when scientific ideas assist us in raising and pursuing questions about ourselves and our interactions with our world.

- Engaging with and valuing science

Being interested and confident in science and disposed towards engaging with and using science ideas, practices, language and values in personally relevant contexts; appreciating science; being creative, innovative and evaluative in using science; drawing on the values and attributes that characterise science, such as being open-minded and ethical.

This final dimension is a cohering one that emerges out of, and connects with, each of the other three dimensions in such a way that they inform and are informed by each other. As such, it is represented by a triangle in Figure 1 to distinguish it from the circles that represent the other three dimensions.

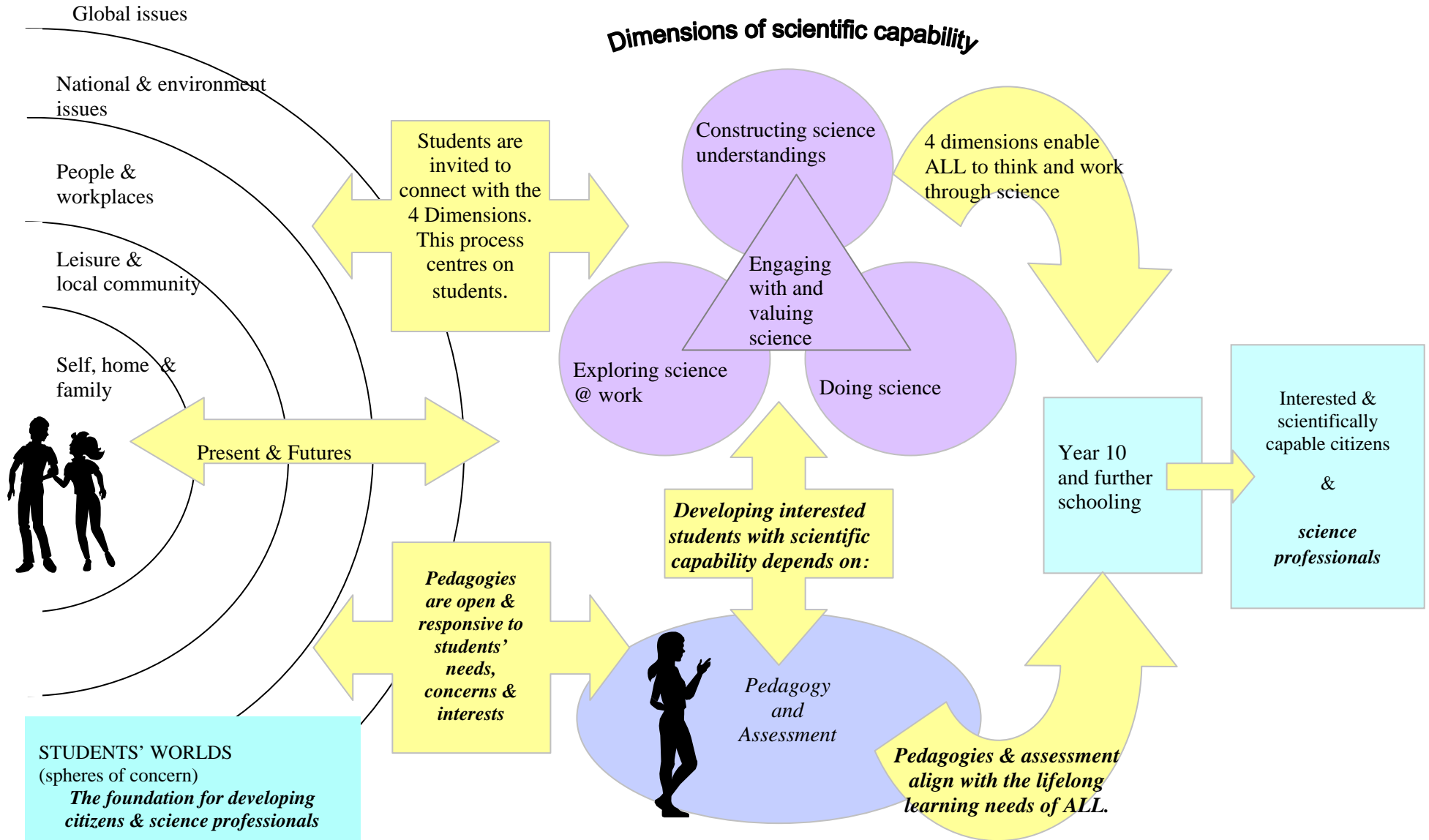
The visual representation, Figure 1, seeks to present this vision of scientific capability in a way that illustrates the importance of starting from students' worlds – their spheres of concern – and being invitational in the pedagogy so that students will continue to be curious about the natural and constructed world, and interested in pursuing additional questions about it. The interactivity of the four dimensions of scientific capability is shown, with 'Engaging with and valuing science' at the centre of the figure. Also embedded in the notion of scientific capability are the skills, values, discourses and attributes that will also be outcomes of a quality science education program in schools. They are not visibly represented in Figure 1 but they are interwoven through each of the four dimensions of scientific capability. These are explicated later in this paper.

This vision prioritises the depth of meaning-making for students and helps to focus teachers on the 'essence' of science, as articulated through the four dimensions above. In planning curriculum, teachers will design rich integrated units that provide opportunities for students to explore science in a deep and sustained manner. This will mean longer periods of time spent in exploring fewer separate 'topics' in any school year. The teacher image in Figure 1 is a reminder of the importance of pedagogy and assessment in building student interest in science and in enabling scientific capability. Without innovations in pedagogy and assessment, any new science curriculum will not have an impact on students' attitudes, values, skills or understandings. Teachers' professional learning is thus the base of the reform. In order to see the realisation of this vision of a Scientific Capability framework, teachers' ongoing professional learning will be a key strategy for change. This professional learning will include formal and informal processes and will need to be supported by time, resources and personnel.

Note:

We have deliberately avoided using the term 'scientific literacy' in this discussion paper. It is a strongly contested concept in the science education research community and, because of the multiple interpretations of its meaning, the term has subsequently lost its usefulness. The concept of 'scientific capability' has a stronger sense of action, interest and agency and we believe it can support an innovative rethinking of the ways of teaching and learning science in Victoria.

Figure 1: Enabling scientific capability



Section 2: What is science?

Science is a mode of generating and evaluating ideas. As a set of ways of thinking, knowing, working and communicating about our natural and social world, it is complex and contradictory. It is both rational and subjective, both creative and methodical, both speculative and logical. Science began, and continues, with people wondering, being curious, investigating and testing how our world works. Science involves observing and classifying, designing and building, measuring and managing risks. It is about perceiving and recording, questioning and testing, arguing and caring.

Science is not a unitary concept. Many sciences have flourished in different communities around the world and in different time periods. Science fields of knowledge are as disparate as biotechnology, stratophysics and palaeontology, with each having its own traditions, ways of working and ways of creating and testing new knowledge. There is no singular ‘scientific method’ practised by all ‘scientists’. For example, NASA space scientist David Morrison has noted that in astronomy, geology, and planetary science, observation precedes theory generation ‘and the journals in those fields never require the authors to state an “hypothesis” in order to publish their results’ (Morrison, 1999, p. 8). However, one of the most persistent myths of science is the idea proposed by Frances Bacon (1561–1626), a non-scientist, that an inductive scientific method should be the preferred *modus operandi* of science. Since then many people have noticed that the practice of science does not match the rhetoric of this ideal: ‘paradoxically, the Baconian view of science is not based on empirical observation of what scientists do’ (Charlesworth, 1982, p. 8). Yet Bacon’s idealised view of the ‘scientific method’ is still described in many introductory science textbooks today, as if it were the reality of practice.

Another myth of science is that it lacks space for creativity, yet ‘science does not suppress the imagination; much of it, like the arts, springs from the imagination’ (Brown, 1986, p. 123). Indeed many creative thought experiments have changed the face of science – such as Einstein imagining he was travelling on a light beam and Kekulé’s dream of snakes turning into benzene rings. An open and scientifically capable mind is needed to generate new theories, new fields of science and new science-based technologies. Science is an interactive mix of intellectual, social and technological practices where inherent tensions have often produced quantum leaps forward (and led us up some blind alleys).

Science has its own recognised history, stories of people and practices including those of Australian science professionals who have generated many innovative ideas over the years. Because this history of science has shaped the way we look at and deal with our world it is a fundamentally important part of our cultural heritage. It has contributed much to our shared wisdom, in that many of our taken-for-granted ways of living would not have been possible if scientific ideas had not been created, tested and practised. For example, we owe at least some of our national heritage to the science that led to the production of an accurate transportable clock and compass; without them international navigation and travel would have been much more difficult, both in times past and today. The personal computer and the Internet are recent technological innovations that have sprung from science and shape our daily lives. Through the technologies that it has produced and utilised – and sometimes been constrained by – science mediates and shapes our life experiences (through our use of resources and our means of communication, for example) and we shape science through our decisions,

priorities and technologies. Science has thus left a large footprint on our social world.

Science is one of the core discourses that educated citizens must have access to, and competence in, to engage in the future decision making of our society. To keep our community open to innovative ideas, we should all, whether citizens or science professionals, have a grasp of the essential ideas, practices, discourses and values of science.

In the practice of science, some trends in ways of working and thinking do emerge. Scientists believe that:

science utilizes unique patterns of argumentation that attempt to establish clear connections among claims, warrants, and evidence and to persuade others that the claims are valid ...[it] distinguishes itself ... through the use of empirical standards, logical arguments, plausible reasoning, and skepticism to generate the best temporal explanations possible about the natural world... [S]cience depends upon a network of knowledge and people to construct and judge new knowledge claims (Yore, Hand & Florence, 2004, p. 343).

Branches of science are often characterised by their interactivity between or within each other, and by the ways in which they use common representational forms, such as physical and mathematical models, theories, principles, laws, concepts and evidence. Dealing with and explaining the world often requires drawing on multiple branches of science, and ideas outside of science. 'Complexity is intrinsic to nature' (Coveney & Highfield, 1995, pp.6–7). Complexity theory moves beyond reducing scientific knowledge systems and processes to separate components. Its premise is that interdependence and relationships are important, where perturbations at the level of individual parts can be shown to impact widely on whole systems. Complexity theory is 'attempting to demonstrate why the whole universe is greater than the sum of its parts, and how all its components come together to produce overarching patterns' (Coveney & Highfield, 1995, p. 5). Complexity theory is not only a new theory of science but also a metaphor for the nature of science itself – a theory about the nature of science as much as a theory about the nature of the universe. It may also be a metaphor for science education.

While we sometimes think that science 'knows' everything, this is not a characteristic of (big) science, which, as a human set of ideas or constructions, is constantly evolving. Often large paradigm shifts occur, rather than smooth transitions, as new speculations and innovative technologies provide alternative framings of our world. If we had placed all of the known science in a time capsule 100 years ago, 50 years, or even ten years ago, and dug it up today, we would be surprised at how our science ideas have shifted. This concept of 'time-capsule science' (Gianello, 1988) clarifies the notion that science is not static, but is dynamic and changing over time. Science is characterised by its very complexity and changeability; and by its openness to self-criticism, refutation and paradigm shifts.

The term 'scientist' itself is a complex label, laden with narrow stereotypes of practices and workplaces, and so it can be more useful to think of people working in and with science as 'science professionals'. Science professionals may engage in pure research (the stereotypical 'scientist') in many fields such as the human genome project, bacteriology, deep space science, waste disposal, energy generation, and so on. A science professional may also be an electronic engineer, a geologist, a physiotherapist, an ecologist, a microbiologist, a systems analyst, a

food technologist, or a forensic pathologist. People working with science include a much broader spectrum of community members such as farmers, hairdressers, sound engineers, gardeners and logistics experts. Almost every aspect of our lives involves us ‘bumping’ into science, where we need to be able to capably make decisions that effect our own and others’ quality of life.

What is school Science?

In providing a glimpse into science, our science curriculum and teaching ought to focus on its complexity, diversity and utility. Science education ought to display a multifaceted view of science – one based more in the complexities of everyday practice and less in the mythologies that surround it. For example, it is possible to show in the science curriculum that science is rational and intuitive; static and dynamic; ordered and chaotic; abstracted and holistic; linear and cyclical. Science is an orientation to phenomena bound up in a range of discursive practices – creativity, responsibility, curiosity, objectivity, precision, verifiability, diversity, among them – and we need to represent all of these facets when we teach science. We should be teaching about the challenges and possibilities of past, present and future ideas of science, not presenting a catalogue of (sometimes outdated) ‘facts’. In teaching about *this* nature of science, more students may see a place for themselves in this creative and innovative world, and it may lead to more young people choosing a route beyond Year 10 that may lead them to become a science professional.

[In Australia in 1971, students] lacked sufficient knowledge of a) the role of creativity in science; b) the functions of scientific models; c) the roles of theories and their relations to research; d) the distinctions between hypotheses, laws, and theories; e) the relationship between experimentation, models and theories and absolute truth; f) the fact that science is not solely concerned with the collection and classification of facts; g) what constitutes a scientific explanation; and h) the interrelationships among, and the interdependence of, the different branches of science (Mackay, 1971, cited in Lederman, 1992, p. 333).

In his wide-ranging review, Lederman found that little had changed in the last few decades. Rosalind Driver and her team (1996) identified several common student perceptions about science. They found students believe that: science addresses ‘questions relating to physical and biological phenomena but not social phenomena’ (p. 138); ‘scientific enquiry involves making generalisations from observations’ with some students seeing that it involves the ‘testing of models and theories’ but few students seeing these as conjectural in nature (p. 139); ‘theories are evaluated in terms of their consistency with evidence’, but few students saw science as a social enterprise, perceiving rather that scientists worked ‘in isolation’, uninfluenced by society’s values and politics (p. 140).

Students’ views on the nature of science indicate that there is much work to be done. If we are teaching towards enabling scientific capability then it is time to change ‘what’ and ‘how’ we teach school science. ‘The false idea that science is exact and therefore that concepts in science are unproblematic can be argued to have trapped science teaching into a pedagogy which misrepresents both the content and the process whereby the content is constructed’ (Carr et al., 1994, p. 158).

The major purposes of science Prep – Year 10 are broader than simply to prepare students for science-related careers or to serve workforce priorities. We need to design and implement a curriculum that will enable scientific capability for all students. An advanced technological society builds its expertise on science in many

ways – through its citizens feeling comfortable with science as a way of thinking and a way of working in the world, and through knowing that science is relevant, accessible and useful. It is also important that people who make decisions that impact on our social and professional lives – for example, in making policies, deciding on funding priorities, planning infrastructure – have the scientific capability to know and value science as a system of knowledge and a way of thinking and working (Symington & Tytler, in press; Fensham & Law, in press). It is also apparent that different purposes and focuses of the science curriculum will be given prominence at different stages of schooling. Thus, considering workplaces where science is utilised may not be very relevant for the Prep–2 years and will have a different emphasis in Years 5–6, but in Year 10, when decisions and choices will have a sense of immediacy, it may be a highly relevant issue to explore.

Becoming scientifically capable involves considerably more than the acquisition of scientific skills, knowledge and understanding. It also involves the development of personal qualities and attitudes, the formulation of one's own views on a wide range of issues that have a scientific and/or technological dimension, and the establishment of an underlying value position ... [It also includes] preparing for and taking action (Hodson, 1998, pp. 3–4).

In deciding which aspects of the huge fields that constitute 'science' to build into the school curriculum, several critical selection criteria emerge. First, students' worlds – their spheres of concern – must be the beginning point: it is their questions, interests, curiosity and creativity that is to be nurtured and nourished. Every science lesson thus begins with students' worlds. Second, the many practices of science are a key part of the essence of science. This means that to build scientific capability it is important to offer opportunities for students to engage in those practices on a regular basis. Every science learning sequence is about doing science, constructing science understandings, engaging with and valuing science, and exploring science at work. The skills, values and attributes (see below) that are instilled through good science teaching are also part of the essence of science. Third, the discourses used in science are fundamentally different to other discourses, so much so that 'language in science matters' and 'learning the language of science is a major part (if not *the* major part) of science education. Every science lesson is a language lesson' (Wellington & Osborne, 2001, pp. 1–2, italics in original). Science as portrayed in popular culture is often a caricature of science, yet identifying the myths and misconceptions exposed in computer games, movies and science fiction may be an entry point for some students.

In planning a school science curriculum and activities, it is thus important that teachers prioritise several things: where students' questions, concerns and interests lie; and how students can be enabled to develop scientific capability through competency in science as a set of practices and discourses. In one sense, the particularities of the science 'content' that are selected are of secondary importance to relating students' interests and concerns to the practices and discourses of science. Content as such is still a priority, but to enable scientific capability it needs to be explored in greater depth, for richer meaning.

Section 3: An agenda for change

This discussion paper should not be seen simply as laying down a set of ‘essential learnings’ consisting of appropriate content for defining a productive science curriculum. Rather, it is a change document which attempts to identify what practice is needed in school science to fulfil the key purposes of schooling in science, how this relates to current practice, and how the process of change might occur and might best be supported. This section of the paper lays out an argument for rethinking the way science education operates. We identify current issues and concerns, and suggest a way forward based on existing examples of innovative and successful practice in schools.

Current concerns and issues

Engagement of students with science

Science education is currently experiencing a crisis on a number of fronts. There is a good deal of evidence, in Australia and internationally, that our students lose interest in science across the secondary school years (Fensham, 2004; Lindahl, 2003; Lyons, 2004; Goodrum, Hackling & Rennie, 2001; SIS Project Team, 2003). There is a decrease in the number of students entering post-compulsory studies in the ‘enabling sciences’ (physical science, mathematics), such that there is increasing concern at government level (Victoria’s Science, Technology and Industry policy, DEST’s ‘Backing Australia’s Ability’) that we can produce enough people trained in the sciences to support the demands of a contemporary, high-technology economy. There have been calls for change at the highest levels to address these issues.

The social and economic implications of a reducing participation and interest in science does not only involve the supply of science professionals. In a study of the views of randomly selected community leaders (Symington & Tytler, in press) it was found that many were involved in science in other capacities despite not having trained in science – as chairs of environmental enterprises, managers of companies producing science-related goods, members of committees making decisions related to science policy, or in the media profiling science. Science and technology are so embedded in our contemporary lives that members of the public are involved with it at many levels (Tytler, Duggan & Gott, 2001). It is too narrow a focus to view the supply of scientifically capable people for societal needs simply in terms of the need to ‘train’ science professionals. The view of the community leaders interviewed by Symington and Tytler was that the focus of school science should be to encourage in students a comfortable relationship with science as part of the set of ideas they like to, and are able to, engage with. The focus they promoted was on agency, rather than content coverage – that is, with the focus on scientific capability.

Research has indicated (see, for example, Lindahl, 2003; Lyons, 2004) that even those students who are highly talented in science are turning away from science for lack of interest, or, if they continue science studies into Years 11 and 12, will often do so because of career choices, despite a lack of real interest in school science. There are students who claim to be interested in science, for instance those who read science or watch TV science programs in their leisure time, yet who are turned off science in school which they see as ‘different’. Terry Lyons, in his study of high-performing Australian science students in Year 10 reported that school science was ‘a transmissive (from the teacher) experience, boring, abstract and

irrelevant, and difficult – not to be studied further unless one had to for reasons associated with one’s tertiary preference’ (quoted in a Fensham commentary in a draft of this discussion paper).

Anecdotally, one does not have to go far in talking socially about these issues without hearing stories of the rigidity, repetition and unresponsiveness of much of science in schools. One also hears stories of a very different character: of schools and teachers doing exciting and innovative things. Victoria, in particular, has a proud history of innovative school curriculum development in science, dating back many years. We argue that indicators for a productive way forward can be found in the many instances of good practice that exist. It is a matter of bringing into the mainstream what is now special practice.

The difficulty of establishing scientific conceptions

There is a substantial body of research into student conceptions that has demonstrated that, even with the content/cognitive focus of our current science courses, students emerge from schooling in science with informal, naïve conceptions untouched by their exposure to science ideas. These informal ideas are very difficult to shift, and even successful students, judged by school test results, retain prior, unscientific ways of interpreting the world (see Duit, 2002, for a bibliography of this research). Hence, even for successful science students it seems that current science curricula are limited in their success. It is commonly argued that the drive for content coverage and the lack of time to explore ideas properly are at the heart of the problem. It could also be concluded that the testing procedures commonly used allow students to achieve high grades, without deep levels of understanding of science ideas.

The focus of the science curriculum

The task of this paper was to argue a case for science as a major discipline, and identify the essential learning appropriate to science. A narrow reading of this task might presume it involves identifying those ideas that are necessary for students to continue on a pathway to professional science, or perhaps necessary for citizens generally. The word ‘learning’ could be taken here to imply particular knowledge and skills. In this section we are arguing first, that the task is not so much a matter of appropriate preparation as of enlistment of students to an appreciation of science, and second, that the notion of a division between two presumed consumer populations (scientists and citizens) is specious, and that the same capabilities are relevant in each case.

Of course, appropriate curriculum choices need to be provided for students as they move into the post-compulsory stages of schooling, or even before that, depending on their preferred pathways. It could be, for instance, that Years 9 and 10 include some elements of choice, including learning sequences more allied to specialist discipline science, or units in which science is embedded in workplace cultures, appropriate to Victorian Certificate of Applied Learning (VCAL). We are arguing, however, that content restrictions of mainstream science should largely be lifted, and the curriculum be more aligned with scientific ways of thinking and acting, and more contextually embedded than at present. We are arguing that a heavy focus on content does *not* focus on the ‘essence’ of science. Science is, essentially, a set of ways of working, thinking and communicating.

It is often claimed, by those who deplore the restrictions imposed by the need to cover content, and the non-invitational way the curriculum is often presented, that the real issue concerns the imposition of the needs of the scientific research community on the curriculum. This was the thrust of the argument associated with

the ‘Science for All’ movement of the 1980s and the current call for a focus on ‘scientific literacy’. We have not argued in this paper in terms of scientific literacy for the reason that the term has been polluted, since it is used in many different ways by advocates of different science education reform aspects. The concept of capability, it seems to us, is more action-oriented and ‘cleaner’ – without the complicating overlay of notions of literacy more generally, and numeracy.

The definition of scientific literacy adopted internationally by Program for International Student Assessment (PISA) 2006 is very close to how we are defining scientific capability. Scientific literacy in their terms refers to an individual’s:

- scientific knowledge, and use of that knowledge, to identify questions, to acquire new knowledge and to draw evidence-based conclusions about science related-matters
- understanding of the characteristic features of science as a form of human knowledge and enquiry
- awareness of how science and technology shape our material, intellectual and cultural environments
- willingness to engage in science-related issues, and with the ideas of science, as a reflective citizen.

These categories map onto the dimensions: Exploring science @ work, Doing science, Constructing science understandings, and Engaging with and valuing science.

The influential *Beyond 2000* report from the UK (Millar & Osborne, 1998) argued that current problems with science in schools related to the fact that while it has become a mandatory subject throughout the stages of schooling, the content has not changed to reflect the vastly changed audience. Their argument is for a curriculum that serves this wider audience, and in their report they emphasise that the curriculum should:

sustain and develop the curiosity of young people about the natural world around them, and build up their confidence in their ability to inquire into its behaviour. It should seek to foster a sense of wonder, enthusiasm and interest in science so that young people feel confident and competent to engage with scientific and technical matters.

They also argue the need to empower students to engage with contemporary science ideas and appreciate science, and that technology should be more strongly represented in the science curriculum. Current initiatives in the UK that are relevant to the argument we are presenting are the design of courses that focus on public understanding and use of science (Millar & Hunt, 2002) and studies on the centrality of argumentation in science education (Newton, Driver and Osborne, 1999). There is a question in our minds, however, as to whether the design of a ‘science for the scientifically capable citizen’ is necessarily different to that required for future science professionals.

The term ‘scientific capability’ carries the implication that this capability is relevant for future students of post-compulsory science as well as for citizens. One of the major thrusts of the argument in Department of Education, Science and Training’s (DEST) ‘Backing Australia’s Ability’ is the need for students and schools to place a premium on innovation (see <http://backingaus.innovation.gov.au>). While ‘innovation’ in the document is somewhat narrowly conceived in terms of needs to develop new technology, the

implication is clear that what is needed are citizens who can think creatively rather than simply know a lot. Fensham and Law (in press) conducted interviews with the directors of a number of Beijing's leading research institutions, about qualities they look for in new staff. The qualities described were consistent, topped by creativity and followed closely by personal interest, persistence, communication skills and willingness to investigate. The focus on affect in this list (half of those interviewed nominated personal interest as the top quality) over specialised knowledge, is striking. A number of the scientists criticised the strong content focus of schooling as stifling creativity. It can, therefore, be argued that the choice of a core-content-focused curriculum, as against one focusing on a wider set of capabilities, is not a matter of contestation between the needs of future scientists as against those of scientifically capable citizens. For both, there needs to be a focus on the dimensions 'Engaging with and valuing science' and 'Doing science', both of which include affect and values.

In Victoria, as elsewhere, Technology has been created as a learning area in its own right, focusing on design and production. This has led to a less confident representation of technology in science curricula (Fensham, 1990), and in the Curriculum and Standards Framework (CSF) a retreat to a more 'pure science' perspective. The perspective of this paper is consistent with a view that scientific knowledge cannot be adequately presented as separate from, and unsullied by, issues of its social or technological uses (see Layton, 1991, 1993). In terms of its use in practical social contexts, Layton argues:

As for the centrality of science to practical action in everyday life, the researches indicated that the scientific knowledge offered or accessible to people is rarely useable without being reworked and contextualised. This involves, at least, its integration with other, situation-specific knowledge, often personal to individuals, as well as with judgments of other kinds (Layton 1991, p. 58).

The relationship between science and technology is complex and highly interactive (see, for example, Gardner, 1994), and needs to be represented as such in the science curriculum. We are arguing for a reinstatement of the close relationship between technology and science, as a necessary component of the development of scientific capability.

There is a national movement concerned with 'knowledge-producing schools' which takes as its major principle that schools, through partnerships and open pedagogies, should be in the business of producing knowledge rather than simply passing on existing knowledge. While this is a challenging ideal, it is in accord with the spirit of this discussion paper.

Science in the middle years of schooling

For a decade or more there has been a strong focus, through major government initiatives, on the particular issues surrounding the middle years of schooling, being those years when students are moving into and passing through the social dimensions of schooling are particularly significant as students develop their sense of themselves as learners, thinkers, and social beings.

Major research projects have been conducted in all states, examining these issues and ways of increasing student engagement in schooling. In Victoria the findings of these research projects have been embedded into significantly funded initiatives for middle years students, including the *Innovation and Excellence in the Middle Years* program. The issue these initiatives are addressing is that of engagement of

students with schooling. The thrust has been on pedagogies and schooling arrangements that pay attention to students' sense of involvement in, and control over, their learning and its connection with their lives, and a sense of intellectual challenge and stimulation. From this perspective, it is not enough to plan for the delivery of science 'essential learning' without accounting for the relevance and challenge of its components, or how the resources of students might be enlisted to engage with the learning. The set of pedagogical components developed for the Principles of Learning and Teaching (PoLT) is closely allied to the findings of this research and to research in the early years. It is argued in this paper that the alignment of these pedagogical principles with the capability dimensions of science provide a productive way forward, since together they represent insights relating to the science that should be learnt, and the learning needs of Prep – Year 10 students.

A way forward for science in schools

Goodrum, Hackling and Rennie (2001) argue that the teacher is a key factor in improving the quality of science education. This is in line with the contemporary focus on pedagogy as a means of spearheading reform. 'Productive pedagogies' (see <http://education.qld.gov.au/corporate/newbasics/html/pedagogies/pedagog.html>), which is part of the Queensland 'New Basics' curriculum and is being adapted for New South Wales, is a set of principles and an approach to professional learning that seeks to help teachers improve their practice. In Victoria, the 'Project for Enhancing Effective Learning' (PEEL) (Baird & Northfield, 1995) has been operating for many years with a focus on teaching strategies designed to promote better learning and thinking strategies. There are many teachers and schools who have utilised PEEL principles in the science area. PEEL was conceived of as developing sets of strategies that supported learning within the existing curriculum. Given that this paper advocates a changing focus to the curriculum and provides examples of schools that are operating outside the focus presumed by PEEL, it may be necessary to revise and extend PEEL to match a new curriculum environment. The School Innovation in Science (SIS) project is a teaching and learning framework as well as a strategy for school and teacher development. The SIS Components have much in common with PEEL, but have extended the focus on learning to include middle years notions of engagement, aligning teaching and learning with students' lives and interests, representing a rich view of scientific knowledge and practice, and linking learning with the community. The SIS Components (Tytler, 2003; Tytler, Waldrip & Griffiths, 2004) were developed from studies of effective teachers. Their substance and form are strongly reflected in the generic Principles of Learning and Teaching (PoLT).

Within both PEEL and SIS, and across the state, there are examples of schools and/or classrooms that had been transformed into exciting places, involving different approaches to teaching and learning, and teachers with reputations for enthusing students and engaging them in quality science learning. The work of some of these schools was presented at a recent national forum, 'Charting Futures', held to explore visions for Science, Mathematics and Environmental Education held in Melbourne, and funded by DEST (see <http://www.deakin.edu.au/education/units/MSEE/index.php>). Some of the schools were recent recipients of National Awards for Quality Schooling, and these in particular demonstrated the extent to which the utilisation of community links can encourage innovative work. School curriculum projects focusing on wine making and on monitoring change on the Snowy River demonstrated that when 'real' issues in the community are taken as a curriculum starting point very interesting things can happen. The links with community are also consistent with current initiatives

in the later years of schooling, where managed individual pathways (MIPs) and VCAL arrangements often include significant industry and community placements.

Out of these examples of quality schools and classrooms featured in the Charting Futures forum, and the experience of SIS, we can generate a set of aspirations for our future science curriculum that are consistent with the literature in science education, governing the different dimensions and players.

A vision concerning the actors in the science curriculum

Students

Students will develop capabilities for productively engaging with science in their current and future lives, as well as acquire a sound basis for specific careers that utilise science.

Students will have opportunities to develop an interest in, enthusiasm for, and understanding of, aspects of science and its importance in daily life and in their future wellbeing.

Teachers

Teachers will be enthusiastic about science and committed to the teaching and learning of science. They will continue to develop their understanding of science and science teaching and become more effective in supporting student learning and conveying the richness and relevance of science ideas.

Teachers will see themselves as challengers of students, supporting them to become better learners and thinkers, rather than as the deliverers of fixed knowledge and skills.

Teachers will work together, within and across schools, to develop a shared vision and program of science that will focus on deep understandings of teaching and learning principles, and will put science at the forefront of innovative thinking within their schools and communities.

Science classrooms

Science classrooms will be innovative and active places, with strong links to the community and with a clear focus on supporting students to become autonomous thinkers and learners within a stimulating science environment.

Science classrooms will be more productive and open places that emphasise deeper and more creative thinking, that capture the excitement of ideas and challenge students to see the relationship of ideas to big issues in their lives and in the wider world. We need to present science as a way of thinking and not simply an accumulation of knowledge.

Schools

Schools will recognise the importance of science in each student's education.

School leaders will encourage a team approach to the development of a science program and provide the necessary support for professional learning and community involvement.

Teachers will be supported to engage in enabling pedagogies that promote students' responsibility for and their commitment to quality learning, to scientific reasoning and application.

School and community

Schools, teachers and students will have stronger links with communities, including other schools, community and professional organisations and their members, industry, universities and TAFE colleges, government departments and their staff.

The implemented curriculum will become more appealing to both students and staff, new connections among different disciplines will be explored, and multi-disciplinary thinking become more accessible.

Education will be seen as a shared responsibility, with schools drawing on and contributing to communities. There needs to be improved information flow between schools and their communities. To be effective, this requires schools to be able to communicate not merely what students are doing but that the activity is producing worthwhile outcomes.

A vision concerning dimensions of the science curriculum

The curriculum

The intended curriculum will capture the multi-disciplinary thinking that is so necessary for approaching many socio-scientific issues, including those impacting on sustainability.

The implemented curriculum will ensure that students grapple with ideas and knowledge that will make them lifelong learners. The curriculum cannot be based solely around knowledge that is already, or soon will be, outdated and redundant, or that students see as irrelevant to their interests and needs.

The curriculum will be sufficiently flexible to allow schools to address the needs and interests of their students.

Assessment

Ways of establishing that learning is taking place and the nature of that learning, and that appropriate attitudes and interests are being developed, will be identified and used. Among the full range of capabilities assessed will be:

- ability to ask investigable questions and explore these using scientific thinking
- ability to link science understanding to the student's present life
- understanding of the way science works and develops
- ability to communicate about a topic that involves science
- understanding and application of science concepts
- exhibiting of curiosity and interest in science ideas
- ability to access and assess the worth of scientific knowledge.

Science as a particular way of knowing

Students will develop understanding of the way science works and has worked historically, and of the sorts of evidence that scientists use and have used to establish claims, including explanations and theories.

Students will value the contribution that science makes and can make to society. In developing their scientific capability, students should come to understand, for instance:

- how developments in science change our world views and values
- how science is used to establish degrees of risk in environmental or occupational contexts, and to inform the setting of standards of practice
- how science interacts with other ways of knowing, for example, ethics, economics, sociology, engineering
- how science is influenced by, and influences, economic imperatives.

Students will participate in and understand the human nature of science and how ideas are generated, explored and validated. They will recognise that science, as an enterprise, is aimed at generating reliable knowledge, but which in its detail exhibits all the human attributes of excitement, contestation, confusion, frustration and satisfaction.

We need to be fearless in exploring what is science, and what is not, and discussing honestly the limitations and strengths of scientific perspectives and approaches. Thus, discussions of evolution versus creation, or astronomy vs. astrology, or alternative vs. conventional medicine, should be treated as an opportunity to contrast science with other forms of knowledge and explanation, and to examine science as a powerful but human system of thought rather than an incontestable set of laws and facts. Students should be led to understand the nature of science explanation and science theory. They should be exposed to the competing claims of scientific ways of knowing and other claims.

We also need to accord respect to other forms of knowledge about the world such as those developed by other cultures, including Australian Indigenous cultures, as effective ways of understanding and acting on the world. Students should be led to think, for instance, about the powerful ecological metaphors developed by such cultures, and how they relate to contemporary scientific thinking.

Vignettes of practice

There are many examples of quality practice in science in Victorian schools which can act as signposts for the future. In the examples below, change took place within a structure of science professional learning teams coming together to discuss what was needed to engage students with science. The resulting practice is quite divergent, but has in common a concern to engage students in quality thinking and learning in science. The case studies contain two types of message. The first relates to the nature of the science experienced by students. The second relates to the process by which improvement in science provision can take place.

Orbost Primary School

Orbost Primary School has become involved in a project centred around the Lower Snowy River Rehabilitation Trial (LSRRT), monitoring the health and changes to the river system. The project is groundbreaking, evolving from a partnership between the Department of Sustainability and Environment (DSE) and the Snowy River Cluster Schools (Orbost Secondary College and six primary schools). Sue Legge, the science coordinator, who is also a Prep – Year 2 teacher, explained at the Charting Futures forum:

The principal aim of the Trial is to test the performance of in-stream works (structures and vegetation) in reconnecting the aquatic habitat of the mainstream and tributaries upstream of Long Point with the estuary. While the main issue is essentially one of improving fish passage through a long, shallow sand-bed section, improvements in aquatic habitat in the same section of the Snowy River are also desired.

Our first encounter with LSRRT was an incursion with the project manager and project biologist in 2001. This had an immediate effect on children's interests and lives, and gave them some insight into what the Trial was about and better understanding of the talk going on in their community to do with Saving the Snowy River. It generated enthusiastic interest amongst our students who began building the Snowy River in their sand pit after some fairly serious rainfall.

Essentially, we wanted students to interact with scientists, involve and educate local teachers in the development and delivery of curriculum related to the trial so they could develop a sense of ownership, and involve school children in real science curriculum related to the trial.

As part of the Trial, a model representing 2 km of the Snowy River has been built at Monash University for the purpose of testing in-stream structures and their effect on fish habitat and passage in the lower Snowy River. Our first interaction with Trial scientists involves Dr Rob Keller from Monash University and physics and advanced mathematics students to explain the features and benefits of physical modelling and relevance to the Snowy River and its rehabilitation. Students will visit Monash later in the year to see the model.

Once the proposal had been established, the committee then went on to develop a curriculum outline [see below] for Preps through to Year 12 and an indicative budget. We wanted to develop a learning journey that encompassed the journey of the river as well as [that of] the children and the scientific processes.

All levels: Identify the problem and formulate a hypothesis, meet the scientists

P-2: What is the nature of water? Survival of living things in the river environment (water watch)

5-6 Revegetation of rainforest

7-8 In-stream ecology/survey techniques

11-12 Related VCE physics curriculum

The fundamental benefit will be students developing community-minded attitudes for human futures and an ability to apply learning to other community developments and needs. It connects children with their community and gives them a sense of ownership and responsibility. It creates an awareness of

personal impact on the environment and positive attitudes towards community-mindedness.

Ocean Grove Primary School (Winner of the National Award for Quality Schooling)

Following an audit of classroom practice and student surveys — part of the school's involvement in SIS — the school developed an action plan which led to a number of initiatives over two Years:

- A science room was set up with equipment and units of work, and facilities for science activities.
- Video conferencing equipment was set up to facilitate communication with Bayswater PS in a Year 5/6 Space project.
- Participation in ASTA Science Week activities and in the STAV Science Drama Awards
- The local community and scientists have been involved in school themes and programs, and guest speakers and local secondary students have given presentations.
- Students were involved in a school Robotics Club which led to a Dominoes Robotics project in 2003 (involving 50 students) with Melbourne schools. This involved online collaborative mentoring in the area of robotics – linking robotics and mathematics, with students and teachers planning and developing a program through video conferencing and group activities.
- Video conferencing with a Melbourne school to allow students to produce an online collaborative mentoring project on 'Space'.

Maroondah SC, Year 7 Science ¹

The Year 7 teaching team at this school was concerned that their students were finding the ideas of motion and force difficult to understand and the examples given in textbooks were often unrelated to their lives and interests. So they decided to write a unit of work on the theme of a local playground, which they believed would engage their students. To begin the sequence they asked students to relate stories about their experiences of using the playground. Much animated discussion confirmed that this was a topic that the students found very interesting and that they had a wide range of experiences they could draw on. In the following lessons students in small teams rotated through a series of 'probe' activities designed to find out what they already knew and understood about the topic. These activities included the use of simple materials such as ramps, ropes and wheels, and open-ended challenges such as: 'Work out how to lift the load using only the materials supplied'; 'How can I make my model car move a distance of 2 m without pushing it?'

From the students' responses the teachers then assessed the level of knowledge students had about combinations of forces and their effects on motion, and whether they could explain how different parts of simple mechanical systems (for example, gears, pulleys and levers) transmit and modify force. Common themes emerged and became the focus for the next few lessons.

The teachers also summarised the student's ideas in the classroom and, from this, further questions were gathered and recorded. Playground equipment was then examined and the operation of these was related back to the physics ideas that

arose from the initial probes. Students then went out to a playground to test the equipment and apply the ideas they had explored to a new setting. Finally, back at school they examined their original questions, clarifying any misconceptions. The unit ended with a creative assessment task where they designed their own piece of playground equipment and used their understanding of the physics ideas they had developed over the course of the unit to explain to their classmates how it worked.

The nature of the unit and teaching strategies used provided opportunity for frequent discussion, and for evaluation of students' understandings, and the teachers encouraged and supported the students to be aware of their changing ideas.

Stawell Secondary College

At Stawell, teams of teachers decided to work towards improving curriculum design to include a wider range of teaching and learning strategies. This included the use of more open-ended practical tasks, more selective use of technology, and linking science with real-world applications. Two units that were developed include a Year 9 Science unit called 'Past, Present and Future' and a Year 10 Science elective unit called 'From Vine to Wine'.

The Year 9 unit was developed by teachers in the school and was supported by an additional grant from Powercor [a major Victorian electricity distributor]. This ecology-based unit includes working collaboratively with land managers to produce a catchment plan and designing and constructing a cycle/walking interpretive trail along Pleasant Creek and the historic Heatherlie Rail line. Learning about science occurs in the classroom and beyond, leading to students developing an awareness and appreciation of local community resources and helping them develop citizenship skills which they can apply in their future lives.

The Year 10 unit was developed in partnership with Southcorp (Great Western). The unit was designed to teach students about the local and export wine industry and to open up possible vocational pathways. Students were fully immersed in the production experience and studied a diverse range of science strands, including plant propagation, chemical applications (fermentation, aerobic and anaerobic activity, writing chemical formulae, and so on), microbiology, soil analysis and weather studies.

Interest in this unit continues to grow, with increased student enrolment and increased teacher involvement. Other science teachers in the school also regularly visit these classes and sometimes lend a hand, and professional support and learning is now broadening with this open classroom approach. Teachers in both the Art and Commerce areas are also showing interest in getting involved next year, with design applications and marketing in mind.

Interviews with effective teachers

The following vignettes were constructed from interviews with teachers of secondary science deemed to be effective, as part of the Science in Schools project. Equivalent, more detailed case descriptions of effective primary teachers can be found in Tytler, Waldrup & Griffiths (2004).

Cleo's view of an effective learning environment involves 'lots of interaction'; students talking about science, doing things in groups, and learning in an interactive, problem-solving way based on practical activity. Part of her justification for these activity-oriented approaches is that they expose students to a variety of teaching styles. Cleo had promoted open-ended investigative work in the

school, instituting an ‘investigations’ unit at each Year level. She is committed to a view of science that is contemporary, relevant to students and linked to social and personal ethical issues. She favours theme-based approaches to science because ‘kids see connections’ with their lives, and with personal issues. The technological and ethical ramifications of gene technologies were illustrative of her excitement in this sort of approach to science. Cleo uses a media file, and continually encourages discussion of current events and their link with science. She is less concerned with coverage of formal content, and enjoys ‘going off tack’ to follow interesting discussions.

Jane’s school has a strong focus on learning technologies and, in response to a question about activities and strategies, she described a range of IT-linked strategies through which students explore ideas, communicate with each other and with international groups, and present material on websites. Open-ended research is carried out with introductory searches for material on the Web. Jane describes how management of learning also involves digital means, whereby students work through websites, and present their work using high-end technology as well as in plays, poetry or posters.

Jane talked of the flexibility offered by the use of such technology, the freeing up of the teacher to spend more time with individuals, for accessing demonstrations or illustrative material as the need arose, and the encouragement of questioning, research skills and a varied set of learnings. Jane’s assessment methods are varied, involving casual observation entered in a spreadsheet, formal prac reports, opinion pieces, posters, multimedia presentations, responses to questions, and online tests. Tasks are often negotiated. She emphasised student engagement as a key feature of a good learning environment, and argued that the learning technologies, along with the introduction of 80-minute periods, allowed time and space for this. She emphasised the need for the teacher to be flexible and responsive. She saw the key purpose of teaching science being that students learn that there are no wrong answers, that science proceeds by chance discoveries, and that it is socially contextual.

Josh believes it is essential to link science topics with students’ lives and interests, such as dune ecology at the back of the local surf beach, studying a local lake, or focusing on chemistry in the kitchen, or swimming pools. The science program, however, is carefully structured conceptually.

He uses a lot of formative assessment and a variety of monitoring methods including annotating on sheets of paper to build up an understanding of students. His assessment methods are sensitive to students’ differing literacy abilities. A large part of Josh’s interest centres on assessment over which students have some control, to promote metacognitive reflection.

Josh uses a variety of strategies such as brainstorming, structured overviews, debates, collaborative group work, and a variety of types of practical work. He uses a variety of learning technologies. He views learning as an active process, where students engage in practical activity and learn to act like real scientists – investigating, researching on the Internet, taking responsibility for their own learning. He described how, if there was an odd result in an experiment, he would challenge and chase that until the issue was resolved. He saw student interest as an important element of learning, and stressed the need to motivate students, to provide interesting stories, activities and insights, and to allow the flexibility to run with conversations the class is interested in, even to the extent of following such interest up over subsequent lessons. For Josh, the delight in teaching science involves seeing students grasp difficult concepts through the use of varied

strategies such as analogies or demonstrations. He feels students enjoy being in his class because it is interesting, and they understand.

Other examples

There are many other examples of practice known to us, that illustrate current innovations in primary and secondary school science, and that point towards productive ways forward for school science. These include:

- A forensic science unit that interweaves many science concepts and understandings of science at work, around a strong concern for establishing concepts of evidence.
- An agricultural science unit run in a regional secondary college.
- A problem-based learning unit on smoking, in which groups of students negotiate individual contracts and investigate the science and social and personal ramifications of smoking from many perspectives, culminating in seminar presentations.
- A regional primary school builds its curriculum around a statewide go-cart competition, covering literacy, numeracy, science and technology, and linking with the community through the competition, and through local engineers and sponsors, and displays.
- Science units based on sport, run during the time of the Olympic and Commonwealth games.
- An astronomy unit that uses the ‘time-capsule’ science idea to compare and contrast what is ‘known’ about the planets now and in other times, for example, in the 1600s, 1800s, 1950, 1980, 2000.
- A ‘science in the media’ unit where students analyse journalistic writing genres and show how different newspapers and magazines use science language selectively to persuade readers of the merits of particular stances on current science-based issues.
- Personal bests for movement – such as in dance, cycling and skateboarding – are analysed from a bio-physical perspective, allowing insights into how students can improve their personal physical performances.
- Medical technology units that explore how diseases have been treated in different times and contexts depending on the understandings of how the body works and on the available technologies, including current innovations that are in trial phases.
- A ‘green school’ science unit that focuses on the issues of ‘reduce, re-use, recycle’ through problem-based investigations and that results in poster design and creation to persuade peers to change their practices.

Characterising learning sequences

While these vignettes of initiatives and learning sequences are different in their focus they have a number of characteristics in common. All involve attention to students applying science ideas in order to learn them. Most involve contexts where problem solving and investigation are built in, and many involve collaboration with communities outside the classroom. A number foreground student autonomy. All of them focus on engaging students in learning through rendering the learning ‘authentic’, in that it looks beyond the walls of the school

and connects with communities and the contemporary practice of science professionals.

In order to develop these units, teachers usually worked in teams. This often involved enlisting the help of the school community and local science expertise. It always involved someone at the school with enthusiasm. There are thus lessons in these vignettes for teaching and learning, and for mechanisms of change to a newly oriented curriculum working towards developing scientific capability in all students.

Section 4: Intellectual challenge

The vignettes cited offer varied models of what it might mean to be engaged with and challenged within a science learning sequence. The sort of intellectual challenge involved is not the same as that demanded by the solving of set-piece problems with the unpacking of links between ideas, although these might be part of what occurs during the sequence. If we are to develop a clear vision of how to prepare students for a life using science, either as citizens or professionals, or if we are to develop a set of science curriculum standards, we need to be clear about what we might mean by ‘intellectual challenge’ or ‘intellectual quality’. As we have already argued using Fensham and Law’s (in press) work, this must include more than conceptual knowledge; it needs to embrace notions of creativity, persistence and, arguably, interest. We need to realign the notion of intellectual challenge away from that of displaying facility with a body of knowledge, towards a more open and applied notion of fluency, flexibility and capability.

Intellectual challenge might be encouraged and evidenced by students:

- following an interest (autonomous exploration) and becoming expert in an area of science (e.g. astronomy enthusiasts, designers of software models)
- competently using a particular problem-solving strategy or achieving a conceptual insight through guided instruction
- entering into a learning contract whereby the teacher negotiates activities, such as analysis or evaluation, with students to ensure that they are challenged to specified levels of understanding
- participating in serious debate about a local issue, drawing on a range of argumentation moves and using significant insight into quality of evidence, or into science concepts, or understandings of the contribution of science ideas to community decision making
- speculating on technologies for the future, drawing together strands of scientific thinking and analysing current trends in innovations in the field
- undertaking to communicate with specified audiences, such as to younger students or a local newspaper, about an aspect of science or its application.

Current formulations of curriculum that centre around content coverage run the danger of encouraging superficial learning, through the felt need to ‘move on’ before ideas are explored in depth. A common research finding of much current science learning is that it is shallow and superficial because of this. There is a tension between ‘coverage’ of science ideas by teachers, and the depth to which they are understood and applied by students.

The depth of learning an idea is evidenced by the ability to use it flexibly in a variety of contexts and to see the multiplicity of phenomena to which it relates. The transference of an idea to new situations extends it and enriches the semantic links attached to it. If we accept this, then learning science ideas in context must lead to deeper understandings of them, since contextual application will inevitably pose more challenging problems than set-piece applications. Thus, learning to understand the role of acids through units on agriculture, or nutrition, will be more

enriching and challenging than ‘extension’ problems involving swimming pool control set at the end of a unit on acids and bases.

Irwin and Wynn (1996) in studies of the public understanding of science in a range of community contexts argue that, to understand the contextual application, there needs always to be a translation of the science to match the particular circumstances. The generalisable knowledge of science is not necessarily directly useful or relevant. Thus, contextual learning should be seen not only in terms of depth and breadth of science ideas, but also as involving an inevitable translation as it intersects with other, local knowledge. If we accept this point, then an understanding of the way science ideas have both generalisable and contextual aspects is an aspect of understanding how science works. Learning science through contextualised experiences that relate to students’ lives and spheres of concern, rather than abstracted content, offers a way forward for producing a generation of scientifically interested and capable citizens who are lifelong learners, and innovative science professionals.

It follows from this discussion that the interests of preparing students for VCE science subjects will be well served by this new approach to P–10 science. Students who are motivated and interested, and have developed the capability to engage at a deeper level with a set of key ideas, in meaningful contexts, will be well placed to take up the demands of those subjects. The VCE science subjects are configured in many respects to emphasise the sort of reasoning and exploration promoted in this discussion paper. However, the demands of a competitive assessment regime have driven the VCE study designs to a tighter specification of content than is promoted in this document for Prep – Year 10 students. In any school there will be a coherent content coverage decided at the local level, sensitive to the local context. We are not aware of any evidence that particular content coverage in Prep – Year 10 is specified by schools as a prerequisite for entry to, for example, Year 11 Chemistry.

Section 5: Focus at different stages of schooling

In outcomes-based curriculum approaches, in particular, development is conceived of in terms of increasing sophistication within each of a number of strands of scientific thinking and acting. In this paper we will argue, consistent with this notion, that over the Prep–10 years there will be a movement towards greater depth and complexity of thinking, and greater appreciation of interactivity between science ideas and practices, and science, technologies and society.

In addition to this we argue that the different degrees of sophistication and complexity imply a different focus and emphasis at each year level of schooling. This idea is explored in Table 1, which identifies a core focus for each level across the stages of schooling. The foci in Table 1 are based on an analysis of the core ideas and practices described in the CSF and related documents, and interpretive work based on the science education literature more generally (for example, Fensham, 2004).

Table 1: Focus at different year levels

Years	Focus	Emphasis
P–2	Encouraging curiosity, exploring and testing ideas	Students in P–2 may be supported to develop their curiosity and wonder, exploring patterns and testing out ideas in simple explorations.
3–4	Exploring relationships and the power of, and interest in, science ideas	Students in Years 3 and 4 will be exploring science concepts and ideas more explicitly, and they will be introduced to the power of conceptual ideas, with a greater focus on asking good questions, on explanation, and on exploring relationships.
5–6	Using science ideas and practices to solve problems	In Years 5 and 6, students will be devising and examining models, problem solving, using text genres in appropriate contexts, and drawing on their imaginations to explore scientific ideas using more formal investigative concepts.
7–8	Engaging with science representations, and with issues related to science	In Years 7 and 8, students will be paying more formal attention to codes of science, representations (e.g. models – visual, mathematical, storied), theories (with their predicting abilities), systems and processes. They will be exploring the multiple ways science works in our personal lives and in the community.
9–10	Exploring science and its relation to society and to the future.	By Years 9 and 10, students will be developing and critically examining metaphors and models, looking at complexity and the inter-connectivity of systems, exploring the many ways science shapes how we live our lives and think about ourselves and the future, and investigating socio-scientific issues and appraising them from an informed position.

Section 6: Four dimensions of scientific capability

Science is too large and complex an area of human endeavour to be covered in any single course of study. Given the choices that must be made in planning a worthwhile curriculum for Prep – Year 10 students, the critical issue concerns the type of choice that is made. The easiest, and traditional way of making such a choice is to use the conceptual products of science as the guiding principle: those concepts developed in the traditional disciplinary spheres of biology, physics, chemistry, geology and so on. However, the danger in doing this is that, once started down a road based on sampling core content, it is hard to know when to stop, and other, very important aspects of science education, are crowded out. These other aspects of science – its complex nature, its modes of working and its usefulness for students in their future lives – have been described at some length in this paper.

A more defensible way of defining ‘essential learnings’ to drive the intended science curriculum is to frame them around the purposes of school science, and around a valid and useful representation of the way science works in contemporary society. In other words, we need to generate a framework that is useful for students in their present and future lives, and that adequately represents contemporary science ideas, thinking and ways of operating. The framework we are proposing is centrally concerned with encouraging students’ interest in science and enabling their scientific capability. It includes knowledge of declarative kinds; understandings of science ideas or about how science operates that students can talk explicitly about; and also skills, values and dispositions that students could demonstrate but not necessarily write down. The framework takes a broad perspective on science content, working at a level of abstraction that attempts to identify the really important conceptual ideas but allows choice in how they are worked through.

Following are the *guiding principles* underlying the Scientific Capability framework:

- It must focus on empowering students to live their lives in a satisfying and productive way, both now and in the future.
- It must be useful as a guide to constructing curriculum and guiding classroom practice.
- It must represent science as a powerful way of knowing, thinking and acting in contemporary culture.
- It must consist of an appropriate mix of ideas, practices, language, skills, values and dispositions that will be enabling for students.

The framework we are proposing consists of four interconnecting, and sometimes overlapping, ‘dimensions’ of scientific capability. In formulating these dimensions, we are cognisant that they both shift the focus from conventional views of science curriculum (largely focused on content and skills) and separate out dimensions of scientific capability that are clearly intertwined. However, we think that the distinctions provide a useful way of highlighting the unique contributions that a science curriculum can make to the lived experiences of students, both in their current and future lives as lifelong learners and/or as science professionals.

The four interconnecting dimensions of the Scientific Capability framework are described below.

Dimension 1: Exploring science @ work

Experiencing and researching how people work with and through science; understanding and valuing how science generates and evaluates new knowledge and innovative science-based technologies; and how science relates to community and environmental needs and issues. Exploring how science ideas are generated, critiqued and verified, and change over time. How scientists and other science professionals work, which people utilise science knowledge and practices, and how; and how science relates to community and societal needs and issues. This dimension is about the nature of science, and the processes within science, but also how science is not a unitary thing, but operates in many different settings and is used by many different people. The exploration that is the basis of this dimension could refer to formal learning about models and theories, or historical and contemporary science and technology narratives of people who have changed science and our lives through their creative and intellectual effort, or whose daily work involves science ideas, practices, language and values.

This dimension can be developed through exploring:

Science as a human activity: Science is constructed by humans who generate ideas, collaborate and explore to establish verifiable knowledge. The process is messy and involves imagination and judgment, values, collaboration and contestation. Science ideas and technologies have a variety of implications for how we understand ourselves and the way we act. Humans in different contexts and times have developed different theories and technologies for understanding and managing their worlds.

Science in the contemporary workplace: How science ideas interact with current and future work opportunities. The ways that science professionals, and a wide range of other workers, use science and science-based technologies in their daily work practices. Reflecting on science-linked work for personal futures.

Structures and representations used in science: Science ideas include theories, models, laws, metaphors and concepts that evolve over time. These ideas are developed by a process of speculation, argument, and appeal to evidence. Developing the representational elements of science is a critical part of theory building.

Science, technologies and society: Science is not a unitary enterprise. It is pursued by many different professions for a range of purposes, and interacts with society as a way of knowing and through the creation and management of new technologies. Local community and global innovations often involve cooperation or contestation between the public and science professionals and/or policy-makers.

Science, innovation and possible societal futures: Science will be critically important for human futures. Large-scale issues and potential solutions to global and national issues require innovative and multi-disciplinary approaches involving different sciences in collaboration with other areas of knowledge.

Dimension 2: Doing science

Working collaboratively and thinking scientifically: being curious and pursuing questions; engaging in reasoning; measuring with precision; undertaking investigative practices; operating with the underlying values, skills and attributes of science, such as seeking verification of evidence and being honest. Developing the capability to operate with the practices and values of investigative science, using a range of procedures through which scientific ideas are generated and tested against

evidence, and through which evidence is generated, collated, validated and analysed, and findings communicated and critiqued. This dimension is closely allied to the traditional ‘working scientifically’ strand of a number of curricula, including the CSFII, but in interpreting it we should be aware of the need to represent the different ways ideas are generated and tested in different discipline areas and in a variety of societal contexts, and not adopt a restrictive view of a singular ‘scientific method’.

This dimension can be developed by:

Designing and pursuing investigations: Generating and refining ideas and questions related to science understandings, and designing investigations to explore these. Responding imaginatively/creatively to observations, problems or unexpected results.

Generating, validating and critiquing evidence: Understanding principles of observation and/or measurement and how to ensure reliability and validity of evidence.

Analysing and interpreting evidence and linking with ideas: Drawing on a variety of processes for data analysis, and being able to frame conclusions based on the interpretation of evidence.

Working and reasoning with models and metaphors: Understanding the use of models and metaphors in science; how to reason with, and to construct arguments from, evidence and models.

Collaborating in teams: working effectively with others, playing a varied and supportive role in science explorations.

Communicating science findings and ideas: Using a variety of modes and media, including information and communications technologies (ICT), to communicate findings and ideas, and to engage an audience with a discussion of implications and consequences of science ideas.

Dimension 3: Constructing science understandings

Building deep understandings of the overarching conceptual ideas of science: wondering why; seeing how science can be used to think through contemporary challenges and issues; and knowing how and when scientific ideas assist us in raising questions about ourselves and our interactions in and with our world. Building on, extending, and rethinking naïve and partial ideas about science phenomena. Interpreting and working with the concepts, laws, theories and models of science that represent the product of centuries of scientific endeavour, drive interpretations of ourselves, the world, and contemporary research and applications, and will continue to be critical for future work. Using science ideas to analyse, speculate, pose and solve problems, and think creatively. This dimension represents the traditional ‘content’ of science, but its focus is on ideas that transcend the current CSF strands, to identify more general and abstract principles through which we make sense of our world and think our way into productive futures. This dimension provides opportunities for cognitive challenges to students that span through understanding to analysing, applying, critiquing and synthesising. Each facet may be explored through the traditional science disciplines or in multi-disciplinary thinking, but planning of rich units and integrated assessment should focus on these bigger picture ideas.

This dimension includes the following big ideas that cross disciplinary boundaries:

Systems and interactivity: The natural and constructed worlds are made up of systems that interrelate in complex ways. Multifaceted models are often needed to describe this complexity. Sustainability of complex systems – including the interdependence of the Earth’s social and physical systems – is a major focus.

Environmental sustainability: Personal and human interactivity with natural systems is a special highlighted case of the first facet, systems and interactivity (see above). The complex understandings and decisions needed to maintain the integrity of global systems. Responsibilities we have to ensure that our actions as caretakers support the ongoing bio-diversity and sustainability of our natural world.

Change and continuity: There are distinct and sometimes predictable patterns of change in natural systems that can be described by principles, laws and theories. Some of these relate to causes of change and others to features that remain constant throughout the change.

Structure and function: Structural features in both natural and constructed systems and entities can be related to particular functions and purposes.

Design, innovation and control: An understanding of systems and principles that recognise their design and control for social purposes. Generating innovative solutions to scientific and technological problems. Respecting the needs and interests of different cultural groups and their right to equitable access to innovative design and control technologies.

Note:

It is not intended that these large-scale ideas would form the basis of curriculum organisation. Rather, these ideas can be demonstrated to apply across all content strands of science and can be used to make judgments about a student’s level of capability in any content area. They can be used as an auditing device to guide the development and focus of learning sequences, as content areas are cycled through.

Thus, in a Year 9 unit on health and the human body, it could be that attention is focused on the reproductive system, including hormonal control systems, and their complex interactions. ‘Change and continuity’ over long- and shorter time spans would relate to the processes of puberty, aging, menstruation and pregnancy. ‘Structure and function’ would relate to sex-related body structures, while ‘design and control’ could be approached through hormonal control mechanisms and through the design of modern pharmaceuticals to control body processes. The unit’s aims relating to Dimension 3 could be couched in terms of levels of student capability on these aspects *in the context of* the learning sequence content.

One intention of this discussion paper is to demonstrate how scientific capability can be powerfully defined in a way that does not rest upon prescription of particular content. In this way, schools can exercise more freedom to design curriculum that pays attention to the multiple dimensions of capability and is more responsive to students’ interests and needs. However, it is expected that each school will plan curriculum mindful of the need to adequately represent the major strands of science – physics, materials science and chemistry, biological and human science, and Earth and space science. It would be assumed they would design content sequences that would cycle through major science ideas such as energy and its many forms and associated processes, force, biodiversity and evolution, genetics and biotechnology, and materials and particle models of matter. The CSFII document would remain a source of ideas for an appropriate sequencing

of content. However, schools need to be freed of the need to cover all forms of energy, or all body systems, for instance.

Dimension 4: Engaging with and valuing science

Being interested and competent in science and disposed towards engaging with and using science ideas, practices, language and values in personally relevant contexts; being creative, innovative and evaluative in using science; drawing on the values and attributes that characterise science, for example, being open-minded, ethical and thinking creatively. Developing the interest, willingness and capability to engage with and use science. This dimension is complex, since it will include affective, cognitive and operational aspects. Thus, confidence, creativity, aesthetics and values will interact with knowledge and a variety of attributes, to determine how interested or curious or committed a person is in respect of engaging with science. In engaging with and using science, students might personally use science, such as engaging with science in the media or talking about science-related phenomena to friends, or they might consider personal explorations of health issues, community issues, or engage with science in a professional sense. Engaging with and valuing science could also refer to practical exploration of the use of science in the classroom and the school-ground, in the local community, or with industry partners. This dimension is a cohering one that emerges out of, and connects with, each of the other three dimensions in such a way that they inform and are informed by each other.

This dimension can be developed by:

Building interest and agency: Generating interest in science and curiosity about natural phenomena, and building student confidence, competence and willingness to engage in science discussions and with science ideas.

Developing a science aesthetic: Stimulating and developing an appreciation for the wonder and beauty of science ideas and science activity, and an enjoyment of exploration of ideas and evidence.

Valuing science as a way of thinking and acting: Being motivated to pursue science questions in engaging with the world. Being disposed to pursue and use science ideas in actions and in making personal decisions. Science ideas and technologies have a variety of implications for how we understand ourselves and the way we act. Recognising that science-related actions will be influenced by personal and societal value systems and interests.

Engaging with scientific reasoning: Arguing from evidence and displaying a disposition to listen to and evaluate others' arguments. Being able to speculate and respond imaginatively to science ideas and situations. Being disposed to retrieve, evaluate and use science information, and being sceptical of claims, seeking evidence that supports or refutes those claims.

Exhibiting critical literacy: Using and responding critically to a range of representational modes; using and critiquing a range of genres of science; communicating science ideas through a range of genres, ICTs and media for specific purposes and audiences.

Enacting the values and habits of mind of science: Adopting values such as objectivity, persistence and honesty in relation to exploring and using science ideas. Appreciating different cultural perspectives on, and responses to, science. Awareness of the potential of science and technology to promote community-based values; caring for ourselves, our community and the environment.

Section 7: Integrated skills, values, attributes and habits of mind

The skills, values, attributes and habits of mind, listed separately below, are integrated with all four dimensions of Scientific Capability. We are gathering them together here in order to highlight their importance in the science curriculum.

While building scientific capability through each of the four dimensions, Victorian students will concurrently become increasingly accomplished across a range of skills, values and attributes. It would be a mistake to draw a strong distinction between the dimensions of Scientific Capability and the skills, values and attributes below, such as reasoning, communicating, scepticism or being creative. Any worthwhile science curriculum inextricably entwines these components in the planning of particular units of work; to separate them out into distinct parts would do violence to the real nature of how science works. For the purpose of highlighting the particular skills, values and attributes that will be acquired during the learning of science, the following categories provide a structure for the intertwined aspects that should be deliberately woven into the science curriculum.

The various sciences and technologies have a huge impact on our lives and on our social arrangements, through local communities and globalisation. It is important that students give consideration to different value systems, cultural understandings, environmental concerns, and issues of personal and communal health, and these perspectives must be included in the science curriculum.

Some of the important embedded skills, values and attributes that are learnt in the process of thinking and working through the dimensions of scientific capability are outlined below. Each of them has specific forms in science, even though some may also be addressed in other learning areas. All students should have knowledge of, access to, and opportunities to develop these skills, values and attributes.

Skills

Inquiring and problem solving: Identifying and asking researchable questions; seeking alternative pathways to solutions; identifying knowns and unknowns; developing criteria for judging the value of evidence; formulating testable hypotheses; designing and conducting experimental investigations that involve choosing appropriate sample sizes, controlling variables, selecting appropriate measuring devices and units, deciding how many repeated observations and/or measurements are required, making inferences from data, and drawing appropriate conclusions.

Reasoning and judging: Recognising the types of evidence that are used to construct scientific arguments and that different evidence requirements and reasoning pathways might pertain to different sciences such as anthropology, astronomy and geology, and that these may differ again from those in other fields of knowledge such as history, art and theology; distinguishing between opinion, hypothesis and evidence; using a range of means to analyse, infer from, and evaluate evidence; being able to create and apply tests to information that scrutinise the authenticity and veracity of truth claims, for example on the World Wide Web; recognising the utility of science as a support for decision-making processes; deciding which argument models are appropriate to use in the defence of science theories; being able to use a range of logical reasoning modes.

Thinking: Facility in creative, critical and reflective thinking is woven into the four dimensions of scientific capability, and these thinking types are also embedded in other skills, values and attributes. They are of such importance in science that they are worth explicating separately here:

Creative thinking: Thinking laterally and beyond the obvious; synthesising ideas in new ways; proposing hypotheses, generating ideas, and seeking alternative insights; applying science ideas across and in new contexts; proposing innovative solutions to problems that draw on a syntheses of science ideas and ways of working.

Critical thinking: Evaluating the quality of evidence used to make claims; analysing arguments and explanations to identify flaws in logic and consistency; demanding justification of claims based on ‘scientific’ evidence.

Reflective thinking: Metacognitive thinking, or being aware of and able to regulate and evaluate their own thinking while engaged in the acts of coming to understand, making decisions and solving problems; being self-reflective and recognising their own strengths and weaknesses in their habits of mind; cognisant of their own preferred ways of thinking and learning; understanding the nature of ideas and how they are created, evaluated and accommodated within new paradigms of thought about how our world works.

Collaborating in teams: Choosing to work cooperatively with others; managing individual accountability in an interdependent context; taking on a range of leadership roles when required; and recognising that shared processes and meaning-making can often produce better outcomes for all.

Using technologies: Utilising computer software and hardware – including digitised data-monitoring instruments – to model and analyse; using tools for laboratory-based inquiry processes in a manner that respects the limitations of the technologies; using technologies to communicate science ideas.

Communicating: Facility with using and switching between common representational forms of science such as physical and mental models, mathematical representations of relationships, analogies and metaphors; constructing a range of written genres, including those frequently used in science, such as recount, reports, procedures, explanations, expositions and discussions; producing other forms of writing, such as hybrid scientific/imaginative texts, that assist learning through writing and enable science ideas to be seen from alternative frames of reference; using a variety of visual, oral and written forms of language in a multi-modal manner to communicate ideas with precision and to a range of audiences.

Values

Through learning science, our students will come to value:

Honesty: Valuing truthfulness; trusting themselves; trusting people and processes that can be relied upon to provide consistent and trustworthy evidence.

Ethical behaviour: Valuing fairness, equity and justness; exhibiting and respecting behaviour that is open, moral and consistent with science’s expectations for transparency of processes.

Scepticism: Valuing a questioning and doubting attitude that expects evidence for claims.

Objectivity, logic and rationality: Valuing the goal of trying to be independent of personal prejudices, and systematic and logical in thinking through ideas; recognising that all human thought has subjective elements – and that this can be a strength in particular contexts.

Diversity: Valuing a variety of perspectives and accepting that they each have useful contributions to make to science, technology, society and their interactions.

Diversity: Valuing a variety of perspectives and accepting that they may have useful contributions to make to science, technology society, and their interactions.

Community: Valuing the input of people into building our constructed and social worlds, and in creating scientific ideas; and valuing working collaboratively in, and with, communities.

Authenticity: Valuing validity, genuineness, and the appropriateness of information in particular contexts.

Verifiability: Valuing processes and dispositions that expect data and evidence to be verifiable.

Reliability: Valuing the reproducibility of evidence and expecting procedures to be available to do this.

Interdependence: Valuing the interdependence of ourselves and our social, physical and constructed worlds; respecting the ways we shape and are shaped by our environment.

Attributes and habits of mind

Curiosity: Wondering how things work; possessing an orientation to inquiry, to speculation, to chasing ideas and testing them against evidence, both informally and formally.

Creativity: A lateral thinking and generative frame of mind that is able to draw on a wide spectrum of ideas and bring them together in innovative ways.

Interest: Seeing science as an enjoyable way of knowing, a means of investigating the wondrous world we live in.

Persistence: Preparedness to persevere in the face of difficulties and problems; a determination to continue seeking evidence and arguments before making decisions; managing impulsiveness.

Precision: Being accurate and aware of the limitations in the accuracy of arguments, evidence, measurements and calculations.

Care and sensitivity: Being sensitive to the needs of ourselves, others and our shared environment; and taking deliberate steps to care for those needs.

Open-mindedness: Being willing to listen to and explore new ideas; willingness to suspend judgment while investigating ideas; having an evaluating perspective on information; a preparedness to look at situations and problems from a range of perspectives.

Responsibility: Accepting responsibility and being accountable for the personal decisions that we make and the consequences of those decisions; taking risks and managing them responsibly.

Section 8: Scientific Capability dimensions for the lower primary school

The dimensions of scientific capability and their different facets outlined above are cast in terms of the level of sophistication that might be appropriate for Year 10 students. Can they be represented realistically in the lower primary school? As a test of this, possible foci and behaviours of P–2 children were generated, corresponding to the various facets of the dimensions *Engaging with and valuing science* and *Constructing science understandings*, and these are represented in Table 2.

Table 2: Dimensions of Scientific Capability seen through the lens of Prep–Year 2

Dimension 4: Engaging with and valuing science	Corresponding Prep–Year 2 focus
Building interest and agency	Being curious and interested in science phenomena and being disposed to suggest ideas. Using science knowledge to decide about housing and feeding pets. Deciding to wear protective clothing in the sun.
Developing a science aesthetic	Wondering about the natural world; enjoying noticing details and suggesting interpretations. Taking pleasure in using precise language.
Valuing science as a way of thinking and acting	Asking questions drawn from curiosity about the world. Providing evidence when making claims about natural phenomena. Willing to use ideas from science for making personal decisions (e.g. minimising personal use of plastic bags).
Engaging with scientific reasoning	Having and valuing ideas; being prepared to logically defend an idea. Participating in open discussions and generating possible explanations.
Exhibiting critical literacy	Writing simple explanations and illustrating them with drawings, or acting them out. Sending email information about data collection; using simple tables and bar charts to display results.
Enacting the values and habits of mind of science	Listening to others' ideas. Being concerned with the care and welfare of animals. Honestly sharing the results of simple experiments (e.g. with magnets).

<i>Dimension3:</i> Constructing science understandings	<i>Corresponding Prep–Year 2 focus</i>
Systems and interactivity	Exploring patterns within various systems and beginning to distinguish between different elements of systems, for example: <ul style="list-style-type: none"> • the different rates and types of dissolving and mixing of everyday substances such as sugar, salt, flour • predator–prey interactions • the conditions under which things move.
Environmental sustainability	Discussing the notion of environmentally responsible behaviour and ideas associated with local and global sustainability, for example: <ul style="list-style-type: none"> • responsible energy use • endangered species • indicators of healthy living, such as clean water, air, food • recycling and packaging.
Change and continuity	Observing and investigating and speculating about different patterns of change, for example: <ul style="list-style-type: none"> • change in animals, such as growth and reproductive cycles • the different types of change that materials undergo, such as when cooking or mixing • the forces that control the flight of a paper plane or the rolling of a person down a slope.
Structure and function	Noticing and exploring simple structures and talking about how they relate to function, for example: <ul style="list-style-type: none"> • the way features of different animal species affect their survival • constructing straw towers and talking about which hold the most weight • investigating how different clothing materials suit different purposes.
Design, innovation and control	Participating sensibly in designing simple processes and artefacts that allow control, for example: <ul style="list-style-type: none"> • making and investigating parachutes or kites • designing a process to make an iceblock last • designing an enclosure to keep crickets healthy.

In each case above it is possible to see, in the Prep–2 years, corresponding precursor behaviours. We argue that most if not all the facets of the four dimensions can be used to guide curriculum planning at all levels of schooling.

However, as we argued in the ‘Focus at different stages of schooling’ section (see page 24), we would expect the different facets of capability to have different flavours and degree of emphasis at different stages. It can be seen, in fact, how the focus ‘Encouraging curiosity, exploring and testing ideas’ sits well with the activities described in the table above.

Section 9: Scientific Capability dimensions for the secondary school

In Table 3, two dimensions of capability and their different facets are again unpacked for Year 10 students – those students preparing for VCE studies, some of which will be in science areas. As a test of the Scientific Capability model, possible foci and behaviours of Years 9 and 10 students were generated, corresponding to the various facets of the dimensions *Exploring science @ work* and *Doing science*. It is expected that the model of the four dimensions of Scientific Capability will provide a rigorous background for those students intending to study science in Years 11 and 12, as they will be richly engaged with the very essence of science.

Table 3: Dimensions seen through the lens of the middle secondary school

<i>Dimension 1: Exploring science @ work</i>	<i>Corresponding Years 9 and 10 focus</i>
Science as a human activity	Investigating different historical, social and cultural conceptions of science ideas, for example: <ul style="list-style-type: none"> • how light and sight work • how blood circulates and how diseases are controlled and/or managed.
Science in the contemporary workplace	Studying science related to contemporary professions, or undertaking science-related work-site projects, for example: <ul style="list-style-type: none"> • carrying out a feasibility study for recycling waste in a workplace • monitoring the quality of air and/or water systems in a workplace • Investigating the way science is used by professionals (e.g. horticulturalists, engineers, forensic experts, or climate change researchers).
Structures and representations used in science	Identifying the distinctions between representations and reality, for example: <ul style="list-style-type: none"> • the similarities and differences between models of electrical ‘flow’ and how electricity actually works • genetic inheritance schema and actual traits in themselves or in animal or plant families that are monitored over several generations • tracing the history of the development of continental drift ideas.
Science, technologies and society	Exploring interactions between science, technologies and society, for example: <ul style="list-style-type: none"> • how navigation, safety and exploration depend on the technologies available at the time (e.g. stars, compass, clock, radar, GPS) • investigating the flammability, warmth, durability and water permeability of different clothing fabrics • the use of modern communication technologies in scientific research.

Science, innovation and possible societal futures	<p>Creating new proposals for solutions to current issues, for example:</p> <ul style="list-style-type: none"> proposing and testing practical forms of alternative biodegradable packaging for the transfer of household goods from shop to home calculating and extrapolating the consequent impact of current non-renewable resource usage on students' children's generation (2040 scenarios) and devising ways of reducing this impact exploring factors affecting the viability of space colonies.
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Dimension 2: Doing science	Corresponding Years 9 and 10 focus
Designing and pursuing investigations	<p>designing and pursuing negotiated investigations into such things as:</p> <ul style="list-style-type: none"> scientific aspects of a sporting or physical activity of their choice (e.g. dancing, football, riding) testing consumer products and proposing means of improving them species distribution in a local environment.
Generating, validating and critiquing evidence	<p>generating, collating and verifying experimental data, for example:</p> <ul style="list-style-type: none"> using controls, taking repeated measurements, allowing for inaccuracies in measuring tools, etc. using digitised data collection and collation tools, and understanding the limitations of the technology.
Analysing, interpreting evidence and linking with ideas	<p>noticing that different means of analysis and data display can suit particular purposes and audiences, for example:</p> <ul style="list-style-type: none"> using of a range of tabular and graphical forms for displaying data using ICTs to record and analyse the results of experimental investigations, and using this evidence to draw plausible conclusions using CD-ROM data on Antarctic penguins to generate and test hypotheses.
Working and reasoning with models and metaphors	<p>participating in debates using scientific reasoning and argument, for example:</p> <ul style="list-style-type: none"> defending the processes used in an experimental investigation in terms of their validity and reliability critiquing models and metaphors used to simplify aspects of everyday experience (e.g. frictionless worlds, germ-free wound care, stimulus–response theories) using heat transfer models in investigating low-energy housing.

<p>Collaborating in teams</p>	<p>collaborating in problem-based learning (PBL) teams, for example:</p> <ul style="list-style-type: none"> • exploring the effects of alcohol and drugs on the body and showing how these relate to personal, sexual and traffic safety • investigating and jointly reporting on the chemistry and chemical safety processes involved in a local workplace • leading a group of younger students in a school-based initiative to improve the school-grounds horticulturally.
<p>Communicating science findings and ideas</p>	<p>communicating science ideas to a range of audiences, for example:</p> <ul style="list-style-type: none"> • writing a book for primary students about electrical safety • creating a poster for the school community about the prevention of sexually transmitted diseases • writing a local newspaper feature article on their investigation into the science involved in a local workplace • writing a scientific report on an investigation • producing a poster for a school science festival.

Section 10: Assessment

In my time in secondary school (disregarding my VCE) I can only remember two different types of assessment in science subjects. There was an assignment once a term and a summative test at the end of each topic. Any other form of assessment was unnoticeable, even in reports. Upon reaching VCE, however, I was expected to put my four years of knowledge into practice, doing analysis, synthesis and application tasks. Previously I had only been taught to regurgitate facts and do short answer questions, never to apply these concepts to new situations. As students, we were not encouraged to make links between the real world and school, between different subjects, or even between different topics in the one subject.

(Student-teacher learning about assessment, Monash University, 2003)

This vignette indicates the enactment, in the writer's school science classroom, of the 'assessment *of* learning' paradigm, where assessment is conceived of as an 'after the event' activity and not *part* of learning. Under that older paradigm, student learning in school science was largely summatively assessed, often through so-called 'objective' assessment test items (which are only objective in their marking, not in their design), with an occasional checklist used for the observation of a skill or two, and an infrequent assignment that was a 'search, retrieval and collation' exercise on a topic like a planet, an element, or how a microscope works.

As assessment frequently drives students' level of motivation and engagement, and teachers' pedagogy, it is important that when we rethink the intended science curriculum that we concurrently rethink the assessment practices we will use to monitor student learning in the implemented curriculum. We need to develop and use fresh, rigorous and convincing assessment protocols with a performance orientation and clear rubrics (Arter & McTighe, 2001) for judging the quality of the performance.

In enabling scientific capability, the discourses, language, values and practices of the expert community – science professionals and citizens who use science – will be foregrounded, experienced and critiqued. The innovative pedagogy that is used to do this requires a different paradigm of assessment – one that is consistent with a new framing of what constitutes 'learning'. In authentic curriculum and assessment, where students negotiate problem situations to creatively and deeply investigate – without someone already knowing 'the answer' – the underlying model of learning is a form of participatory and critical socio-cultural constructivism, called 'critical activism' (Hildebrand, 2001). In the critical activism model of learning, students both participate *in* a community of practitioners (Wenger, 1998) and engage *with* such a community. For science, this means participation in science (constructing science understandings, doing, and engaging with and valuing science) and in issues and debates about how science works (exploring science at work).

In the recent learning and assessment paradigm shifts (Kuhn, 1970, Shepard, 2001), thinking has moved from a framework of assessment *of* learning, described by Shepard as being driven by psychometricians' views of learning (Shepard, 1991), to assessment *for* learning (Black et al., 2003; Shepard, 2001) and, most recently, begun moving into a paradigm of assessment *as* learning (Earl, 2003).

The assessment paradigm shifts have been brought about by a rethinking of the driving purposes and principles of classroom assessment. Rather than assessment being primarily aimed at summatively measuring students' scientific knowledge (as in the old paradigm), assessment is now perceived as a vehicle that can be used to shape, support and enable learning. In this assessment paradigm – assessment *for* learning – there is an increased focus on integrated formative assessment that involves better quality questioning (of and by students), improved feedback from teachers to students on their learning as it happens, and an increased use of self-assessment and peer-assessment to foreground the criteria used to judge learning (Black et al., 2003) and to focus students' attention on all the aspects that are valued in their developing scientific capability.

Assessment can also serve a curriculum-defining structural purpose, where assessment can become the backbone, or integrating thread, of an authentic, problem-based and/or rich curriculum (Newmann, 1993; Earl, 2003; Torp & Sage, 1998) and where student self-monitoring of learning is scaffolded through the use of tools and tactics that move into the most recent paradigm of assessment *as* learning (Newmann, 1993; Earl, 2003). 'Students, as active, engaged, and critical assessors ... ask reflective questions and consider a range of strategies for learning and acting ... and have ways of deciding what to do next' (Earl, 2003, p. 25). Authentic achievement in this paradigm is characterised as involving 'the challenge of producing, rather than reproducing, knowledge' (Newmann, 1993, p. 136) and assessment tasks that carry units of work can be a rich way of providing for this in the implemented curriculum. For example, an extended piece of writing that synthesises a range of science learnings, using key terminology in ways that are consistent with scientists' usage, may begin at the commencement of a unit and be returned to regularly, as capability is developed, until the whole 'story' can be completed at the conclusion of the unit. Another example is problem-based learning (Torp & Sage, 1998) where student curiosity drives the problem-defining and refining stages, and processes are established to investigate (in its broadest sense) the problem in collaborative groups; formalised assessment processes are designed to assist students through the learning and help them shape the communication of their learning to their peers (and other audiences).

For assessing scientific capability there will be a focus on rich and deep tasks. Much learning and assessment requires little active engagement; on the contrary, students are often able to create a 'vener of accomplishment through activity of a dependable and effective kind' (Lave, 1997, p. 31) such as the superficial understandings that have frequently been assessed in conventional science topic tests that focus on recall of content at low cognitive levels. Quality assessment requires deep understanding and to expect anything less is to trivialise the development of scientific capability.

The two most recent assessment paradigms (assessment 'for' and 'as' learning) are underpinned by the same redefined purposes, and these purposes are aligned with the notion of enabling scientific capability.

Assessment purposes and principles

The two major purposes of assessing students' scientific capabilities are to provide feedback to students in ways that enable their learning, and to provide feedback to teachers that will help them refine their curriculum and pedagogical choices.

'In shifting to a new paradigm of assessment it seems that we have to take on some new principles' (Gipps, 1994, p. 29). In the case of the essentials of science that means developing some working principles such as 'assessment practices are an

integral part of teaching and learning’ (See principle 5 of the *Principles of Learning and Teaching*, below). Because assessment shapes learning and teaching strategies, it drives the curriculum. This implies that assessment will be planned along with the curriculum so that learning activities and resources are appropriately chosen to work towards the building of scientific capability. Assessment is not ‘tacked on’ towards the end of a unit but shapes the learning within the unit.

Classrooms that reflect this principle:

PoLT 5.1 The teacher designs assessment practices that reflect the full range of learning program objectives

All four dimensions of scientific capability will be built into the assessment program, along with the appropriate assessment of skills, including creative, critical and reflective thinking, and values and attributes. For example: a student who ‘fiddle-factors’ experimental results will be given feedback on the unethical nature of this behaviour.

PoLT 5.2 The teacher ensures that students receive frequent constructive feedback that supports further learning

In providing constructive feedback to students, teachers will give more detailed descriptions of what is done well, and why, particularly in formative stages so that students can continue to refine their own learning. Teachers will also help students identify what needs to be worked on in order for their capabilities to be improved. This may mean a shift in the balance of formative and summative assessment.

PoLT 5.3 The teacher makes assessment criteria explicit

Assessment is a more transparent process if explicit criteria for judging the quality of student work are given to students, or designed with students, so that they are clear on what they need to demonstrate in their learning. Rubrics that indicate performance levels on criteria in a transparent way will be developed so that students no longer need to ‘guess what’s in the teacher’s head’.

PoLT 5.4. The teacher uses assessment practices that encourage reflection and self assessment

Both the assessment *of* and *for* learning paradigms prioritise self-assessment and peer-assessment as critical processes in enabling learning. Both these forms of assessment require explicit criteria, as mentioned above, in order that the process can be as supportive as possible.

PoLT 5.5 The teacher uses evidence from assessment to inform planning and teaching

In designing the implemented curriculum, teachers can use feedback from the assessment program to shape their selection of processes, activities and resources for enabling scientific capability across all four dimensions, and also in the skills, values and practices that are entwined in the curriculum.

* * * * *

Two additional working principles that teachers can use for assessing scientific capability are added here. While they may be implied in some of the above PoLT principles, they need to be clearly articulated so as to support the building of a rich assessment program.

Each assessment task should be rich, deep and carry many different aspects of the dimensions of scientific capability

Simple summative tasks that focus on low-order thinking (Anderson et al., 2001), or an abstracted view of science knowledge are no longer sufficient for enabling students' development of scientific capability, a more multi-dimensional, complex concept than 'recalling' science ideas. When designing assessment, teachers should focus on the big ideas, the core aspects of the dimensions of scientific capability, not on the minutiae of the 'facts' of science.

Students are offered a variety of types and modes of assessment opportunities

As not all students can show what they know and can do in the same manner, students need to be offered multiple ways of providing evidence of their learning. This means a broadening out of the 'test' focus in many classrooms to include a variety of ways of demonstrating learning, suiting a spectrum of learning preferences, student contexts and types of capabilities to be assessed. There will be less emphasis on written assessment since much scientific capability will be assessed as a performance of a capability or the demonstration of an attribute, skill or value.

Assessment policy at the school level

In order to implement the new science essentials, individual schools will need to be given support and advice on how to develop a localised assessment policy that ensures that the focus on enabling scientific capability is supported and not distorted by the assessment program. For example, the advice in developing a policy will address questions such as those below.

Rationale/Philosophy: What factors about students/curriculum/context are important for our Area/Faculty? How does assessment and reporting link into our overall position on good curriculum, teaching and learning?

Purposes/Goals: Why are we assessing and reporting? (There are usually several reasons – which ones are the main drivers of practice here?)

Principles/Guidelines: What key principles underpin our practices? What models of assessment will be used? (e.g. criterion-referenced, formative, summative, authentic, performance-based)

Assessment processes:

Types: What types of assessment tasks should be included, as a guideline, across each year level/semester (e.g. portfolios, writing, self-assessment, peer-assessment)?

Integrated assessment: How integrated into the regular curriculum and teaching processes should the assessment tasks be? Can one task carry a whole 5-week unit of work? What elements need to be incorporated to ensure that all the dimensions of scientific capability are assessed?

Evidence: How will the evidence of learning be collected (e.g. via a range of types of tasks such as open-ended, problem-based learning oral presentations, imaginative writing, concept map, Microsoft PowerPoint show, article for a local newspaper, book for younger students, working model, annotated collection, role play, trail, game, cartoon strip)?

Frequency: What are the expectations/requirements regarding the breadth of evidence of student learning (e.g. at least three different types of tasks per semester)? What weighting is given to different tasks and/or types of tasks? Who will do the assessing (e.g. peers, self, teacher)?

Consistency of judgments: How consistent are the judgments that are made about students' work (in the same year level)? Do we need to develop graduated criteria and rubrics for judging commonly set tasks? How will consistency be checked (e.g. discussion in the team of the meaning of rubrics; cross-marking of samples of student work)?

Recording: How will evidence of learning be interpreted (e.g. criteria in rubrics, global judgments)? In what form will the evidence of learning be recorded (e.g. profiles, scores, grades, qualitative records)? What tools will be used to record (e.g. running records, anecdotes, checklist, database on computer)?

Reporting: How often will formal reporting occur? To whom will reports be directed? How will reporting occur (e.g. oral, written)? What is the frequency of face-to-face consultation (e.g. P-T interview, student progress interview)? What report formats are appropriate? What will be included in formal reports (e.g. standards, criteria, work habits, suggestions for improvement, general comments)?

Assessment practices in the classroom

If the new paradigms of assessment *for*, and *as*, learning are implemented, classrooms might look quite different from those where assessment *of* learning still operates. In new classrooms, students are aware of how they are assessed, do much of the assessment themselves, informally and formally through both self- and peer-assessment; and are more self-directed in their inquiries because they know where they are headed. Students will seek clarification of the criteria because they will use them in doing assessment themselves, they will see that the criteria relate to the depth of meaning-making that they are engaged in, and that many facets of becoming scientifically capable – not predominantly content knowledge – are assessed. Rubrics will be developed, sometimes with the students, sometimes by teachers, to ensure that assessment is carried out in a valid and reliable manner (Arter & McTighe, 2001).

Science classrooms will be more lively and focused places where students will be working together to refine and direct their own learning. The teacher's role will be to provide tools for students to use, or to assist students in creating those tools. Students will know, or negotiate, the goals, criteria, scope (size, magnitude), the format (oral, visual, performance, portfolio, etc) and the assessors of their work so that judging students' scientific capability becomes transparent.

Assessment tasks will include a wide range of 'products' such as imaginative writing (for example, a series of postcards home from the digestive tract), a concept map, a Microsoft PowerPoint show, an article for a local newspaper, a book for younger students, a model that works, an annotated collection, a science role play, a local trail with question points for their peers, a student-designed game, a cartoon strip, a short video. Other assessment formats might involve group (self and peer) assessment and rubrics for checklists of capabilities that can be performed, and skills, values and attributes that can be demonstrated. The focus of assessment will be the students' developing scientific capability.

Section 11: Writing the standards

One of the problems with the CSF and other outcome-based documents is that learning is envisaged to occur along a uni-dimensional line, encompassing increasingly sophisticated ideas that are mastered as stages on the way. Thus, progress within a 'level' is conceived of as 'beginning', 'consolidating' and 'established' as a prerequisite for moving on to the next level. Science ideas are not quite like that. It is possible, for example, to move on to a study of 'cells' without having achieved mastery of structure in living things. Also, there is a sense of spiralling understanding as consideration of cellular processes uncovers larger realisations of plant and animal structures and control systems.

In addition, this simple notion of progression tends to force a description of outcomes as mastery of lower level understandings, without acknowledging higher order thinking such as application, analysis and creative thinking. Progression within a level could be thought of as having two axes: one concerning increasing mastery of concepts, the other concerning using concepts flexibly in applying them to disparate contexts or unpacking their deeper meanings using speculative, analytical thinking. We may not be able to require high levels of analysis and creativity as a necessary part of achieving the standard; however, we must acknowledge such thinking and encourage it.

Standards should be set around the dimensions of Scientific Capability. There is no suggestion that particular content should be covered in any particular level. Standards statements would be framed in terms of capabilities and have a number of 'for instance' indicators, that schools could use for guidance.

If there were to be statewide assessment, the lack of specific content requirements would require a different sort of assessment, similar perhaps to the PISA international testing regime. However, within schools, assessment will need to be content specific.

The existence of four dimensions within the Scientific Capability framework has significant implications for assessment. Assessment strategies need to be developed for each of the dimensions. All dimensions are critically important to promote the sort of science that will interest and attract students. The dimensions provide, in effect, a definition of what it is to study science in school. They can be used as markers to encourage particular pedagogies, as signposts for planning curriculum experiences, and as the basis of assessment.

In the following section we develop an argument and ideas concerning the way we might conceptualise progression within each of the dimensions, and also the level of detail at which standards might be productively written. In particular, we provide examples of standards at levels from the very broad, down to a micro level of analysis. In this case, we argue that too much detail would be an imposition on teachers if required for assessment, but may be useful in providing support.

If standards were written for each facet of each dimension, the number would exceed the number of outcome statements for each level in the CSF. While this would probably constitute too much detail to be realistically reported on, it should be pointed out that it does not have the same implications for curriculum content as did the CSF outcomes, where each outcome essentially indicated a unit of work to be included. The nature of the dimensions of essential learning in this document is such that all could be productively covered within any learning sequence. Thus, the nexus between standards and curriculum content has been broken.

Conceptualising levels

The different capabilities will develop alongside each other and interrelate in any particular setting, so that in one activity a number of capabilities may be addressed. Levels of performance need not be thought of as being defined for every facet of capability, but could be defined more broadly at the dimension level or even at a more general level.

For instance, an analysis of the outcomes from CSFII, looking across the conceptual strands, yielded a reasonable coherence in terms of the entities that were described at a level, across strands. Thus:

Level 1	Emphasis on the use of language in describing explorations.
Level 2	Seeking and identifying simple patterns using observation.
Level 3	Exploring science concepts and ideas more explicitly. Introduction to the power of conceptual ideas. Greater focus on explanation. Beginnings of looking at systems, structure and function, change. Explicit science investigations, more formal vocabulary.
Level 4	Use of more formal codes and more complexity. Exploration of distinctions and relationships between conceptual entities. Beginnings of formal models and system constructs. Some consideration of design and control in systems. Design and measurement and analysis processes are explicit.
Level 5	<p>More formal attention to different modes of representation – the use of models, diagrams, text genres. System interactions. More explicit design and control relationships.</p> <p>Introduction to the distinct procedures and codes of the disciplines. Beginnings of studying laws governing change. Describing components of more complex systems.</p> <p>Linking ideas and evidence in more formal ways, and representing and judging evidence.</p>
Level 6	<p>Focus on systems. Greater degree of interconnectivity, complexity. Greater reference to the characteristics of models and theories. Explicit consideration of the interactions between science and community, industry.</p> <p>Knowledge of different experimental designs, explicit awareness of procedural ideas and control over a range of representations in analysing and communicating.</p>

These could be crafted, for each level, into outcome statements that transcend content in the different disciplines. They could be broken down to represent each of the facets of the ‘Constructing science understandings’ dimension of capability, and extra statements added for the other dimensions.

They could also be used to describe an appropriate depth of focus for each level, to provide advice on curriculum planning.

Depths of scientific capability

Taking a slightly different view from that developed above, to look at *curriculum focus* rather than outcome statements, it should be possible to make statements about the appropriate *depth of focus* on science ideas at each schooling level, that incorporate the four dimensions without prescribing particular content or particular level descriptions for each facet of capability. Table 4 represents an attempt to frame this.

Table 4: Curriculum and depth of focus over the schooling years

Curriculum focus	Depth of focus					
	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
Curiosity and wonder Seeking patterns Having and exploring ideas						
Conceptualising and making distinctions, exploring relationships Questioning and explaining Designing and interpreting simple investigations.						
Problem solving and investigating, displaying creativity Working with models, different text genres and representations Exploring relationships between concepts, and simple relationships in systems						
Describing and working with system ideas and relationships Learning representations of science ideas; theories, laws, models Working with science investigative procedures; critiquing evidence Relating science to personal and social issues; industrial procedures						
Exploring complexity in systems and change Using principles of evidence to critically analyse and argue Exploring science–technology–society interactions Working with science to make sense of possible futures						

Possible models for writing standards

The focus of the standards should be on a level of working and thinking, in a way that supports the development of scientific capability, but does not specify particular content. In this way schools will be freed to plan curriculum that is sensitive to the local context, and not feel obliged to cover so much ground that depth of thinking and engagement in extended investigation are not possible. Broad specifications would also provide schools and teachers with guidance as to what types of thinking and practice should be focused on through whatever content is studied. Below we suggest one type of specification at Level 6 that might work in this way. Following that, we present several other models of standards.

Level 6

At Level 6, students can use science ideas to interpret and predict the behaviour of a variety of systems, and can sensibly discuss a variety of interactions between science and society, and personal contexts, interests and choices. They are aware of the relevance of science in shaping the way we see the world, and possible world futures. They can describe and use a range of investigative principles and practices in exploring science ideas and critically appraising scientific and socio-scientific practices. They show an interest in, and are prepared to be creative in, engaging with and using science in relation to aspects of their lives and that of the wider community. They are familiar with and can use a variety of scientific representations and communication genres.

Exploring science @ work

Capability at Level 6 could be evidenced by, for example:

- using science theories and models to explore a socio-scientific issue (such as the nutrition requirements of different body systems, or the evidence for a need to reduce greenhouse gas output) and identifying who works in related areas
- displaying an appreciation of the relative place of scientific knowledge in conjunction with other knowledge, in suggesting sensible policies on a socio-scientific issue (such as the siting of a toxic waste dump or the genetic modification of foods) or a technological process (such as the use of chemicals in agriculture, horticulture or athlete blood-testing)
- explaining the way science ideas were generated and established in a historical case study, relating this to the technological resources and human contexts pertaining at the time
- relating scientific theories, models or laws to aspects of personal hobbies or sports (such as surfboarding or skating, or the physics of ball games, science fiction texts or popular media).

Doing science

Capability at Level 6 could be evidenced by, for example:

- designing and conducting scientific investigations that demonstrate an understanding of the need to produce trustworthy evidence, and display knowledge of procedures for ensuring that evidence is convincing

- analysing publicly available evidence using sensible representations and procedures, to draw justifiable conclusions
- developing an argument using evidence, which builds on models or metaphors to establish its claims
- demonstrating a commitment to the values and practices of science (such as honesty and perseverance and creativity in solving problems) in pursuing investigations.

Constructing science understandings

Capability at Level 6 could be evidenced by, for example:

- using the theories, models, concepts, laws or metaphors of science to explore and analyse interactions within systems (such as the flow of energy in ecological systems, or global energy interactions and their implications, or the use of particle models to explore material transformation)
- using the theories, models, concepts, metaphors and laws of science to identify change processes in systems, and features of continuity scientists use to interpret and predict change (such as in physical systems using the conservation of energy or laws relating to energy flow, or ecosystems, or human growth and reproduction, or changes to materials in an industrial or natural process).

Engaging with and valuing science

Capability at Level 6 could be evidenced by, for example:

- being willing to draw on scientific theories and models to explore and explain aspects of a community issue, such as environmental degradation, or the design of a technological process
- using science argumentation, drawing on knowledge of scientific ideas and practices, to critique an article or series of articles from the daily media or popular press, that presents a science-related issue
- taking an active part in a community-based exploration of science and its uses
- being able to use scientific representations in imaginative ways to explore and communicate science ideas
- displaying enjoyment in interacting with science issues in the local community
- displaying an appreciation of the forms and values of scientific exploration and interpretation, in interacting with problems related to science.

What is a standard?

Is a standard a minimum level? If that is the case, then in order to make it achievable the language needs to be explicit and emphasise capability.

We might think of different levels of exemplification of the standard:

Beginning: Ability to display some facility with the idea or performance of the capability in restricted contexts and with support from the teacher or fellow students.

Competent: Comprehension of the idea or performance of the capability at a level where it can be evidenced in a number of familiar contexts where the student is working independently, and extended to unfamiliar contexts with support.

Exceeded: Deep understanding of the idea or high-level performance of the capability at a level where there is fluency in application in a number of relatively familiar contexts, and at least the beginnings of imaginative extension to unfamiliar contexts.

In other words, rather than using the terms ‘beginning’, ‘consolidating’, ‘established’, which imply levels of performance up to defined or contained display, we should be considering the issue more flexibly so that at the highest level there is a recognition of imagination, creativity and fluency beyond a standard minimum expectation.

Exemplar performance standards

In order to present our vision of scientific capability more clearly, we provide here two exemplar standards. They are presented in different formats and with differing levels of detail in order to illustrate that standards can be written at the *micro-level* or *mezzo-level* or *macro-level* for each of the dimensions of scientific capability. It is our expectation that writing at the macro-level will be a better pathway forward, given that this vision of enabling scientific capability is attempting to free up the curriculum and provide for greater depth of meaningful learning for students. One of the difficulties with the CSFII has been its (micro-level) attention to learning outcomes – and the consequent effect of crowding the curriculum, creating a disincentive for teachers to allow sufficient time for meaningful student learning as they try to ‘cover’ a large number of outcomes. We also argue that it is possible to combine several standards from different dimensions of scientific capability within a particularly rich assessment task. For example, teachers already commonly assess within a single assessment task facets of Dimension 2, ‘Doing science’, along with facets drawn from Dimension 3, ‘Constructing science understandings’.

For illustrative purposes we have selected the two more innovative dimensions of scientific capability: Dimension 1, ‘Exploring science @ work’ and Dimension 4, ‘Engaging with and valuing science’. In presenting these exemplars we have tried to show what the standards might look like at Level 4 (Years 5 and 6), Level 5 (Years 7 and 8), and Level 6 (Years 9 and 10). We have used three possible models to do this: a micro-level, a mezzo-level, and a macro-level model.

Writing standards for Dimension 1: Exploring science @ work

In presenting this standard we have opted for a **micro-level** analysis of the outcomes that could be used to design performance standards for Levels 4, 5 and 6. Because this dimension of scientific capability will be a new one for many teachers, it will require careful unpicking so that teachers see both nuances of the term ‘Exploring science @ work’ – how science itself works, as a way of thinking and acting, and how science operates in the workplace.

Each of the facets of this dimension can be unpacked to expose many attainable learning outcomes. For example, a micro-level analysis of Level 6 follows. Below this detailed list, we have presented a single performance standard for each facet of ‘Exploring science @ work’, each of which could be further analysed to produce micro-level outcomes, as we have done for level 6 above.

A micro-level analysis for Level 6 (Years 9 and 10)

In order to demonstrate the multitude of outcomes that could be expected from including a dimension such as this in the vision of Scientific Capability, we have listed below 24 different outcomes that could be identified as coming from Dimension 1 alone. Given that each of the other three dimensions could have a similar micro-level analysis, there could be over 100 separate outcome statements produced for Level 6 alone – with potentially over 500 shades of standards for the Essentials of Science P–10. While we present this here to show the complexity of the dimensions and their embedded facets, we do not recommend this pathway for developing performance standards. We do so to show that it is possible, and to indicate that teachers may need such an analysis to assist their planning of units of work or lesson sequences (see later in this discussion paper).

Science as a human activity

Students:

- discriminate between science and non-science
- recognise the tentative nature of science knowledge and how people use imagination, collaboration and argument in producing it
- analyse and trace the multiple, messy and complex ways that science professionals imagine, produce, debate, verify, represent and use scientific knowledge – historically, and in contemporary research and workplaces
- investigate and present different historical, social and cultural conceptions of science and how these relate to the technologies available and the values of the society at the time
- interpret and critique the ways that science, technologies and society have interacted historically and in today's world
- illustrate how the science and technologies available and used in our lives imply particular values and priorities – in past and present societies
- propose ways in which our lives can be modified to capitalise on the innovations that grow from science and technology to create a more sustainable future
- compare and contrast how humans in different contexts and times have developed different theories and technologies for understanding and managing their worlds.

Science in the contemporary workplace

Students:

- analyse where science is located in a range of contemporary workplaces, and collate the ways that science professionals, and a wide range of other workers, use science and science-based technologies in their daily work practices
- map work contexts that utilise particular types of science understandings and practices that are of interest to themselves in order to reflect on science-linked work for personal futures
- compare the ways that science and technologies interact with broad societal work opportunities, both currently and possibly in the future.

Structures and representations used in science

Students:

- distinguish between theories, models, laws, metaphors and concepts, and map examples of how these evolve over time
- competently use science theories, models, laws, metaphors and concepts to argue for particular positions and/or actions
- devise and critique models and metaphors to explain science phenomena and compare and contrast these with those found in the established science literature
- discriminate between speculation and argument and provide instances of where both have been important in advancing thinking in science
- argue from a base of evidence that is verifiable and defensible
- use cases to interpret how metaphors and models – and other representational forms such as diagrams – contribute to theory building in science.

Science, technologies and society

Students:

- evaluate ways in which science and technologies interact with our social worlds
- investigate the multiple ways that science is pursued by many different professions for a range of purposes and interacts with society as a way of knowing and through the creation and management of new technologies
- analyse how local, community and global innovations often involve cooperation or contestation between the public and science professionals and/or policymakers
- prepare and deliver arguments that contribute to current debates about how science and technologies impact on societies.

Science, innovation and possible societal futures

Students:

- explain the critical significance of science/technology as a means of changing human futures, and predict ways in which innovations might change our social worlds
- appraise ways that large-scale issues and potential solutions to global and national issues require innovative and multi-disciplinary approaches involving different sciences in collaboration with other areas of knowledge
- expect that they, as citizens or science professionals, will be able to competently contribute to debates about how science and technologies can innovatively resolve personal, local, technical and social problems.

A mezzo-level analysis for Levels 4, 5 and 6

An alternative, **mezzo-level** approach for identifying the performance standards is to look at each embedded facet within a dimension of Scientific Capability and write a standard for each of those. Rather than trying to be exhaustive of all the

individual components within the facets subsumed under each dimension, this approach recognises the legitimacy of the facets but paints a broader brush view of the dimension. In Table 5 (below), we demonstrate that it is possible to write standards for each facet of each dimension at different performance levels. This approach generates 15 standards, and could generate up to 30 standards if Levels 1, 2 and 3 were included as well. We believe that this is still an overly detailed approach, although it might be possible that it gives clearer guidance to teachers as to the sorts of focus and activities they might include in their science programs.

For Dimension 4, 'Engaging with and valuing science', we have taken an even broader, **macro-level**, approach to identifying standards (see further below). This is the option that provides the most flexibility for teachers designing programs that meet the needs of the students in their context.

Table 5: A mezzo-level analysis of Dimension 1, Exploring science @ work' standards

Exploring science @ work Embedded facets:	Level 4 performance standard (Years 5 and 6) Students are able to:	Level 5 performance standard (Years 7 and 8) Students are able to:	Level 6 performance standard (Years 9 and 10) Students are able to:
Science as a human activity	<ul style="list-style-type: none"> describe and explain ways in which science knowledge is tentative and changeable. 	<ul style="list-style-type: none"> chart how science ideas in a particular field have changed over time, and relate the changes to the technologies available at different times. 	<ul style="list-style-type: none"> distinguish between science and non-science through investigating what counts as evidence and what approaches have been taken to the development and testing of theories, models and concepts.
Science in the contemporary workplace	<ul style="list-style-type: none"> map a local workplace to identify the ways in which aspects of science interact with the work of the people there. 	<ul style="list-style-type: none"> collate a report on at least two workplaces that summarises how science from a particular field, e.g. chemistry, is relevant in those contexts. 	<ul style="list-style-type: none"> appraise how science from more than one field is used in workplaces, including the technologies and safety issues that relate to the science.
Structures and representations used in science	<ul style="list-style-type: none"> appropriately use simple scientific concepts and models to explain phenomena. 	<ul style="list-style-type: none"> create a physical or mental model to explain ways that phenomena behave, then self- and peer-critique the model in terms of how reality differs from it. 	<ul style="list-style-type: none"> distinguish between theories, models, laws, metaphors and concepts, as used in science, and map an example of how these have changed over time.
Science, technologies and society	<ul style="list-style-type: none"> evaluate how an aspect of science and technology has interacted with their personal life, or with life in the local community as a whole. 	<ul style="list-style-type: none"> analyse and critique the perspectives of more than one stakeholder in a current issue where science and technology interact with society. 	<ul style="list-style-type: none"> debate, from an informed position, a current societal issue that relates to the use of science and technology, considering the validity of the evidence used in support of multiple positions.
Science, innovation and possible societal futures	<ul style="list-style-type: none"> inquire into how an innovative technology is used in a local workplace. 	<ul style="list-style-type: none"> critique an issue, such as water and salinity, where science and technologies interact with possible local and national futures. 	<ul style="list-style-type: none"> evaluate how large-scale societal problems can draw on a range of science and technologies for possible resolution.

Assessment instruments for Dimension 1, Exploring science @ work

Capability in Dimension 1, 'Exploring science @ work' can be evidenced in multiple modes. Since much of this dimension requires exploration with workplaces, and also investigating the knowledge production processes used in science, both historically and in contemporary society, it would be possible to use a range of extended tasks to assess standards here. While standardised test instruments for aspects of Dimension 1 are not ruled out, they may be more difficult to design than those for Dimensions 2 and 3.

Some possible assessment modes for Dimension 1 are shown below.

Assessment mode	Type of criteria
Extended pieces of writing drawing on a range of genres such as journalistic feature writing, reports with recommendations, and oral presentations with support text and visuals (such as Microsoft PowerPoint slides). This writing would be targeted at a particular audience and not be done under test conditions.	Evidence of having investigated actual work places. Analysis of science and technologies used in the investigated workplaces. Plausibility of the critical analysis of how and where science and technologies are used in the workplace. Readability and relevance of the final product for the intended audience. Accuracy and appropriateness of the science language used in the writing.
Negotiated problem-based project work.	Means chosen to generate evidence of how science ideas have been used in history (or the workplace). Evidence of collaboration with peers to jointly investigate the workplace problem – e.g. chemical safety. Collation and display of evidence, using tools such as tables, graphs and metaphors. Coherence and viability of the final written product to persuade an audience.
Portfolio of workplaces and the science used there.	Variety of examples selected as exemplars of science used in the workplaces. Level of complexity of the analysis of the particular science used in the workplaces.
Created and constructed models – including virtual models such as metaphors.	Accuracy of the model in terms of the scientific principles that it demonstrates. Suitability of the model for the stated purpose. Analysis of the ways the model compares and contrasts with the actual phenomenon. Usefulness of the model for predicting how the science might be further tested. Creativity and simplicity in the model design. Evidence of background research in designing the model.

Writing standards for Dimension 4: Engaging with and valuing science

Given that 'Engaging with and valuing science' is a mix of dispositional and conceptual factors, its assessment may present some difficulties. Certainly there are potential types of assessment of valuing and appreciating that might smack of indoctrination, such as asking students to essentially express a liking for science in order to achieve a grade. However, unless we assess this dimension, we run the risk

of teachers not taking it seriously as a dimension of capability to be focused on and planned for. That has generally been the case to this point in time.

The other purpose of taking seriously the question of assessment of engagement and valuing is that, in developing assessment, we move towards a sharper, and publicly agreed, understanding of what this dimension really means. Were it to remain unassessed, there would be limited pressure to clarify its nature. To assess is to clarify.

One other potential problem with assessing Dimension 4 involves the interaction of disposition with the conceptual. If we talk of ‘curiosity’ and ‘interest’ and ‘appreciation’, then it is possible that a Prep child exhibits these to a great degree. Such attitudinal dispositions, in pure form, do not really allow for the identification of a sequential trajectory around which a set of outcomes could be designed. A person may be curious and interested in science all their lives; what changes over time, however, is the focus of that interest and curiosity. An adult will be interested in and disposed to act in relation to aspects of science that are not accessible to Prep children. Thus, while a child may be interested in the detailed structures or behaviour of small animals, an older student might be interested in the reason for distributions of those same animals, or how aspects of their behaviour enable their survival. As knowledge grows, so does the focus of the interest.

Standards for Dimension 4 must consist of an interaction between the pure disposition, and the conceptual content underpinning it. In judging interest and agency, the level will be decided by the degree of interest and commitment to action, and also the level of conceptualisation that is the object of interest or action. We have written these standards at the broad **macro level**.

Examples of standards at the macro level

At Level 6, students are able to:

- show evidence of being interested in and engaging personally with Level 6 ideas in ‘Constructing science understandings’, ‘Doing science’ and ‘Exploring science @ work’. They enact the values of science and demonstrate creativity and criticality in respect to studying science ideas at this level, and engage in exploration and debate that involves societal and personal perspectives and reasoning through different investigative designs. They engage critically with a range of media reports and public arguments concerning local and global socio-scientific and technological issues.

At Level 5, students are able to:

- show evidence of being interested in and engaging personally with Level 5 ideas in ‘Constructing science understandings’, ‘Doing science’ and ‘Exploring science @ work’. They adopt questioning attitudes and imagination in responding to science investigations and applications, and engage productively in discussions about socio-scientific issues. They show a willingness to speculate on the meaning of science models and theories, and the implications of findings of a range of types of investigation.

At Level 4, students are able to:

- show evidence of being interested in and engaging personally with Level 4 ideas in ‘Constructing science understandings’, ‘Doing science’ and ‘Exploring science @ work’. They enjoy and participate

in problem solving and investigations using straightforward experimental designs, and display values of open-mindedness and honesty and care in performing experiments. They show a willingness to engage with and use different science representations and models, and to follow and comment on socio-scientific issues reported in public media.

Assessment instruments for Dimension 4: Engaging with and valuing science

Engaging with and valuing science can be evidenced in many ways. The extent of engagement and valuing will be one of the determinants of how much effort students put into exploring a topic or idea, so that engagement might be partly judged by the quality of work in other dimensions. It may be judged by the approach a student has to work, or the extent to which they push further than needed to make sense of or comment on the science being dealt with. It may be assessed through the approach to particular aspects of the assessment, asking, for instance, for extensions of ideas to other situations. While standardised test instruments for aspects of Dimension 4 are not ruled out, they are more problematic than those that may be applicable in the other dimensions.

Some possible assessment modes for Dimension 4 are:

Assessment mode	Type of criteria
Written instrument: extended response.	Evidence of having read and thought through science ideas in an open response about possible science-related actions. Quality of ideas in engaging with a science issue, task or investigation. Identification of ethical issues around a scientific advance or technological development. Quality of response to extension questions asking for embellishment of an issue or the drawing out of potential implications. Extent of commitment to critical analysis in selecting and responding to media treatment of public science issues.
Guided or negotiated project work.	Extent to which evidence was collected or analysis completed beyond the minimal requirement. Degree of confidence shown in approaching the generation and collation of information, and interest expressed in speculating, hypothesising or going below the surface in interpretation. Willingness to engage with project options asking for community commitments or meaningful action.
Report from experimental or other investigation.	Extent of willingness displayed to seriously engage with questions. Honesty and integrity in generating, collating and analysing evidence. Quality of speculative questions arising from the investigation, or ideas for further investigations. Concern shown in the design and implementation of investigations, for people or other species, or materials involved. Evidence of a personal stance being taken on relevant issues relating to science, such as recognition of meaningfulness of aspects of the investigation, or ethical position in relation to the implications relating to science insights.

Observation of classroom behaviours, personal interaction.	Evidence of willingness to use and critically analyse science ideas in engaging with socio-science issues and applications. Extent of enjoyment and enthusiasm for bringing personal perspectives to discussions on science ideas. Imagination and creativity shown in engaging with science investigations and critical analysis, or ideas for extending science understandings. Extent of collaboration and personal commitment to science related discussions, debates, group projects etc. Extent of development of a personal aesthetic of science ideas.
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Section 12: An enabling pedagogy

The action of the teacher in the classroom is the key element of the implemented curriculum and for students to learn effectively. Whatever the shape and structure of the ‘intended curriculum’, it is the teacher who controls the implementation, and it has long been understood that innovations stand or fall according to the extent they are actually enacted in the classroom. The extent of uptake of a particular reform agenda will depend, critically, on teacher knowledge and beliefs as drivers of practice.

A key principle of this paper is that teachers should see themselves as supporters and challengers of students to become more effective learners and thinkers, rather than as the deliverers of a knowledge and skills edifice. It is time to change both the intended science curriculum and the implemented curriculum to better mirror the ways of thinking and working through science.

The teacher, of course, may be enabled or constrained by the content and scope of the intended science curriculum. The constraints occur in two ways: first, the imposition of expectations of content coverage such that revisiting, exploration and extension cannot occur; and, second, that the form of the curriculum implies the primacy of knowledge structures over the use of that knowledge in meaningful ways. The development of an enabling pedagogy, and the planning of content in curriculum learning sequences, thus must proceed in tandem. To focus on the deep learning that will be required in the new conceptualisation of science in schools, teachers will need to build problem-based learning and collaborative models, extended investigations, and language-focused activities into their practice.

The Principles of Learning and Teaching, below, are a means by which classroom practice can be explicitly discussed and reflected upon, and as an instrument by which activities in learning sequences can be planned to support student learning. The Principles reflect the insight that students need to engage with their learning, and take responsibility for it. The learning needs to connect with their lives and with communities and practices beyond the classroom. There needs to be a focus on deeper understanding, and investigative thinking that emphasises the nature of reasoning in science and the need for creativity and imagination.

Principles of Learning and Teaching P–12 (draft)

Students learn best when:

1. The learning environment is supportive and productive.

In learning environments that reflect this principle, the teacher:

- 1.1 builds positive relationships through knowing and valuing each student
- 1.2 promotes a culture of value and respect for individuals and their communities
- 1.3 uses strategies that promote students’ self-confidence and willingness to take risks with their learning
- 1.4 ensures each student experiences success through structured support, the valuing of effort, and recognition of their work.

2. The learning environment promotes independence, interdependence and self-motivation.

In learning environments that reflect this principle, the teacher:

- 2.1 encourages and supports students to take responsibility for their learning
- 2.2 uses strategies that build skills of productive collaboration
- 2.3 involves students in decision making on a variety of aspects of the classroom program.

3. Students' needs, backgrounds, perspectives and interests are reflected in the learning program.

In learning environments that reflect this principle, the teacher:

- 3.1 uses strategies that are flexible and responsive to the values, needs and interests of individual students
- 3.2 uses a range of strategies that support the different ways of thinking and learning
- 3.3 incorporates strategies which engage students actively in their own learning.

4. Students are challenged and supported to develop deep levels of thinking and application.

In learning environments that reflect this principle, the teacher:

- 4.1 plans sequences to promote sustained learning that builds over time and to emphasise connections between ideas
- 4.2 promotes substantive discussion of ideas
- 4.3 emphasises the quality of learning with high expectations of achievement
- 4.4 uses strategies that challenge and support students to question and reflect
- 4.5 uses strategies to develop investigating and problem-solving skills
- 4.6 uses strategies to develop students' capacity to think and act imaginatively and creatively.

5. Assessment practices are an integral part of teaching and learning.

In learning environments that reflect this principle, the teacher:

- 5.1 designs assessment practices that reflect the full range of learning program objectives
- 5.2 ensures that students receive frequent constructive feedback that supports further learning
- 5.3 makes assessment criteria explicit
- 5.4. uses assessment practices that encourage reflection and self-assessment
- 5.5 uses evidence from assessment to inform planning and teaching.

6. Learning connects strongly with communities and practice beyond the classroom.

In learning environments that reflect this principle, the teacher:

- 6.1 supports students to engage with contemporary knowledge and practice
- 6.2 plans for interaction with local and broader communities
- 6.3 uses resources, including ICT, that reflect professional and community practices
- 6.4 uses strategies that support the development of multiliteracy skills.

The PoLT principles can be broadly matched to the Scientific Capability framework thus:

Engaging with and valuing science

Principles 1, 2 and 3, focusing on supportive learning environments, independence and interdependence, and individual perspectives and learning needs, are central to the development of that sense of agency and disposition to engage with science ideas. The capacity to engage will link with Principle 4: the development of thinking and understanding of the reasoning processes of science.

Exploring science @ work

Principle 6, connecting with communities and practice, is central to the development of understandings of science interacting with science and technology and Principle 4, focusing on deep levels of thinking, is relevant to an appreciation of the structures and representations of science.

Doing science; Constructing science understandings

Investigative and problem solving skills, and learning about key science ideas and the way they are used, are mainly the province of Principle 4 – pedagogies focused on building deeper understandings and developing investigative understanding, and Principle 6 – pedagogies focused on the way science ideas are used.

The particular pedagogies needed to develop science understandings and reasoning/investigating may differ from those used in the past, may differ from other learning areas and may differ from the tactics and practices used in science itself.

These principles of learning and teaching, if they are taken seriously, are a significant challenge for any teacher. Within the PoLT initiative they sit within a detailed model of teacher professional learning and school improvement, so that schools developing their curricula to match the essential learnings document can access a process through which pedagogy can be developed to support this. Teacher professional learning will be a requirement of the implementation phase of this vision of enabling scientific capability, as mentioned later in this discussion paper.

Developing an enabling pedagogy

When rethinking pedagogy it is important to focus on aspects of pedagogical practices that will enable scientific capability. Teachers' principles, tools, tactics, strategies and everyday practices together form their pedagogy. In this new way of viewing the essence of science, the pedagogy must be tightly focussed on enabling capability and not on the transmission of content. Six important elements of an enabling pedagogy that many teachers will need support in developing a clearer focus on, are: the affective, the creative, the critical, the cognitive, language practices, and all of these set within appropriate socio-cultural contexts. Providing resources, time, and support across and within schools will be important factor to consider in implementing this vision of scientific capability.

Affective element

Aspects of the affective domain, such as pleasure in learning science, motivation and volition, engagement and confidence are integral to the changed pedagogical practices of teachers. Pleasure is the heart of the matter. If students do not leave this new science curriculum with a deep and abiding interest in science, and a willingness to engage with science phenomena and ideas, then we have failed (again). From their personal experiences, teachers know that students learn when they are pleasurably engaged; and to engage students with learning science, teachers provide for enjoyment in the process, through setting the science in students' worlds and through the use of fun activities that allow for deep learning such as using role-play and imaginative writing for example.

Creative element

One of the practical principles of innovative teachers of science is that creativity must be built into an enabling pedagogy: teachers can model it in their own innovative approaches, and through activities, students can be encouraged to act, think and write creatively; and both science and students will benefit in the longer term.

Critical element

If the four dimensions of Scientific Capability are to be enacted in Victoria then teachers will teach students that science theories are frequently tentative and conjectural, at least until science can build a substantial body of supportive evidence – and even these may be seen as fallible when new theories are developed, when the theories are applied in new social contexts, or when new technologies become available to test the propositions of the theory. Students can thus be shown that science is changeable and challengeable and not set in stone. An enabling pedagogy encourages students to be sceptical and become informed critics of science theories and of authoritative positions that impact on their lives; and also to be self-critical of their own work processes and their own learning. This is equally true for learning citizens as well as for those who will go on to become science professionals.

Cognitive element

Teachers know that an enabling pedagogy is about learning: learning to explore science @ work, learning to do science, learning to construct and interpret science ideas, and learning to engage with science and to value it as a way of working and thinking. Teachers act on the premise that learning can be meaningful, active, holistic, involve synthesis and transformation, and relate to students' social worlds. They use transparent assessment practices with explicit criteria to promote

learning. They act on the premise that the activities and experiences devised for students to learn science do not need to always be congruent with those that the community of practitioners (science professionals) engage in as the social purposes are different; and they act on the assumption that all students can learn science, given appropriately varied learning experiences and opportunities. This may mean negotiating aspects of the curriculum – such as problem situations to be investigated, or the contexts within which to situate the science.

Language practices

In an enabling pedagogy teachers build in more diversified language practices into their classrooms to help students ‘own’ scientific language. They enable students to work with a broad range of genres, beyond those used by ‘scientists’, recognising the diversity of forms of communication that science professionals use, and thus reconstruct the power of scientific language to exclude students. If the language of science is foregrounded, and played with, it can become a useful tool for learning, rather than a tool for failure. Teachers using an enabling pedagogy mindset know that power comes with using scientific language competently – not just acquiring it – and take seriously their responsibility to scaffold students into understanding and using the language of science.

Socio-cultural contexts

In catering for diversity in students (e.g. sex, ability, cultural and language backgrounds), teachers know that socio-cultural contexts matter. Science curriculum needs to be contextualised in students’ social worlds. It must be authentic and have relevance to students’ lives. The science will be embedded within students’ social worlds, drawing on students’ questions and ideas as resources to help teachers do this. Personal experiences and needs can then be connected with learning, rather than abstracted from it, helping students see science holistically, not as fragmented and disparate concepts. Teachers cater for diversity through providing a multiplicity of active learning experiences, recognising the preferred modes of learning vary among their students. An increased diversity in who is interested in, and actively participates in, science – in school, as a citizen and as a science professional – is a practical goal to achieve through an enabling pedagogy for all students. In an enabling pedagogy strategies and activities that engage girls, and other disenfranchised groups, in learning science are developed and used.

Section 13: A curriculum planning framework

The argument in this paper is that the core agenda of the school science curriculum is to nourish and sustain students' interest in the natural world and to enable students' scientific capability. This is a much broader conceptualisation than understanding science content, and taps into a strong strand of contemporary thinking about engaging students with their learning and thinking, and with their schooling. Developing students' capabilities involves:

- focusing on the enabling aspects of science ideas and ways of thinking and acting for students in their current and future lives
- working with large scale ideas that transcend particular content but represent important strands of contemporary understandings
- exploring these ideas in the context of the way science works, through contemporary technological innovations or socio-scientific issues
- reasoning and problem solving and investigating through science
- multi-disciplinary thinking where appropriate
- enabling pedagogies that develop students' control over and responsibility for learning.

Thus, a school's science curriculum planning, and individual unit planning, needs to be multi-layered in the way it is planned and executed. There are three levels at which the science curriculum needs to be planned and implemented:

- the school program – ensuring students engage with a coherent program over time that develops the dimensions of scientific capability across different areas and contexts
- the unit or learning sequence – planning each learning sequence to focus deeply on one or two aspects selected from each dimension, and supporting these with integrated activities and strategies that are enabling of students' capabilities
- the teacher in the classroom – teachers need to develop innovative pedagogies they can draw on to support the intended program. Each teacher will bring different knowledge, skills and capacities, and the school must encourage the sharing and harnessing of these in the interests of students.

The school program – interweaving the dimensions with content

Each school's science learning program needs to be planned such that students' experiences support the development over time of each of the dimensions of scientific capability in an integrated manner. Some aspects of capability, such as building interest and agency or enacting the values and habits of mind of science, will be approached mainly through the use of appropriate pedagogies. Others, such as engaging with scientific reasoning, working and reasoning with models and metaphors, science in the contemporary workplace, will be addressed through a combination of pedagogy and sequenced content. Many, for instance those in the Constructing science understandings dimension, or in Doing science or in Exploring science @ work, will involve an explicit content focus. In these cases also, pedagogy is of central importance.

Working within the Scientific Capability framework at a program level will involve schools performing an audit of their current curriculum against both the capability dimensions and the Principles of Learning and Teaching. Most schools' curricula will already incorporate a good deal of the scientific capability framework, particularly the 'Constructing science understandings' dimension, if they are aligned with the CSFII, but the emphasis, and some aspects of 'Exploring science @ work', 'Doing science' and 'Engaging with and valuing science', will very likely need rethinking. The freeing up of specific content requirements, compared to the CSFII, will allow schools to design new units and pedagogies to reflect more strongly the driving purpose of enabling students' scientific capability.

It would be expected that the introduction of the new essential learnings curriculum will encourage many schools to reduce their 'content coverage' and move towards exploring ideas in greater depth and in varied settings. They may refine units or introduce new learning sequences to better support the development of scientific capability. In designing a program it will be necessary to make sure there is a balance in content, in type of focus, and context, across years. Many learning sequences may take ideas from a number of disciplines. While this paper does not suggest mandating specific content, schools should ensure each of the major discipline areas is sampled in a planned way, since these disciplines represent different types of modelling, different bases for explanation, and different investigative methods. A coherent program should plan for the laying of foundational ideas, and a revisiting of ideas at greater depth. However, 'capability' should be the primary planning metaphor, rather than 'coverage'. In choosing big ideas of science to focus on, those that are most useful for engaging in contemporary life should be given precedence.

Students' worlds and curriculum planning

A core premise of this vision of enabling scientific capability is that the teaching of science ought to begin in students' worlds. Figure 2 (below) illustrates how the notion of students' worlds, or 'spheres of concern', could be used to identify contexts that are relevant starting points for developing units of work and lesson sequences. Students in different settings may be more interested in some spheres than others, although by Year 10 students would have a more sophisticated view of their place in the world, and have worked with science ideas drawn from all the spheres in Figure 2. These spheres relate directly to students' experiences, questions, curiosities, needs, interests, passions and concerns, and run across year levels.

The spheres can be configured to include both a present and a futures perspective on:

Science and 'me, my family and my home'

For example: my body: senses, growth, healthy diet, body systems (structure and functions), diseases and medical technologies; communication; genetics; making babies and other aspects of sexuality education; everyday chemicals such as personal products (shampoos, soaps, cosmetics, etc) or gardening chemicals; food preparation and storage; the science of stuff (natural and synthetic materials, fibres and fabrics); animals and their habitats (healthy pets – fish, cats, dogs, horses, mice, lizards), wild animals, interesting insects; science of toys (motion, work, simple machines).

Science and ‘my leisure and my local community’

For example: science in popular culture – science fiction/faction – myths and misconceptions; sport science, including motion and forces in sport as well as body demands (dance, skate-boarding); photography (light, chemical images via film/SLRs, digital images); music (sound, electronics); computer games; crafts (fabrics, materials, glues, dyes, paints); gardening; parks; trails; blood samples and drug testing (on roads, in sport).

Science and ‘people and their workplaces’

For example: forensic science; preventative medicine; pathology of blood; antibiotics; biotechnology using stem cells; engineering and construction science (tinkering with tools/machines; building static/dynamic systems); agricultural/horticultural science (food production, animal health); hairdressing; farming; paramedics.

Science and ‘national issues and my environment’

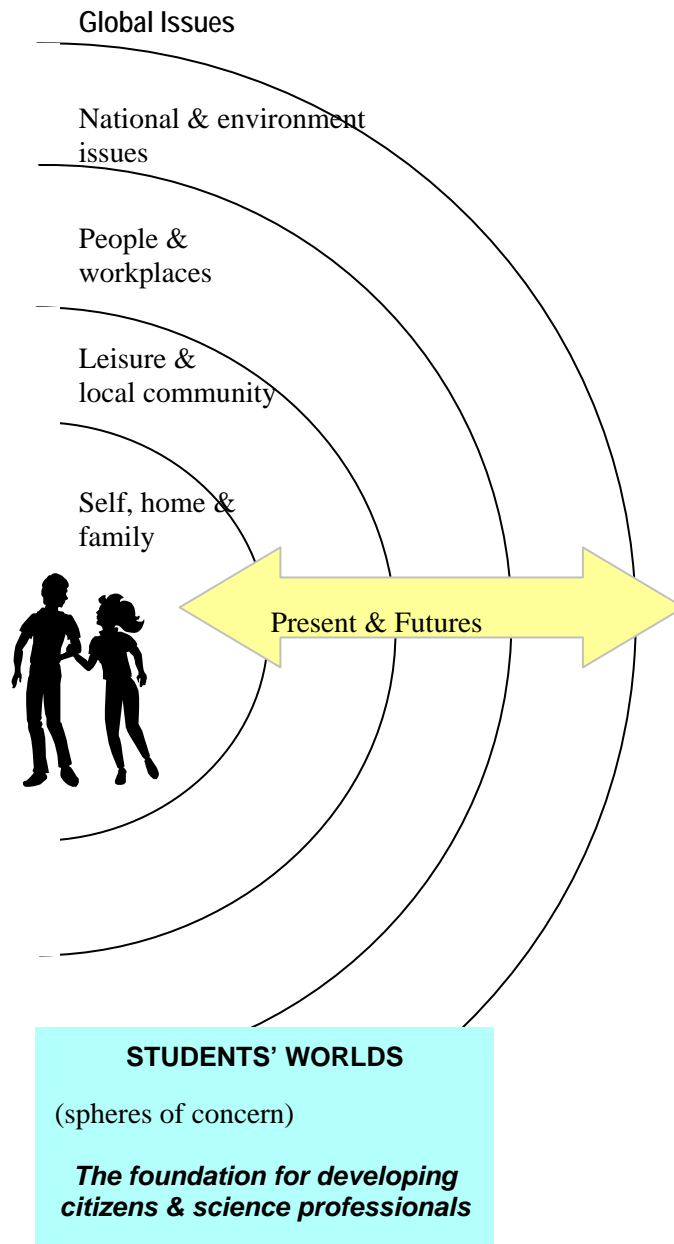
For example: salinity; water resources and usage; flora/fauna/geology and their interactions in the environment; minerals and mountains; fossilised life (palaeontology); how the Earth moves; industries (wine, dairy, plastics); transport; electricity and other power sources (wind, solar, coal); greenhouse gases; ozone layer (and holes); hot and cold worlds.

Science and ‘global issues’ (present and futures-oriented)

For example: ICTs; innovative technologies; conflicts and weapons; stargazing (astronomy/space science); time-capsule science (how and why science ideas change over time); climate change; ecology; sustainability; Indigenous science; societal issues (GM foods, cloning, Star Wars ... whatever is ‘current’ and ‘important’); new theories in science (paradigm shifts); innovative media for new representational forms.

(Expanded and adapted from the ideas of Derek Hodson [1998, p. 6])

Figure 2: Beginning in students' worlds ('spheres of concern')



When planning where to set the science, it is imperative that teachers begin with students' worlds. Encouraging and supporting an abiding interest in science will then be a more manageable task.

A learning sequence planning model

Figure 3 (page 68) is a model that emphasises the student as the central focus when planning for learning. In planning learning sequences, the choice of context, the particular aspects of capability to be developed, the pedagogy, and the wider purposes and context of the sequence, must all refer to the students and their current and future needs.

Learning sequences and units of work may be built around different organising ideas, as the vignettes of practice showed. The simplest test of a worthwhile sequence is: Does it develop students' scientific capability and does it demonstrate to them the usefulness of science ideas and ways of thinking in their lives? The ten 'inclusion tests' of a worthwhile unit or sequence (below) demonstrate that this vision of the essence of science is a rigorous and challenging way of studying science in school. And it is also an enjoyable, rich and meaningful way for students to connect with the science in their lives.

Ten inclusion tests for curriculum planning

When using the planning diagram (Figure 3), there are some simple 'inclusion tests' that can be used to design local science curriculum units, or lesson sequences. These include:

The 'capability' test:

Which aspects of the four dimensions of scientific capability are you including in this unit/topic?

The 'creativity' test:

In what ways are you providing for creative thought and activity?

The 'relevance' test:

How authentic is this in connecting with students' worlds?

The 'rigour' test:

What level of challenge are you expecting your students to meet?

The 'futures' test:

How useful will this work be for your students in 2 days? 2 weeks? 2 years? 20 years?

The 'pleasure' test:

What personal enjoyment and fun will the students receive from doing this science?

The 'skills' test:

What skills will the students be learning?

The 'values' test:

What values will be exhibited/exposed while students do this science work?

The 'attributes' test:

Which attributes will students develop through this work?

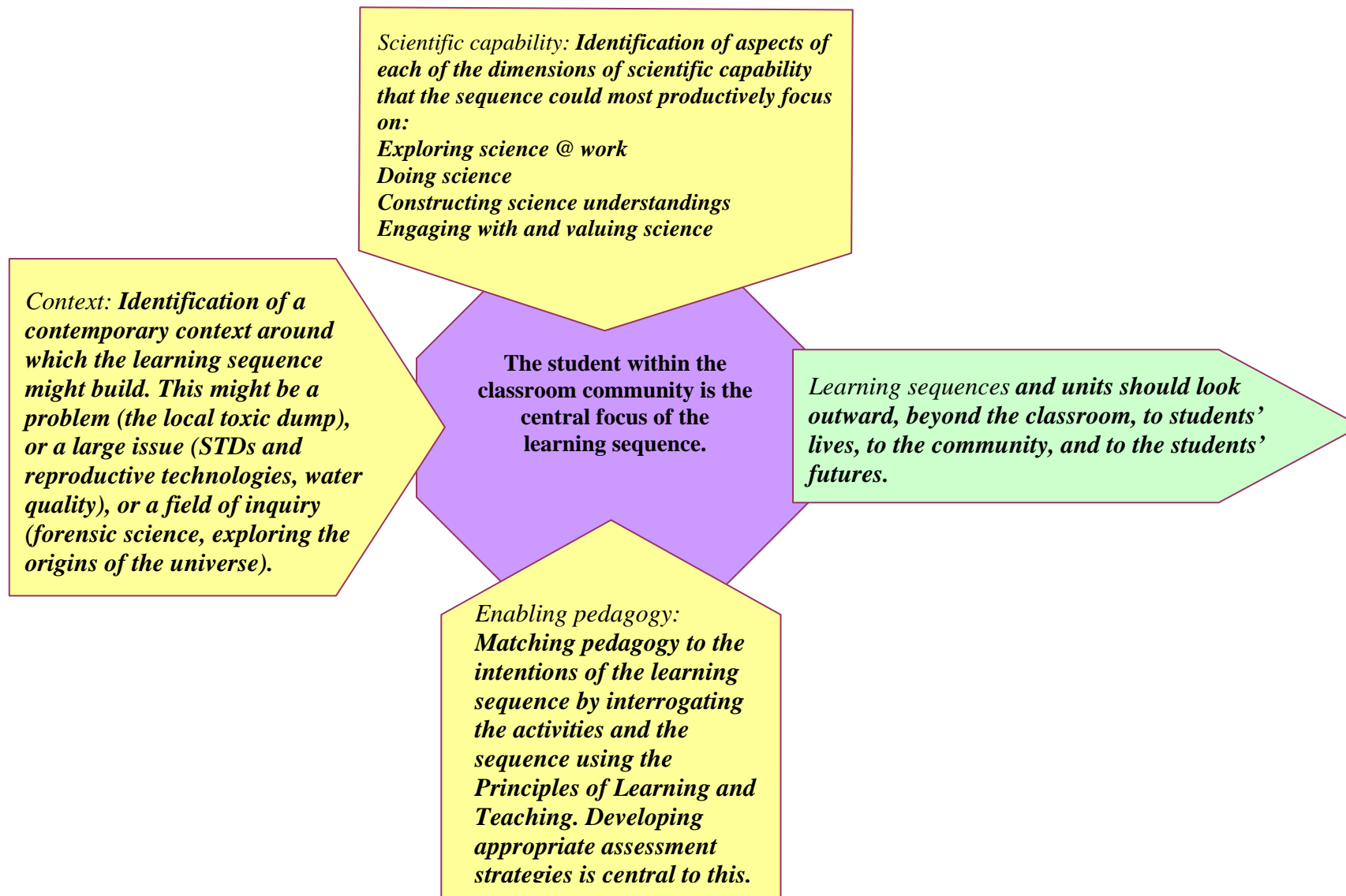
The 'assessment' test:

How can you assess all this so that the valued components are assessed?

As argued above, learning sequences take as their central focus contexts and ideas that attach directly to students' questions, current life interests and concerns, and

link these with the ways science can help them make sense of and engage in significant community practices or concerns. Thus, rich contexts that carry student interest and engagement might include: personal and community health, local or national or global resource and environmental concerns, technologies students use or might use, local industry links, leisure pursuits, or media. We might expect to see, with these criteria, more units of work such as ‘Agricultural science’, ‘Forensic science’, ‘Sport science’, and more problem-based units such as ‘Designing the playground’, or ‘Smoking and health’ appearing to replace sequences focusing on ‘Light’ or ‘Cells’ or ‘Chemicals and their properties’.

Figure 3: A model for planning a learning sequence



The teacher's practice

Repackaging traditional content will not of itself make the material more engaging, nor will it build student interest in science or student capability.

The purpose of choosing a context is to open up the sequence to a wider range of possibilities for tapping into interests, representing the capability dimensions, and calling into play a greater range of teaching and learning strategies. Thus, there needs to be an audit of the sequence against the Scientific Capability framework, against the ten inclusion tests, and against the Principles of Learning and Teaching (PoLT). It is not envisaged that there should be a focus on more than one or two elements of each of the capability dimensions, in any one sequence. If this is done explicitly, many of the elements would fall naturally into place as new pedagogies are developed. However, the PoLT are a set that should underpin all sequences and be present across a teachers' practice. In a sequence-planning exercise, what can be decided by a planning group is not 'Which principles need we cover?' but rather 'What types of activity, and assessment, can be used to best represent these principles?'

Teacher pedagogy is central to the development of scientific capability, and a teacher's practice develops over all learning sequences. It cannot be compartmentalised. Thus, the issue of pedagogy needs to be approached at the science professional learning team level, where teachers discuss their practice and work together to develop and refine their classroom practices to better engage and support students. The PoLT initiative has developed audit instruments and professional experiences to support such learning. Nevertheless, in planning learning sequences it is important that teams explicitly discuss details of the strategies that can be used to effectively implement the pedagogy.

Section 14: Planning to enable scientific capability — some examples

The number of facets of capability is large and it is not suggested that each be focused on in every learning sequence. Rather, they are there to guide curriculum planning – and this can be done flexibly. Two examples, showing how activities or pedagogies might flow from the Science Capability framework, are provided here to illustrate its flexibility. The first concerns an imaginary unit on ‘The Science of Toys’ for Years 3–4. The second is the Year 7 playground unit described in the Maroondah Secondary College vignette (see page 17).

‘The Science of Toys’ – a lower primary unit

In this unit, a number of science ideas are pursued using toys. The potential number of activities is greater than may be selected since it is not necessary to cover all facets in one learning sequence. Part of the intention is to show the ‘flavour’ of a unit that emerges from the Science Capability framework.

Exploring science @ work	
Science as a human activity	Find information about the development of these toys and how they differ from toys of differing types and eras.
Science in the contemporary workplace	Who makes toys? Where are the toys made? What jobs and technologies will be needed? Could you make it yourself? How?
Structures and representations used in science	Modelling energy flow in a toy. Talking about how we used the idea of energy. Can we link energy in toys with our own body energy flow?
Science, technologies and society	Why are they made of these materials? Are there safety issues with toys? What toys are used in other countries?
Science, innovation and possible futures	Imagine a toy of the future. Draw it. How will it be used?
Doing science	
Designing and pursuing investigations	Comparing different brands or types of toy. Exploring the effect of altering aspects across examples.
Generating, validating and critiquing evidence	Discussions take place about what measurements we’ll need to make. How will we do this so that it’s clear and accurate?
Analysing and interpreting evidence, and linking with ideas	Children do experiments then come together to compare findings. They report using a template that focuses on evaluating evidence.
Working and reasoning with models and metaphors	Perhaps a model could be developed to represent energy flow in toys – ‘The way my toy works is like ...’
Collaborating in teams	Children work in groups with specified tasks, to explore and report on toys or to design toys.
Communicating science findings and ideas	Think about different ways children can display findings so that others can understand. Use of an authentic audience.
Constructing science understandings	
Systems and interactivity	Students draw what they think the mechanisms inside their

	toy looks like and how the parts work together. Constructing a toy made of a number of parts.
Environmental sustainability	Looking at toy packaging, and materials.
Change and continuity	Energy flow in toys and why they move, or balance, or ...
Structure and function	Looking at the way the materials and structures of toys help them work.
Design and control	Construction task – studying how a toy’s design helps it do what it does.

Exploring science @ work

Engaging with and valuing science

Building interest and agency	Encouraging curiosity and exploration and providing support for generating ideas. Using a range of toys and allowing play.
Developing a science aesthetic	Encourage enjoyment of problem solving and finding out how toys work.
Valuing science as a way of thinking and acting	Children discuss how science insights and explorations can add to the pleasure of toys.
Engaging with scientific reasoning	Focusing on supporting children to speculate and share ideas, holding interpretive discussions in which students discuss ideas and what might be happening.
Exhibiting critical literacy	Children report their work using diagrams, tables and bar charts, acting out movements.
Enacting the values and habits of mind of science	Emphasis on non-destructive testing. Children listen to others.

The overriding impression of these activities is of student-centredness and exploration: ‘encouraging curiosity, exploring and testing ideas’. The demands on content are minimal, and different foci could be adopted. The framework could be used to generate ideas from which the unit emerges, as above, or as a checklist against which an existing sequence is judged. Most of these activities could be found in science books. However, those dealing with empowering students are often not explicitly mentioned, and have to do both with pedagogy, and the nature of the activity. Note the strong emphasis that has emerged on exploration, reasoning and discussion. Perhaps a sensible focus for the learning sequence could be on aspects of ‘Engaging with and valuing science’ (curiosity and interest, reasoning), ‘Doing science’ (questioning, exploring, investigating) and ‘Constructing science understandings’ (change and continuity, structure and function).

'Science in the Playground' – a Year 7 unit

In this case the unit exists, described in the vignette from Maroondah Secondary College (see page 17). In this case we will audit the unit against the dimensions of Scientific Capability and not check through each facet.

Capability dimension	Aspect of unit
Exploring science @ work	The use of science in a community technological setting. Technologies of levers, pulleys etc.
Doing science	Testing designs, evaluating playground equipment. These are not set-piece 'pracs'.
Constructing science understandings	Studying systems (levers, pulleys); design and control; change and continuity (force and motion). These ideas are used in a real context. Note the use of a 'conceptual change' teaching approach.
Engaging with and valuing science	Motivation using an authentic setting and linking with the community. Element of student choice; control over much of what they do. Creative design of equipment. Problem solving. Explaining to classmates – communication to an authentic audience. Relaying stories of playgrounds.

A number of elements of the Maroondah SC unit, mainly flowing from the community context and the student choice of procedure, are aligned with the thrust of the capability dimensions. The important idea is to design units that are rich, that enable deep learning, and that support and sustain students' interest in science.

Section 15: The nature and extent of the change envisaged in school curricula

The shift from a focus on science content as articulated in the CSFII, to a focus on enabling scientific capability in students, as articulated here, does not mean a move to a 'content-free' curriculum. It is a way of allowing schools and teachers to have greater flexibility in developing units that are richer and broader, and that allow for deeper and more meaningful understandings for students. Scientific capability cannot be pursued free of content.

One of the criticisms that is regularly levelled at the CSF is that it is too focused on content and that the large number of outcomes and the way they are presented has led to curricula constrained because of the need to 'cover' too many topics. The teacher may have 'covered' the outcomes, but many students did not have sufficient time to be able to feel that they had 'covered' the ideas expected in the crowded CSF-based curriculum. While this may not have been the intention, for many schools it has been the reality. The prevailing metaphor has been one of bringing the structure of science ideas to students. This paper is advocating a quite different metaphor: acknowledging and serving students' lives and learning needs as scientifically capable future citizens and, in some cases, science professionals, through a deep exploration of science ideas and ways of thinking and working. This paper provides a much more flexible conception in terms of the content mix.

We would expect a number of changes to occur in schools' science programs:

- A change in the number of units covered, with schools abandoning some units to make room for more serious and in-depth treatment in other units, or amalgamating units that could be productively linked. For instance, similar topics at Years 7 and 10 might be amalgamated.
- A change in the amount of material covered within units, with some content dropped to make way for more in-depth treatment, or contextual linking of other science ideas.
- A change in the focus of units to incorporate all four dimensions, with associated changes in assessment processes, such as including explicit activities to study contemporary issues or technologies, or focusing on students' personal responses by introducing debates, or group project work.
- Where flexibility allows (and this may be more readily achievable in primary schools), the introduction of learning sequences that are problem or project based, or a semester's work for a Year 5/6 class based around planning for entry in a statewide go-cart competition that incorporates mathematics, technology and language as well as science, or a Year 7 combined mathematics and science problem-based unit on smoking that involves groups of students contracting to look at different aspects prior to a culminating seminar.
- A realignment of learning sequences to make them more contextual or, perhaps, problem based. Thus, it might be productive to reshape a unit dealing with plants to focus on local flora and fauna and their current viability, or to refocus physical science units around local contexts such as Maroondah SC's playground unit or Stawell SC's wine production unit.

Time scale

These changes will, of course, take time to work through, and it is envisaged that each school will plan carefully to put in place a program of teacher professional learning that is realistic and that shares responsibilities among staff.

Supporting the change

The changes will of necessity involve school science teams working together to plan and develop a shared view of the process and the principles underlying the new curriculum. This will be happening alongside similar discussions for other disciplines. Thus, the process needs to be supported by the Department, across the system.

There are a number of implications not only for science teams and curriculum planning, but also at the individual teacher level in terms of their pedagogy and their beliefs and orientations concerning the nature of science and the purposes of school science. These will need to be worked through. Teacher professional learning is discussed in the next section.

Schools who have not been part of SIS, PEEL or the Quality Teacher Programme, may find daunting the ideas of science teams developing a shared view of the purpose of their work, and working towards a coherent change process. Teachers who have not been a part of such projects may also be daunted by the pedagogical implications of the Scientific Capability framework. Schools which have been involved in SIS or PEEL or similar change initiatives, should find that this new direction opens up possibilities that are enabling, and should feel comfortable with the direction being taken.

For secondary schools who are grappling with the problem of how to engage students in science, this document should open up possibilities, and productive ideas. For secondary schools which have a strong academic tradition and a science program aimed at Years 11 and 12, this discussion paper will provide a challenge to them to think through the implications of the case being made, and the possibilities that might be opened up by a focus on students' scientific capability and the associated pedagogies that support this.

Section 16: Teacher professional learning

In one sense the suggestion for structure in this document will involve a freeing-up of schools from the restrictions imposed by the content focus of the CSFII, so that it will legitimise the direction many schools are already taking towards more open curriculum structures, including community-based units, theme-based units, integrated units, problem-based learning scenarios, and similar options. On the other hand, what is being suggested is a substantial change of focus, for many schools and teachers, away from a content focus (the needs of the subject) towards a student capability focus (the needs of the student). To implement this vision, it will be necessary to plan and implement a program of teacher professional learning.

The key issues are:

- Teacher knowledge
- Teaching and learning strategies: teacher pedagogies
- Teacher beliefs and commitments concerning the nature and purposes of science
- The operation of professional learning teams
- Support for teachers in rethinking their curriculum, pedagogy and assessment processes.

Teacher knowledge

A shift from traditional content structures to learning units or sequences that are more responsive to students' lives and more open to contemporary issues and applications will need to be accompanied by the production of resources and support for teachers in schools. It will be possible to some extent to draw on expertise existing in schools, such as teachers with special interests and knowledge, or members of the school community. However, support, including time to plan together, will be required.

There will be a need to prepare resource materials to support new ways of organising programs. These should consist of examples of units and planning processes, and materials for teachers and students, based around the working of science in industry or society, or examples to support investigations that are different from traditional practical work (for instance, examples of evidence involved in socio-scientific issues, science-based technologies, magazine articles to support debates or explorations, explorations involving lists of appropriate websites).

Teacher pedagogies

The proposed shift in emphasis for school science has implications for teaching and learning strategies. Goodrum, Hackling and Rennie (2001) reported on the restricted range of pedagogies used by science teachers, and the need to adopt more student-centred approaches. PoLT, as a project, incorporates a framework of effective pedagogy and a model by which this can be implemented in schools. The SIS project, working on a similar action-planning model, reported a significant increase in the range of teaching and learning strategies used, particularly in secondary schools. We can have some confidence, therefore, that PoLT provides a realistic and effective way forward. However, the success of PoLT will depend critically on the resources of time (for planning), consultancy support, and

materials (examples of learning sequences and activities), provided to help schools. It would be valuable to produce advice concerning the particular operation of the PoLT principles for science.

Teacher beliefs and commitments

Most teachers of science will respond positively to the suggestion that the curriculum be refocused on empowering students through developing their scientific capability, and most of the aspects of the capability framework will be recognisable to teachers. However, the shift implied – to a greater emphasis on the way science works in the world, the futures orientation, and a more flexible and community linked program – may challenge teachers who see their expertise mainly in terms of content knowledge, and their primary task to prepare students for the possibility of pursuing science-related careers. There will need to be materials produced that lay out a convincing vision of the intent of the curriculum document and provide examples of productive ways forward. School science teams will need time and support to work through the implications and plan for change.

Professional learning teams

To implement the change of focus, many schools will need to develop a shared view of purposes and pedagogies that are different from those currently existing. The change to the curriculum will involve science team discussions over a period of time, if the plan for curriculum change is to be implemented in a coherent manner.

A change vignette

In 1996 Glen Waverley SC began to explore and implement models and programs to develop a ‘Thinking Curriculum’. It was conceived of as a whole-school approach. The description below draws on a presentation at the Charting Futures forum by Annette Gilbert, the curriculum coordinator.

The conversation began with fundamental questions: What does effective teaching and learning ‘look like’ and ‘sound like’?, What is ‘powerful learning’ and What is ‘powerful to learn? The aims of the project included ‘to engage students in deep and powerful learning, to teach students how to learn and how to think and solve problems more effectively, to develop students as autonomous (independent and interdependent) and lifelong (intrinsic ‘love’ for learning) learners, and to develop a ‘learning community’. The school’s focus is thus very much

The school has three major principles for students: valuing diversity and learning to live together, embracing lifelong learning, and creating personal futures. Pedagogy to support these has become a major focus for the school. For students, the school identified a set of generic attributes, and in science the work of the team focused on identifying the major ‘essential learnings’. These were identified under the headings: to use science constructs to explain and understand the world; insights into science as a dynamic process that occurs within a context and interacts with society, and knowledge of key concepts; scientific attributes, processes and skills, and engagement in informed debates about scientific issues; and communicating and understanding scientific representations.

Glen Waverley SC has subjected itself to a rigorous and challenging change process, and the benefits include: ‘Improved relationships and more connectedness with team members and the organisation as a whole, happier and more energised staff, confident and more articulate staff who are innovative and more willing to take risks’. Students are ‘more confident and articulate, more effective learners and thinkers, more creative and more willing to take risks, and have increased interest in and enjoyment of learning (*especially for Science!*)’.

Section 17: Support for implementation

There are two levels at which support will be needed if the changes envisaged in this discussion paper are to take place. One level is that of the science team in the school. The other level is the individual teacher and his or her pedagogy.

Support for school science teams

Advice is provided through PoLT for the management of change at the school and professional learning team level, but further advice regarding the particular needs of science and the implications of this change will be needed. The School Innovation in Science (SIS) project is currently [2004] running in all regions in Victoria, and is being extended to mathematics and technology in a wider project (School Innovation in Teaching: SIT). SIT is supported by Regional Project Officers who understand the change process and the ideas underpinning SIS that are entirely consistent with the ideas in this discussion paper. Thus, there is an infrastructure in place that could support a school improvement process at either a generic or a science-specific level. The SIS professional development modules are also aligned quite well with the framework of Scientific Capability advanced here.

Support for teachers in rethinking their curriculum, pedagogy and assessment

For many teachers, the ideas presented in this discussion paper will align closely with their view of the purposes of teaching science, their ways of engaging students with science and ensuring quality learning. For other teachers, the ideas will in many respects not align with their views and practices, or pose pedagogical challenges, and they will need support in negotiating new practices. In any proposed change, there is a need for clarity of vision, of support at many levels to initiate and embed the change, and time for teachers and schools to work their way through the implications of the change. When teachers are implementing this new curriculum they will need access to time (for redesigning their units, planning together and sharing curriculum, assessment and pedagogical ideas); resources (such as integrated, rich units, quality assessment tasks and rubrics); and personnel (consultants to support the change process). Again, some schools that have already been involved with such projects as SIS, PEEL, the Quality Teacher Programme and the Innovation and Excellence Project, will have thought through some of these issues and indeed would act as exemplars of the principles being espoused. For most schools, however, the quality of the outcome will be heavily dependent on the resources supporting the change.

There are many bodies in Victoria well positioned to support science teachers and schools in such a change process, and these need to be harnessed. Apart from the government initiatives such as SIT, and the variety of resources developed by DE&T and VCAA to support the CSF, the Science Teachers Association of Victoria (STAV) and the Australian Science Teachers Association (ASTA) have support structures and projects consistent with these proposals. Public resource centres such as the Melbourne Museum, Scienceworks, the Melbourne Aquarium, the Gene Technology Centre and the Monash Science Centre, provide complementary support. The Australian Academy of Science is involved in providing curriculum resources for science and literacy. The Australian government has a range of initiatives aimed at science in schools that are consistent with this new 'essential learning' approach. Thus, while teacher professional learning and school resource support will be critical in driving this innovation, one can draw encouragement from the number of support structures schools can draw on.

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Appendix: Unpacking the dimensions

Dimension 1: Exploring science @ work

This dimension can be developed through exploring:	Illustrative examples
Science as a human activity	Team processes in science The people who carry out scientific exploration – their workplaces, tools and practices Use of digitised data generators and analysers ‘Time-capsule’ science & why/how ideas have changed over time – the importance of available technologies in constraining or providing space for changed theories
Science in the contemporary workplace	Visiting workplaces and noticing the science there Undertaking science-based work experience Seeking out how ICTs and other technologies interact with peoples’ work Considering a range of science-related work for themselves
Structures and representations used in science	Subjecting science claims to critical and sceptical scrutiny Distinguishing between models, laws, principles and theories Contrasting science ideas across cultures and time periods Examining how representations emerge as science ideas out of the exploration of phenomena
Science, technologies and society	The importance of science in the way we see ourselves, and our relationship to the world Exploration of science-related initiatives in communication, resources or the environment management Involvement in local community schemes involving environmental monitoring, risk management, or industry partnerships
Science, innovation and possible societal futures	Sustainability and environmental degradation Genetics and genetic control Climate change Health, pharmaceuticals and disease Food, nutrition & GM technologies in a range of contexts Energy and material resource issues

Dimension 2: Doing science

This dimension can be developed by:	Illustrative examples
Designing and pursuing investigations	Raising questions and refining them to be investigable Designing investigations to allow for sampling, controls and other means of ensuring the trustworthiness of evidence Adjusting procedures to accommodate growing insights during an investigation
Generating, validating and critiquing evidence	Devising measurement processes that provide for repeatability Operationally defining variables in a way that ensures they are measurable Paying attention to sample size Critiquing evidence presented in public science issues Taking accuracy of measurements into account when making claims
Analysing and interpreting evidence and linking with ideas	Constructing graphs or charts from data to explore relationships between variables Constructing flow or Venn diagrams and concept maps to show links and relationships Constructing a chain of argument using different pieces of evidence
Working and reasoning with models and metaphors	Using data from an ecological system to determine energy flow between trophic levels Analysing data concerning energy flow in a house using a simplified diagrammatic model Identifying strengths and weaknesses of models and metaphors
Collaborating in teams	Coordinating with others in experimental design and data collection Supporting analysis by offering appropriate critique
Communicating science findings and ideas	Using multiple genres and formats to communicate science ideas, such as formal reports, posters, letters, emails, spreadsheets and charts Participating in forums for different groups in a class to present and compare results and discuss implications Selecting appropriate genres and media for communicating science ideas to specific audiences

Dimension 3: Constructing science understandings

This dimension includes:	Illustrative examples
Systems and interactivity	Energy and material flow, and animal–plant interactions within ecological systems Particle and atomic models to explain material transformation processes The operation of systems within living things to ensure their survival Planetary and larger scale cosmological systems The patterns of large-scale geological features allied to plate tectonics
Environmental sustainability	Energy production and distribution The interconnections of Earth systems via chemical and energy flows Global energy interactions and climate Factors affecting biodiversity
Change and continuity	Relationships between force and motion Physical and chemical changes to materials Conservation laws (energy, matter) The continuity of life through genetic processes Evolution as an explanatory theory for the diversity and interconnectedness of species The processes leading to the formation of planetary and galactic systems
Structure and function	Design related to energy transfer, transformation, force Material properties related to their use Functional structures of living things and links with their survival
Design, innovation and control	Controlling energy systems Designing devices for controlling forces Control processes to produce useful materials Pharmaceuticals and health Breeding and genetic engineering Climate modification Minimising waste (innovating to reduce, reuse, recycle)

Dimension 4: Engaging with and valuing science

This dimension can be developed by:	Illustrative examples
Building interest and agency	Choosing media eg. science fiction Engaging with societal enterprises or issues linked with science by taking part in an industry- or community-linked project, or debating a newspaper science report
Developing a science aesthetic	Wondering over science insights Enjoying the development of ideas and their validation through experiment Enthusiastically engaging in science debates, using argumentation techniques
Valuing science as a way of thinking and acting	Thinking critically about STDs, health, food issues Using science ideas in choosing which technologies to use Making environmental choices Valuing science ideas
Engaging with scientific reasoning	Articulating science and non-science ideas in framing views on socio-scientific issues Being interested in, and speculative about, science ideas Developing personal stances on science-related issues
<i>Exhibiting critical literacy</i>	Critically analysing science arguments in the popular media Interpreting and critiquing a range of diagrams and models, or different types of graphical and tabular representations Being aware of the way meanings are conveyed in different media
Enacting the values and habits of mind of science	Showing concern for the practices, products and people in scientific and technological investigations Clarifying the values implicit in scientific activity of various kinds Identifying areas in need of local action (school community) where students make a difference

Endnotes

¹ This, and the following vignettes, are adapted from Tytler & Nakos (2003).