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Conference Proceedings

Australian Council for Educational Research



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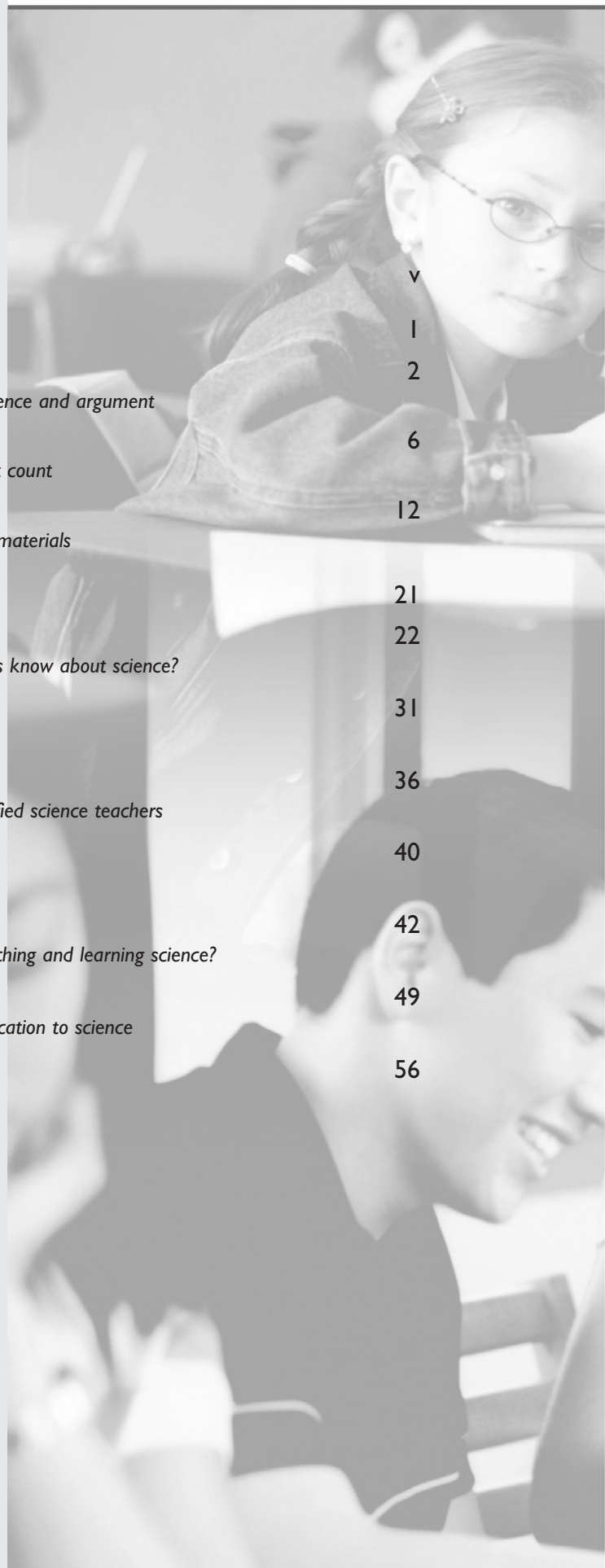
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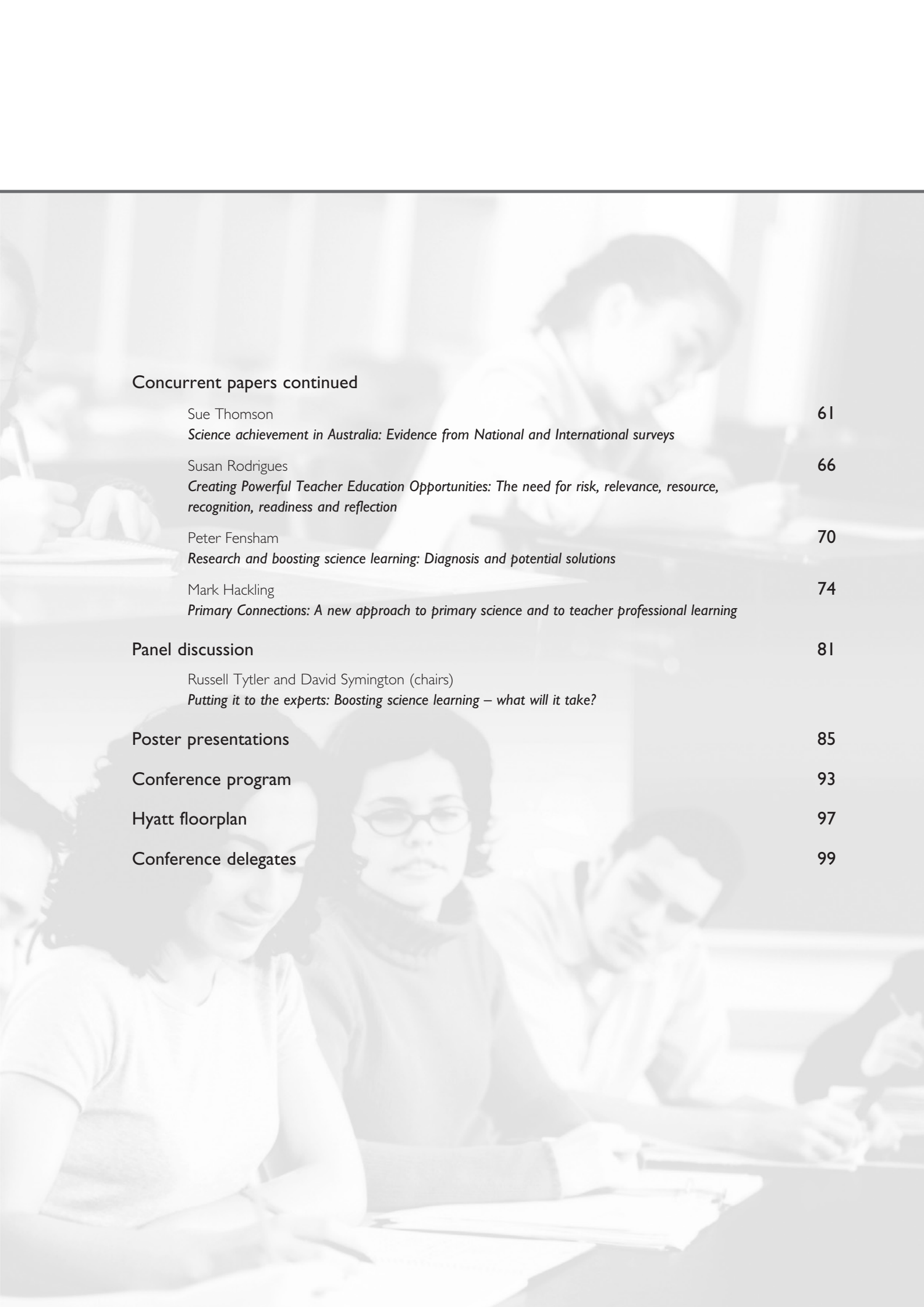
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19 Prospect Hill Road Camberwell VIC 3124 AUSTRALIA

www.acer.edu.au

ISBN 0 86431 597 x

Design and layout by Integral Graphics and ACER Project Publishing

Editing by Carolyn Glascodine and Kerry-Anne Hoad

Printed by Print Impressions

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Foreword



Geoff Masters

Australian Council for Educational Research

Geoff Masters is CEO of the Australian Council for Educational Research (ACER), Immediate Past President of the Australian College of Educators and a member of the UNESCO National Commission in Australia. For more than 20 years, Professor Masters has been an international leader in developing better measures of educational outcomes. He has chaired the IEA Technical Advisory Committee for the introduction of the Third International Mathematics and Science Study (TIMSS); chaired the initial OECD PISA International Technical Advisory Group; directed the only national survey of Australian primary school literacy levels; and worked with all Australian states and territories to introduce statewide testing programs in literacy and numeracy. In 2005-06 he undertook an investigation of options for the introduction of an Australian Certificate of Education on behalf of the Australian Government.

Research Conference 2006 is the eleventh national Research Conference. Through our research conferences, ACER provides significant opportunities at the national level for reviewing current research-based knowledge in key areas of educational policy and practice. A primary goal of these conferences is to inform educational policy and practice.

Research Conference 2006 brings together key researchers, policy makers and teachers from a broad range of educational contexts from around Australia and overseas. The conference addresses the question 'Boosting Science Learning – what will it take?'

We are sure that the papers and discussions from this research conference will make a major contribution to the national and international literature and debate on promoting interest and engagement in science.

We welcome you to Research Conference 2006, and encourage you to engage in conversation with other participants, and to reflect on the research and its connections to policy and practice.

Professor Geoff N Masters
Chief Executive Officer, ACER

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Keynote papers

Towards a science education for all: The role of ideas, evidence and argument



Jonathan Osborne

King's College, London

Jonathan Osborne holds the Chair of Science Education at the Department for Educational and Professional Studies, King's College London where he has been since 1985. Prior to that he taught physics in high schools. Professor Osborne is currently the head of department and the President of the US National Association for Research in Science Teaching (NARST). He has conducted research in the area of primary children's understanding of science, attitudes to science, informal learning, argumentation and teaching the nature of science. He was a co-editor of the influential report *Beyond 2000: Science Education for the Future*, winner of the NARST award for best paper published in JRST in 2003 and 2004, and is a co-PI on the National Science Foundation funded Centre for Informal Learning and Schools. A particular agenda for his research is advancing the case for teaching science for citizenship. To this end, he has conducted a significant body of work exploring the teaching of ideas, evidence and argument in schools.

Abstract

This presentation offers a critical analysis of contemporary science education and the values on which it rests. Science education wrestles with two competing priorities: the need to educate the future citizen about science; and the need to provide the basic knowledge necessary for future scientists. It is argued that the evidence would suggest that it is the latter goal that predominates – a goal which exists at least, in part, in conflict with the needs of the majority who will not continue with science post compulsory education. The argument is advanced that there are four essential elements to any science education – the development of conceptual understanding; the improvement of cognitive reasoning; improving students' understanding of the epistemic nature of science; and affording an affective experience that is both positive and engaging. The decline in students' interest in school science is, in part, due to the emphasis on science for future scientists. This presentation will aim to show how a focus on ideas, evidence and argument can offer an education that is more appropriate to the needs of the future citizen and the values of contemporary youth.

Introduction

Curriculum innovations in science, such as those sponsored by the Nuffield Foundation in the UK and the National Science Foundation in the USA in the 1960s and 70s, have had little impact on the practices of science teachers (Cuban, 1990; Welch, 1979). Four decades after Schwab's (1962) argument that science should be taught as an 'enquiry into enquiry', and almost a century since John Dewey (1916) advocated that classroom learning be a student-centred process of enquiry, we still find ourselves struggling to achieve such practices in the science classroom.

Witness the publication of the AAAS edited volume on inquiry (Minstrell & Van Zee, 2000), the release of *Inquiry and the National Science Education Standards* (National Research Council, 2000), and the inclusion of 'scientific enquiry' as a separate strand in the English and Welsh science national curriculum. The latter, in particular, has now been incorporated into a more embracing program which explores 'How Science Works' with an eponymous title (Qualifications and Curriculum Authority, 2005). These developments serve as signposts to an ideological commitment that teaching science needs to accomplish much more than simply detailing what we know. In addition, there is a growing recognition of the need to educate our students and citizens about *how* we know, and *why* we believe in the scientific world view. While acknowledging that the distinctive feature of science is its ontology, the argument will be presented that such a shift requires a new focus on the following: (1) how evidence is used in science for the construction of explanations; and (2), the development of an understanding of the criteria used in science to evaluate evidence. Central to this perspective is a recognition that language is not merely an adjunct to science but a core constitutive element (Norris & Phillips, 2003; J.F. Osborne, 2002)). In particular, that the construction of argument, and its critical evaluation, are discursive activities which are central to science and central to the learning of science.

The starting point for this argument is the recognition that science education exists on the 'horns of a dilemma'. On the one hand, it wishes to pursue the liberal notion of demonstrating and communicating the best that is worth knowing about this discipline. In so doing, it seeks to lay before the neophyte student the wondrous achievements of science, showing that

it has freed us from the shackles of received wisdom, teaching a respect for empirical evidence as the basis of belief, and offering a vision of how new knowledge can be created.

Yet, science's dilemma (its second horn) is that it can only function effectively within a tradition where it is taught as received knowledge (Kuhn, 1970) – knowledge that is unequivocal, uncontested and unquestioned (Claxton, 1991). Presented to the young student in this manner, it is perceived as a body of authoritative knowledge which is to be accepted and believed. This second perspective is an inevitable product of a view that sees the function of science education as a propaedeutic training for the next generation of scientists. The fundamental flaw with this approach is that, while the unity and salience of such information is apparent to those who hold an overview of the domain, its significance is arcane for the young student. Only for those who finally enter the inner sanctum of the world of the practising scientist will any sense of coherence become apparent. As a consequence, only those that ever reach the end get to comprehend the wonder and beauty of the edifice that has been constructed.

More fundamentally, such an education does harm to the future citizen (Irwin, 1995; Layton, Jenkins, McGill, & Davey, 1993) and limits the development of the young person's understanding of the scientific enterprise. First, it oversimplifies and misrepresents the practices and processes of science, providing an education which fails to develop the skills and knowledge necessary to understand or interpret contemporary accounts of science, scientists and their findings. And second, its failure to develop any understanding of the nature of science beyond naïve empiricist notions (Driver, Leach, Millar, & Scott, 1996), leaves the majority poorly *educated about* science. Never

is there any recognition that students have a right to what Arnold has called the 'best that is worth knowing'. Rather, the outcome leaves many students with an ambivalent or negative attitude to science (Gardner, 1975; Osborne, Simon, & Collins, 2003; Schibeci, 1984).

Yet, science education for all can only ever be justified if it offers something of *universal value to all* (Millar & Osborne, 2000). 'Science for all' requires a 'science curriculum for all' – one that recognises the cultural significance of science by offering insights to the knowledge, practices and processes of science. In essence, a science education that pursues *depth rather than breadth, coherence rather than fragmentation, and insight rather than mystification*. In such a curriculum, the study of the history of ideas and the evidence on which they are founded must lie at the core.

The goal of a science curriculum for all

What kind of science curriculum might then justify science's compulsory status? The starting point of the argument to be presented begins with the view that it is the developments of science and technology which are most likely to pose the political and moral dilemmas for the generations to come (Independent Editorial, 1999). The question of how we address climate change; whether we replace ageing nuclear reactors; invest more heavily in energy conservation; or how to minimise the effects of flu pandemics are just some of the examples that are currently confronting contemporary society. And, since answering such questions makes demands on the finite and precious resources available to a given society, the public have a right to part of the decision-making process. In short, the case that only science should decide what are the salient questions of interest is unacceptable.

Yet confronted with the need to engage a broader set of public(s) in the debate, society is confronted with a dilemma that the majority of people lack the knowledge to make an informed choice. What, then, does it mean to offer a science education that would contribute to enabling young people to make good decisions about issues associated with science and technology? This presentation will argue the view that science is one of the greatest cultural achievements of western society, if not the greatest. Any education in science must attempt to communicate, therefore, not only what is worth knowing, but also *how* such knowledge relates to other events, *why* it is important, and *how* this particular view of the world came to be. That in short, as well as teaching what we believe to be true in science, there is a need to address why we believe it to be true. It will be suggested that such an approach provides a better balance to the following goals of learning science.

The conceptual: There is a body of domain-specific knowledge which is essential to any understanding of science. At one level, this is simply a knowledge of the entities that populate the world – that is, what is meant by a cell, an atom or an electric current. Engaging with scientific concepts is not possible unless individuals are provided with the opportunities for these concepts to be introduced, and with time to learn their use and how to interpret their meaning in an appropriate context.

The epistemic and social practices of science: If the rationality of science is secured by a methodological commitment to evidence as the epistemic basis of belief, then surely the careful consideration of the practices that lead to secure and reliable knowledge should be a core feature of school science? An exploration of some of science's crowning achievements,

even of such simple ideas as the explanation of day and night, would permit science teachers to show that scientific knowledge was hard won – the product of imaginative and creative endeavour, derived often in the face of fierce opposition. More importantly, it would permit the science teacher to show how science uses a range of methods; the features that demarcate science from non-science; the social practices and values that both sustain the scientific enterprise and lead to the production of reliable knowledge; the moral and ethical issues raised by the application of scientific knowledge; and to explore the relationship between science and technology.

The cognitive: from a liberal perspective, one of the goals of education is to develop the autonomous individual who is capable of making rational decisions. It is, for instance, almost a commonplace assumption of post-Enlightenment ethics and political theory that individual autonomy is a necessary condition of human fulfilment (Winch, 2006). In a society where science and technology permeates its foundational fabric, the ability to pursue what might constitute a worthwhile life is dependent on the ability to think critically about science and technology. Science education bears a responsibility for providing experiences which both maximise students' cognitive potential – the argument which underlies, for instance, the CASE program (Adey & Shayer, 1994) to accelerate cognition through science education – and to ensure that the experiences are offered that require the practice and application of critical thinking in science. Thus, science education must show how argument and its evaluation – in short, critical thinking – is a core feature of science.

Perhaps a more fundamental reason for the inclusion of this element is its value as a pedagogic heuristic. The case for the inclusion of argumentation

as a form of pedagogy comes from the increasing evidence that learning to argue is learning to think (Billig, 1996), and from the increasing empirical evidence emerging from the work of social psychologists that the knowledge and understanding of school-age children can be facilitated by collaborative work between peers.

The affective and social: the education of young people in science should afford experiences that generate inspiration at the achievement of their scientific culture. Thus, while being challenging, it must offer 'feelings of understanding' and fascination at what it has to offer. Such elements are crucial to motivation and enduring engagement. In addition, science like any other subject must recognise the growing body of evidence (Daniels, 2001; Doise & Mugny, 1984; Rogoff, 1998) that suggests that learning is best facilitated through a process of social interactions and discourse where children are offered structured experiences that engage them in their zone of proximal development. Such experiences not only teach them how to reason, but also how to listen, how to evaluate the arguments of others, and how to construct counter-arguments – skills that are essential for life as an adult in general.

If an education for citizenship is to be the primary focus of formal science education – the central question is: what is the appropriate mix of these elements? The argument will be developed that the four pillars of such an education are a knowledge of scientific 'facts'; an understanding of the methods and process of science; an awareness of the context and interests of the various actors; and an ability to analyse the risk and benefits of developments in science and technology.

Drawing on a wide body of research, this paper will argue that a focus on examining ideas, evidence and

argumentation has the potential to (a) improve students' conceptual understanding of science; (b) enhance their ability to reason and think critically; (c) develop a deeper understanding of the nature of belief in science; and (d) to make the quality of the learning environment and learning experience more enjoyable.

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The community's contribution to science learning: Making it count



Léonie Rennie

Curtin University of Technology

Léonie Rennie is Professor of Science and Technology Education at the Science and Mathematics Education Centre and Dean, Graduate Studies at Curtin University of Technology, Perth Western Australia. She has a background in science teaching and curriculum, and is particularly interested in how people learn, and want to learn, in a variety of settings. She is a co-author of the Report "The Status and Quality of Teaching and Learning science in Australian Schools" and has participated in national school-community projects arising from that report. Currently, she is working on two research projects relating to integrated curriculum in science, mathematics and technology, and a state-wide program to enhance scientific literacy in the community. Her scholarly publications include over 150 books and monographs, book chapters and refereed journal articles. She has delivered keynote addresses to audiences in Australia, Brazil, South Africa, Sweden, the US and the Netherlands on her research relating to gender, learning and assessment in science and technology, both in school and out.

Underpinning the title of this address are two assumptions. The first is that the community should contribute to science learning. To justify this assumption, I describe a little of what we know about the outcomes of learning science. The second assumption is that the potential community contribution needs some assistance to 'make it count'. To explain this, I outline community-based opportunities for learning science, meld this with what we know about learning outside of school, and then use case studies to illustrate how we can make it count.

Outcomes from learning science at school

A major driver for this conference theme is declining enrolments in science at all levels of education where it is not compulsory and the consequent shortage of people pursuing science-related careers. Research suggests that a significant reason for this is that science at school does not engage the majority of our students. Why might this be so?

Several years ago, Denis Goodrum, Mark Hackling and I surveyed the quality of teaching and learning science in Australian schools (Goodrum, Hackling, & Rennie, 2001). Our review of international trends made it clear that the aim of science education is to assist students to achieve scientific literacy. We defined this term by stating that scientifically literate people are interested in and understand the world around them; engage in the discourses of and about science; are able to identify questions, investigate, and draw evidence-based conclusions; are sceptical and questioning of claims made by others about scientific matters; and make informed decisions about the environment and their own health and well-being. Yet Denis, Mark and I found that, in most cases, current

science education was unlikely to produce the outcome of scientific literacy. For example, in our survey of students in a stratified random sample of secondary schools, less than 20 per cent told us that, very often or almost always, science at school was useful, dealt with things they were concerned about, or helped them make decisions about their health. Sadly, these findings are consistent with a large corpus of research findings: 'A recurring evidence-based criticism of traditional school science has been its lack of relevance for the everyday world' (Aikenhead, 2006, p. 31). As a result, many students are simply disenchanted with the school science curriculum on offer because the culture of school science, with its traditional emphasis on what Aikenhead termed 'canonical science concepts', is at odds with students' self-identities, and they find science at school unimportant, unengaging, and irrelevant to their life interests and priorities. For them, science has little personal or cultural value.

Of course, this is not true for all students. There are some for whom the rather abstract canonical science concepts are a comfortable fit. These are the students most likely to study further science, but they are the minority. The majority seems to be disinterested, even alienated, and many able students give science superficial attention by memorising information for assessments, for example, rather than achieving meaningful learning that will last. Over the last 30 or so years, an incontrovertible accumulation of research on learning in science indicates that 'most students tend not to learn science content meaningfully (i.e., do not integrate it into their everyday thinking)' (Aikenhead, 2006, p. 27).

Our challenge is to turn around this disinterested majority by making it worth students' while to learn science in a meaningful way. This requires changing the science curriculum so that

it has demonstrable relevance and value to these students. A powerful avenue to achieve this involves bringing school science and the out-of-school science community much closer together. In this way, the nature and content of school science is exposed to scrutiny, for students to judge whether or not it is worth their while to engage with it, and if they do, achieve a useful level of scientific literacy or even build a science-related career in adult life. In other words, we aim to develop in students not only the ability but also the desire to learn science meaningfully at school and thus have a disposition to engage with, and use, science long after school. We aim to prepare them for life-long learning in science.

Community-based opportunities for learning science

Within our community is a range of institutions and services that deal with science. Some relevant to school-age children are outlined in the following (incomplete) list.

The students' families and friends – the people with whom they spend most time – are important models for learning. Teachers need to understand the roles these people play, engage their support and avoid possible conflict when dealing with controversial science-related issues.

Institutions, such as museums, zoos, aquaria, environmental centres and similar places that have an educational aspect to their mission, are significant community resources for science.

Many community and government organisations endeavour to educate the public about science-related issues, including health (e.g., skin cancer, smoking, obesity), safety (e.g., fire, electricity, chemicals) and conservation (e.g., recycling, water resources, pollution, quarantine).

Media, particularly television and the internet, but also radio, newspapers, magazines (especially related to hobbies) and advertising, are pervasive sources of science-related information, but of variable quality.

These resources provide almost continuous opportunities for students to learn about science, explicitly or implicitly. Consequently, students come to school informed (and sometimes misinformed) by their experiences in the community. Teachers need to be aware of what students have already 'learned' from these sources in order to harness their potential and engage students' interests.

Learning science from community resources

In the context of learning science outside of school, it is helpful to consider learning as a personal process that is contextualised and takes time (Rennie & Johnston, 2004). Understanding these characteristics enables us to see how extending learning beyond school science and into the community multiplies learning opportunities. First, because people have different interests, backgrounds and motivations, learning is a personal process. Catering for people's different learning styles and prior experiences requires a range of different learning opportunities. Using community resources to complement those in school increases the variety of stimuli and sources of information, and thus increases the likelihood that students will want to engage in meaningful learning.

Second, learning is contextualised according to where, when, with whom, and how it happens. Falk and Dierking (2000) articulated the personal, social and physical contexts that interact to shape learning outcomes. Using community resources extends the

variety of physical environments where learning may occur, and also extends the range of people and social and cultural circumstances available to stimulate learning. Further, placing opportunities for learning in out-of-school contexts enables science knowledge to be demonstrated in the everyday world, thus aiding transfer of learning to new situations.

Third, meaningful learning requires the assimilation of new experiences with previous experiences to revise and reconstruct understanding. Learning takes time because it is cumulative. Linking community resources with science at school means that learning occurs in circumstances or places that students may continue to experience or visit after they have left school, so the likelihood of subsequent learning is enhanced when familiar circumstances jog old memories to help assimilate new experiences.

Readers will recognise the socio-constructivist perspective that underpins these characteristics of learning. If students choose to learn, they will construct their own knowledge and understanding from the experiences and sources of information available to them. In fact, if the ultimate aim of science education is scientific literacy, then the best school science can do is give students a repertoire of experiences that can be retrieved from memory to aid interpretation of new situations and provide direction for making decisions about them.

Using scientific knowledge in real-world contexts – a caveat

Research shows that, in the context of real-world issues, individuals need to transform (i.e., deconstruct and reconstruct) the information they obtain into a form that is usable to them in their own personal

circumstances; that is, construct 'knowledge for practical action' (Layton, Jenkins, Macgill, & Davey, 1993). Students must do this same transformation in order to use the science knowledge available to them to make decisions in new situations. But attempting to use science learned in school to resolve science issues in the real world is complicated. Here is an example.

Academically talented Year 9 students were challenged to make a solar-powered boat as part of an integrated science, technology and mathematics curriculum (Venville, Rennie, & Wallace, 2004). Students needed to construct an electric circuit incorporating solar cells and a small electric motor that was affixed to a hull. The motor operated a winch to wind up fishing line and hence pull the boat through the water. During science lessons, students learned about series and parallel circuits, Ohm's Law, and the relationships $V=IR$, $P=VI$, $P=W/t$ and $W=Fs$. From the second equation, students could see that for maximum power output, high voltage was needed (favoured by a series circuit) together with high current (favoured by a parallel circuit), so there was a trade-off in designing the circuit to incorporate the solar cells. Further, the resistance of the motor varied according to load, and the load (pulling the boat through the water) depended mainly on the design of the hull, but also on the location and efficiency of the winch, among other things, and could not be calculated. Students used trial and error, rather than application of the science concepts (which provided algorithms to get the 'right' answer, but could not be used because other variables came into play), to get their boat to 'work'. The complications of 'real-world' contexts were amply illustrated, and students' boat-building and circuit construction knowledge eventually drew from a range of sources (friends, parents,

watching other students' efforts) rather than the science concepts. Solving their task required students to 'repackage' their canonical science knowledge to fit an imperfect, but real, context. Such experiences are invaluable because they encourage deep thinking in science, and a realisation that although scientific knowledge may be a useful starting point, decisions for practical action must be made in context.

Aikenhead (2006) concluded from an extensive review that 'when the science curriculum does not include the difficult process of transforming abstract canonical content into content for taking action, canonical science remains unusable outside of school for most students' (p. 30). Science curricula can only do this by moving beyond the textbook, using community resources to explore community issues, and keeping three things in mind. First, there are so many uncontrollable variables that the canonical science concepts taught in the traditional science curriculum rarely have immediate practical relevance in real-world situations. At best, they provide only abstract explanations and imperfect predictions. Second, it is often the case that 'the science knowledge featuring in everyday contexts is characterised by uncertainty and dispute amongst scientists' (Ryder, 2001, p. 37). Third, there are often competing social and cultural values that provide conflicting interpretations of how to use science knowledge. Teachers must become aware of these issues and help students learn to cope with uncertainty and risk. Doing so is an important part of becoming scientifically literate.

Using community resources requires time and effort to ensure worthwhile outcomes. Organising a successful field trip, for instance, involves overcoming administrative and financial hurdles, as well as careful pedagogical planning. In the short space remaining, I will concentrate on the challenge

of developing school–community partnerships, briefly describe two examples and identify their successful characteristics. Readers seeking further information are referred to a review of research in the field of out-of-school learning (Rennie, in press) and guidance for teachers in using the other community resources mentioned earlier (Braund & Reiss, 2004).

Successful school–community partnerships

Monitoring Air Quality – a science-awareness raising project

Poor air quality with smoke haze, especially in winter, was a recurring environmental problem in a mill town. A local science teacher led his Year 9 academic extension class on a project to raise community awareness and understanding of the problem, establish a website so that current meteorological information would be available online, and erect air monitoring equipment on the roof of the police station as a tangible outcome of the project.

The major contributor to poor air quality was suspected to be the (foreign-owned) paper mill. However, students found that it was not a simple matter to blame a company that employed many of their parents and sponsored the local football team. The company even donated the expensive air-monitoring equipment to the project! When students inspected the mill, they concluded that it was operated responsibly and was a trivial contributor to the haze. They soon realised that the smoke haze resulted from domestic wood-fired stoves and heaters, many of which were poorly maintained. Students surveyed the community about their knowledge and use of wood burners via the local

newspaper and published their results there. Community interest was so high that at one time students had to be rostered to answer telephone calls to the school. A town meeting organised a petition for the local member of parliament requesting that the government implement a buy-back scheme to reduce reliance on wood burners. Not all went according to plan, however. The launch of the monitoring website was postponed due to difficulties in coordinating bureaucracies to obtain a continuous stream of meteorological data to publish on the website, and there were ongoing software problems. Nevertheless, evaluation showed very high levels of community awareness about this project and positive changes in people's ideas about science education (Rennie & ASTA, 2003).

Class lessons dealt with science issues (combustion, smoke haze settling in valleys, etc.) and this science content was given relevance by the context of the project. Risks, benefits, trade-offs, social interactions between various community members and groups, and communication and understanding of the science and technology issues in the dynamic social context that was central to the project provided significant opportunities to develop scientific literacy.

Living with Tiger Snakes – a wildlife science partnership

The Manager of Herdsman Lake Wildlife Centre led a project involving the cooperation of Years 4–7 students and teachers at a nearby school to develop a community educational program to reduce the indiscriminate killing of venomous tiger snakes. Over approximately six weeks, at the Lake and at school, students enjoyed a presentation by a snake expert on snake identification, behaviour and first aid; endeavoured to observe snake

behaviour and activity; and collected samples of organisms from the Lake to learn about food webs and food chains in the context of the ecology of the area. In addition, students prepared, conducted and analysed a community survey regarding awareness about tiger snakes, and they designed and made snake safety posters, badges and wallet cards. The project culminated in students demonstrating the outcomes of their work at a community night at the Wildlife Centre, with PowerPoint presentations, role-plays of administering first aid, dioramas, and information signs for the lake perimeter.

Evaluation of this project revealed that participants worked together to explore a science-related problem and generated new understanding of the snakes' role in lake ecology and ways to promote safe living with tiger snakes.

Reasons for success

Living with Tiger Snakes was one of 24 School Community Industry partnerships in science (SCIPs) projects across Australia (ASTA, 2005), an initiative built upon the Science Awareness-Raising Project (Rennie & ASTA, 2003), which included the *Monitoring Air Quality* project. Both projects were led by the Australian Science Teachers Association (ASTA) and supported by the Department of Education, Science and Training. Together these projects validated the following guiding principles for effective school-community projects. Successful projects:

- are based on some *issue/stimulus that comes from the community* and is not imposed;
- require *local knowledge* to ensure input of community members;
- are *educative*, because they:
 - focus on science as a way of knowing, thinking and acting, and
 - model science inquiry (working scientifically);

- are *integrated into science at school* and so legitimise participation by students and teachers;
- involve *negotiation and decision-making with the community* in regard to
 - social, political and economic factors,
 - differing perspectives from different groups, and
 - information collected (both local and science-related);
- have a *tangible outcome* to indicate when the project is complete and has achieved something worthwhile.

In addition to these characteristics, these projects had something else in common – some funding. A small amount of money provided seed funding and the impetus to get the projects underway, but the outcomes were far in excess of what money could buy.

Making the community's contribution count

If the major aim of school science education is to assist students to achieve scientific literacy, then the focus must be on developing the skills that underlie that concept. In Table 1, the components of scientific literacy referred to earlier have been separated and matched with the skills and abilities that underpin them.

Table 1 Components of scientific literacy and underlying skills and abilities

Scientifically literate people	Underlying skills and abilities
Are interested in and understand the world around them	Apply science knowledge and skills in daily life Seek information to explain new phenomena or solve problems
Engage in the discourses of and about science	Feel comfortable to listen to, and to read, write and talk about science in everyday situations
Are able to identify questions, investigate, and draw evidence-based conclusions	Think through issues and identify, obtain and use needed information Understand the meaning of 'fair test' Defend an argument
Are sceptical and questioning of claims made by others about scientific matters	Distinguish between fact and opinion Assess quality of evidence
Make informed decisions about the environment and their own health and well-being	Recognise and cope with risk and uncertainty in decision making Choose to act responsibly and ethically

The outcomes of the partnership projects described above are consistent with research findings about effective excursions, incursions, and many other kinds of school–community links, because they encouraged development of the skills and abilities identified in Table 1. An essential characteristic is that they were built into, not added on to, the school science curriculum. In fact, if there were three simple rules about using community resources successfully, they would be:

1. **Integration:** Experiences with community resources are integral, not peripheral, to science at school;
2. **Preparation:** Teachers and students understand what the tasks and expected outcomes are and what needs to be done to achieve them, and
3. **Accountability:** Teachers and students are jointly responsible for ensuring task completion.

Learning in the community, away from the constraints of the school curriculum, has been described by the National Association for Research in Science Teaching's Ad Hoc Committee on Informal Science Education as 'learning that is self-motivated, voluntary, guided by the learner's needs and interests, learning that is engaged in throughout his or her life' (Dierking, Falk, Rennie, Anderson, & Ellenbogen, 2003, p. 109). This is the kind of learning we need to encourage at school, to boost learning and interest in science. Involving community resources promotes opportunities for learning science that students perceive as relevant and worthwhile, so that learning is meaningful and lasting. By using experiences in the community to help students develop and practise the skills and abilities that contribute to scientific literacy, we will make the community's contribution count.

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Enhancing science teaching and student learning: A BSCS perspective



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Abstract

How can curriculum materials enhance science teaching and student learning? In answering this question I draw upon my experience at the Biological Sciences Curriculum Study (BSCS) to describe the design and development of effective science curricula.

Describing effective curriculum materials requires an understanding of how students learn science. Research in the cognitive and developmental sciences provides a body of knowledge for curriculum developers. Three principles of learning provide the basis for curriculum and instruction in the sciences (Donovan & Bransford, 2005).

1. Students have preconceptions about how the world works.
2. Students' competence in science requires factual knowledge and conceptual understanding.
3. Students can learn to control their own learning through metacognitive strategies.

These findings have clear and direct implications for the design and development of science curricula.

1. Science curriculum and instruction should facilitate conceptual change.
2. Science curriculum and instruction should be based on fundamental concepts and complementary facts.
3. Science curriculum and instruction should provide opportunities for students to learn and develop metacognitive strategies.

Since the late 1980s, BSCS has used a research-based instructional model to organise and sequence developmentally appropriate experiences for students that consist of the following phases: engagement, exploration, explanation, elaboration and evaluation. Known as the BSCS 5E Instructional Model, this model addresses the need for systematic science teaching based on

a contemporary understanding of how students learn.

BSCS also has used the *National Science Education Standards* to guide the decisions about the content in curricula developed or revised since the mid-1990s when the standards were released.

Recent studies have indicated that when BSCS programs are used with fidelity, the gains in student learning are great. These results may be attributed to close attention to criteria for learning in the selection of science content and instructional sequence, the use of 'backward design' in developing materials, the extensive support for teachers in the form of teachers' guides, and the complementary professional development of teachers implementing the curriculum.

How can curricula enhance science teaching and student learning? A slightly deeper and more specific question than that is: what is the form and function of effective curriculum materials? These questions will be addressed in the following discussion. After a brief introduction to BSCS (Biological Sciences Curriculum Study), I will first discuss what we know about how students learn science and introduce an instructional model based on this research from the cognitive sciences. I will then review the curriculum development process at BSCS and describe a contemporary high school program and evidence of student learning attributed to that program.

A brief history of BSCS

A committee of the American Institute of Biological Sciences (AIBS) established BSCS in 1958. At its birth, BSCS had a single grand vision – to change the way biology was taught in American high schools. BSCS accomplished this goal by publishing three innovative biology textbooks in 1963. These textbooks became known as the Yellow Version

(*Biological Science: An Inquiry into Life*), the Blue Version (*Biological Science: Molecules to Man*), and the Green Version (*Biological Science: An Ecological Approach*). These textbooks were widely adopted in the United States, and by the mid-1970s, BSCS programs had over 50 per cent of the high school biology market. Further, the international community recognised the quality of these new biology programs and began adapting them for use in their respective countries. One of the enduring examples is the adoption of the BSCS Green Version by Australia. The Australian program is titled 'The Web of Life'. To date, BSCS programs have been translated into 25 languages for use in more than 60 countries.

Though BSCS began with a focus on high school, the organisation quickly expanded beyond high school by developing programs for elementary school, middle school, and college. A 1992 BSCS elementary program *Science for Life and Living* was adopted for Australian schools by Denis Goodrum and his colleagues. In Australia, that program was adapted and implemented as *Primary Investigations*.

BSCS is a 'curriculum study'. Our name indicates that the organisation does not focus on curriculum development in isolation. BSCS also has provided professional development and conducted research and evaluation studies for as long as we have developed instructional materials.

This brief introduction and history of BSCS sets the stage for an important point: BSCS and organisations like it in the United States and other countries such as Australia have developed sophisticated approaches to designing, developing and implementing innovated curriculum materials. The time, effort and expertise of professional curriculum development groups stand as an important innovation from the Sputnik era.

This introduction provides a context for the BSCS perspective on curriculum development and what we do to enhance science teaching and learning. I will describe what goes into contemporary curriculum development at BSCS and use *BSCS Science: An Inquiry Approach*, a new multidisciplinary program for high schools, as an example. Our work begins with an understanding of recent research on learning.

How students learn science

If one is interested in enhancing science teaching and learning, it seems only reasonable to begin with an understanding of how students learn science. Several decades of research in the cognitive and developmental sciences have built a knowledge base that curriculum developers can use. This research has been synthesized by the National Research Council (NRC) and described in several publications, *How People Learn: Brain, Mind, Experience, and School* (Bransford, Brown, & Cocking, 2000), *Knowing What Students Know* (Pellegrino, Chudowsky, & Glaser, 2001), and *How Students Learn: Science in the Classroom* (Donovan & Bransford, 2005). Three principles of learning from this body of knowledge establish the basis for curriculum and instruction.

1. Students come to the classroom with preconceptions about how the world works. If their initial understanding is not engaged, they may fail to grasp the new concepts and information, or they may learn them for the purposes of a test but revert to their preconceptions outside the classroom.
2. To develop competence in an area of inquiry, students must (a) have a deep foundation of factual knowledge, (b) understand facts and ideas in the context of a conceptual framework, and (c) organise knowledge in ways that facilitate retrieval and application.

3. A 'metacognitive' approach to instruction can help students learn to take control of their own learning by defining learning goals and monitoring their progress in achieving them (Donovan & Bransford, 2005, pp. 1–2).

Based on these research findings, curriculum materials should be designed with the knowledge that students' current conceptions may not align with recognised scientific knowledge about how the world works and those current conceptions must be engaged and challenged in order for change to occur. Second, both facts and a sound, conceptual framework are essential. And, third, curriculum and instruction should embed 'metacognitive' strategies.

Finding 1 reminds us that students have preconceptions, misconceptions, and naïve theories, which is to state the obvious. Identifying the means to facilitate conceptual change seems to me to be the essential insight and extension of the research on students' understanding of how the world works – from a scientific perspective. The work of individuals such as Rosalind Driver and her colleagues (1986; 1989), Peter Hewson and his colleagues (1981; 1989), Richard White and Richard Gunstone (1992), Mike Atkin and Robert Karplus (1986), and Bill Kyle and Jim Shymansky (1989) addressed the crucial process of conceptual change and science teaching and set the stage for the design and implementation of instructional models in curriculum programs. At BSCS we had to meet the challenge of translating the findings and insights from the aforementioned individuals to something understandable, usable, and manageable by science teachers. In the late 1980s, we created the BSCS 5E Instructional Model, which I will return to later in the discussion.

Finding 2 reminds us that any discipline is based on a structure of facts and concepts. Although this idea at first

seems obvious, what is not so obvious is that textbooks and classroom instruction often disregard the structure of disciplines in the information that is conveyed to students. Not only must these structures be made explicit, but students must also be taught how to retrieve information about the discipline. Like many other educational recommendations, using a curriculum framework for instructional materials has historical connections to Jerome Bruner's (1960) idea of that 'structure of disciplines' should be the basis for science curricula.

Finding #3 tells us that a 'metacognitive' approach to instruction presents an additional element to the design of instructional materials. Michael Martinez (2006) recently elaborated on this aspect of student learning. Going beyond the introductory definition of metacognition as 'thinking about thinking', Martinez proposed the definition 'monitoring and control of thought' and the specific function of meta-memory and meta-comprehension, problem solving, and critical thinking. Martinez suggests three ways of introducing metacognitive strategies in science teaching and curricula. First is an obvious recommendation – students must have experiences that require metacognition. Second, teachers should model metacognitive strategies by 'thinking aloud' problem solving and inquiry-based activities. Finally, students should have opportunities to interact with other students. This suggests the need for group work and an inquiry-oriented approach to the science curriculum.

Using the key findings from *How Students Learn* (Donovan & Bransford, 2005), one can identify factors that are important for science teaching and the design of curriculum materials. I have done this in Table I, which is based on an original table prepared by several colleagues at BSCS (See, Powell, Short, & Landes, 2002).

Table I Design specifications for teaching and curriculum materials

Key findings from How Students Learn	Implications for science teaching	Requirements for curriculum materials
Students come to educational experiences with preconceptions.	Teachers should recognise preconceptions, engage the learner, facilitate conceptual change, and employ strategies that respond to students' prior knowledge.	Incorporation of information about common preconceptions in the process of conceptual change, and the means by which the curriculum can bring about conceptual change. Inclusion of structured sequences of experiences that will elicit challenge and provide opportunities to change preconceptions.
Students should develop a factual knowledge based on a conceptual framework.	Teachers should have a conceptual understanding of science and the appropriate factual knowledge aligned with the concepts.	Base the curriculum on major concepts of science. Connect facts to the organising concepts. Provide relevant experiences to illustrate the concepts and opportunities to transfer concepts to new situations.
Students can take control of their learning through metacognitive strategies.	Teachers should make goals explicit and provide class time and opportunities to analyse progress toward those goals. Teachers should model metacognitive 'think aloud' strategies.	Make goals explicit in materials. Integrate metacognitive skills development into activities. Use small group activities as part of instructional units.

Implications of the findings from cognitive science suggest the need for systematic instructional strategies. The next section describes an instructional model used in contemporary BSCS.

The BSCS 5E Instructional Model

Since the late 1980s, BSCS has used an instructional model consisting of the following phases: engagement, exploration, explanation, elaboration and evaluation. The instructional emphasis for each phase of the model is described in Table 2.

Table 2 The BSCS 5E Instructional Model

Phase	Summary of emphasis
Engagement	Strategies or activities designed to elicit thoughts or actions by the student that relate directly to the lesson's objective.
Exploration	Experiences where students' current understandings are challenged by activities, discussions and currently held concepts to explain experiences.
Explanation	Presentations of scientific concepts that change students' explanations to align with scientific explanations.
Elaboration	Activities that require the application and use of scientific concepts and vocabulary in new situations.
Evaluation	Culminating activity that provides the student and teacher with an opportunity to assess scientific understanding and intellectual abilities.

Although the BSCS model was created prior to the NRC synthesis of cognitive research, that research provides support for the model. Following is a quotation from *How People Learn* (Bransford, Brown, & Cocking 2000).

An alternative to simply progressing through a series of exercises that derive from a scope and sequence chart is to expose students to take major features of a subject domain as they arise naturally in problem situations. Activities can be structured so that students are able to explore, explain, extend, and evaluate their progress. (p. 172)

The quotation presents a research-based recommendation that uses terms to describe an instructional sequence that very closely parallels the BSCS 5E Instructional Model. The BSCS model provides experiences and time for students to recognise the inadequacy of their current ideas, to explore new ways of explaining the world, to reflect on their thinking, and to construct new conceptions of the natural world.

In 2006, the NRC published *America's Lab Report: Investigations in High School Science*. This report further supports the use of instructional models such as that used by BSCS. In the analysis of

laboratory experiences, the committee also applied results from cognitive research. Researchers have investigated the sequencing of science instruction, including the placement and role of laboratory experiences, as these sequences enhance student learning. The NRC committee proposed the phrase 'integrated instructional units'.

Integrated instructional units interweave laboratory experiences with other types of science learning activities, including lectures, reading, and discussion. Students are engaged in forming research questions, designing and executing experiments, gathering and analyzing data, and constructing arguments and conclusions as they carry out investigations. Diagnostic, formative assessments are embedded into the instructional sequence and can be used to gauge the students' developing understanding and to promote their self-reflection on their thinking. (p. 82)

The BSCS 5E Instructional Model meets the criteria for integrated instructional units described above. Note also the inclusion embedded assessments and the connection of those experiences to students' self-reflection, or

metacognition. This recommendation aligns explicitly with the evaluation phase of the BSCS model. However, each phase of the instructional model provides an opportunity for embedded assessment. Each phase allows teachers and students to assess different aspects of the students' growing understanding of science and abilities of scientific inquiry.

Designing and developing curriculum materials at BSCS

Since the mid-1980s, curriculum development at BSCS has been initiated with a design study. These studies take about a year to conduct and involve a current review of science education at the grade level or levels under study; national and state priorities; careful consideration of curricular elements such as content, instructional strategies, use of laboratory investigations, tests and assessment exercises; and issues of implementation and professional development. The BSCS design studies result in a detailed curriculum framework, specifications for a new program, and a proposal to develop the curriculum. Table 3 lists recent design studies and the resulting core curriculum materials.

BSCS design studies have helped identify what to include in the program; for example, student materials, teacher editions, and implementation guides. Further, the design studies have clarified the goals and constraints as best we could prior to initial development. One of the important and enduring outcomes of this work has been the BSCS 5E Instructional Model.

Since the mid-1990s, BSCS has used the *National Science Education Standards* (NRC, 1996) as the basis for several aspects of curricular design; for example, content and professional development.

Table 3 BSCS design studies and the resulting core programs

<p>New Designs for Elementary School Science and Health (BSCS, IBM, 1989) <i>Science for Life and Living: Integrating Science, Technology, and Health</i> (1992) <i>BSCS Science T.R.A.C.S.</i> (1999) <i>BSCS Tracks: Connecting Science and Literacy</i> (2006)</p>
<p>New Designs for Middle School Science (BSCS, IBM, 1990) <i>Middle School Science & Technology</i> (1994, 1999)</p>
<p>Developing Biological Literacy (BSCS, 1993) <i>BSCS Biology: A Human Approach</i> (1997, 2003, 2006) <i>Biological Perspectives</i> (1999, 2006)</p>
<p>Making Sense of Integrated Science: A Guide for High Schools (BSCS, 2000) <i>BSCS Science: An Inquiry Approach (9–11)</i> (2006) <i>BSCS Science: An Inquiry Approach (6–8)</i> (proposed)</p>
<p>A Design Study for a Capstone Biology Course (BSCS, 2006)</p>

Beginning in the late 1990s, BSCS incorporated the backward design process described by Grant Wiggins and Jay McTighe in *Understanding by Design* (2005). In this process, we begin with a clear statement about what we want students to learn (an enduring understanding based on the content standards). Next, we determine what will serve as acceptable evidence of student attainment of that targeted understanding. Then, we decide what learning experiences would most effectively develop students' knowledge and understanding of the targeted content.

The BSCS 5E Instructional Model provides a concrete example of this process. After identifying the enduring understanding and stating the content outcomes, we go to the 'evaluate'

phase and design an activity that would assess students' knowledge and understanding of the content. After clarifying the desired outcomes and means to assess for those outcomes, we design and develop experiences that will provide students with the opportunities to learn the content. This process is interactive as it may result in further refinement of the evaluation activity and activities in other phases of the instructional model. Table 4 summarises this process.

A contemporary example

This discussion centers on an example, *BSCS Science: An Inquiry Approach*. This program is based on the design study, *Making Sense of Integrated Science* (BSCS, 2000) and is currently under development (funded by the National Science Foundation in 2000). The program has been conceptualised as a standards-based science program for grades 9 to 11. We explicitly used the *National Science Education Standards* (NRC, 1996) as the conceptual basis for designing and developing this program (see Table 5). Each year of

the program begins with a two-week 'Science as Inquiry' unit and is followed by three core units (eight weeks each): Life Science, Earth–Space Science, and Physical Science. In each of these core units, the first several chapters are devoted to helping students build conceptual understanding of the core concepts. The last chapter helps the students understand how these core concepts play a part in problems and events in the integrated setting of the natural world. The final unit uses problems and projects that are relevant to the lives of high school students to develop an integration of ideas across the sciences.

The design of the program units and lessons builds a conceptual foundation and introduces factual knowledge through the use of meaningful activities that are structured by the BSCS 5E Instructional Model. Table 5 displays the conceptual framework.

The use of a conceptual framework and an instructional model accommodates the research on learning discussed in earlier sections (Bransford, Brown, & Cocking, 2000; Donovan & Bransford, 2005).

Table 4 The Backward Design Process and the BSCS 5E Model

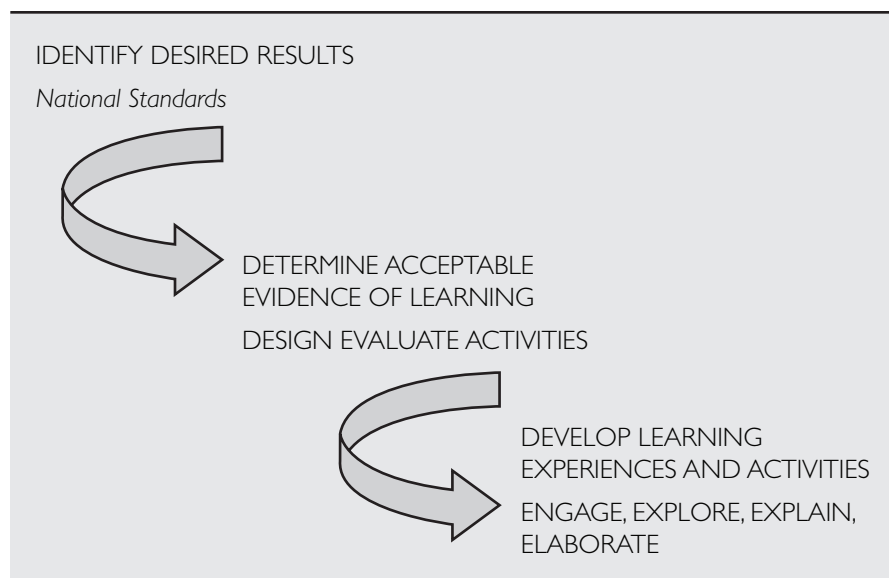


Table 5 BSCS Science: An Inquiry Approach Framework for Grades 9–11

Units	Major concepts addressed at each grade level		
	9	10	11
	Abilities necessary to do, and understandings about, scientific inquiry with a focus on:		
Science as Inquiry	<ul style="list-style-type: none"> • Questions and concepts that guide scientific investigations 	<ul style="list-style-type: none"> • Design of scientific investigations • Communicating scientific results 	<ul style="list-style-type: none"> • Evidence as the basis for explanations and models • Alternative explanations and models
Physical Science	<ul style="list-style-type: none"> • Structure and properties of matter • Structure of atoms • Integrating chapter 	<ul style="list-style-type: none"> • Motions and forces • Chemical reactions • Integrating chapter 	<ul style="list-style-type: none"> • Interactions of energy and matter • Conservation of energy and increase in disorder • Integrating chapter
Life Science	<ul style="list-style-type: none"> • The cell • Behavior of organisms • Integrating chapter 	<ul style="list-style-type: none"> • Biological evolution • Molecular basis of heredity • Integrating chapter 	<ul style="list-style-type: none"> • Matter, energy, and organization in living systems • Interdependence of organisms • Integrating chapter
Earth–Space Science	<ul style="list-style-type: none"> • Origin and evolution of the universe • Origin and evolution of the Earth system • Integrating chapter 	<ul style="list-style-type: none"> • Geochemical cycles • Integrating chapter 	<ul style="list-style-type: none"> • Energy in the Earth system • Integrating chapter
Science in a Personal and Social Perspective, Science and Technology	<ul style="list-style-type: none"> • Personal and community health • Natural and human-induced hazards • Abilities of technological design 	<ul style="list-style-type: none"> • Population growth • Natural resources • Environmental quality 	<ul style="list-style-type: none"> • Science and technology in local, national, and global challenges • Understandings about science and technology
	The following standards are addressed throughout grade levels and units: Science as a human endeavor Nature of science History of science		

Evidence of student learning

A national field test of BSCS Science: An Inquiry Approach was conducted from January to June 2002. The field test comprised urban, suburban, and rural classrooms across 10 states, 31 teachers, 64 classes, and nearly 1600 students. Among the findings, several

stand out with respect to the quality and effectiveness of the instructional materials and student achievement.

First, overall results from pre- and post-tests were tracked per student in a total of 1550 paired results. For all pre-post tests, the results demonstrated strong and statistically significant gains in student achievement. Average student

gains at both 9th and 10th grade levels were between 20 and 25 per cent.

Second, for both grade levels, classes characterised as having students with ‘general ability,’ ‘high ability,’ and classes where these abilities were ‘mixed’, each demonstrated a significant increase from pre-test to post-test, independent of ability level of students (See Figures 1 and 2) (Coulson, 2002).

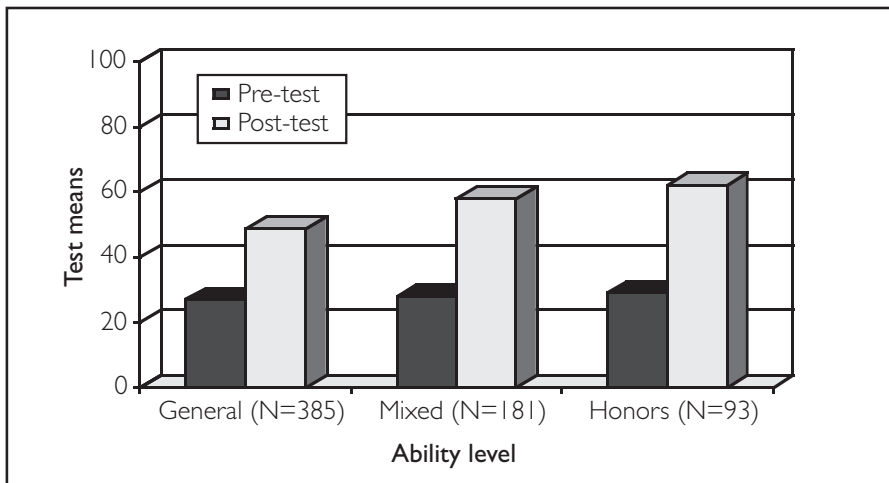


Figure 1 9th grade test score means by ability level

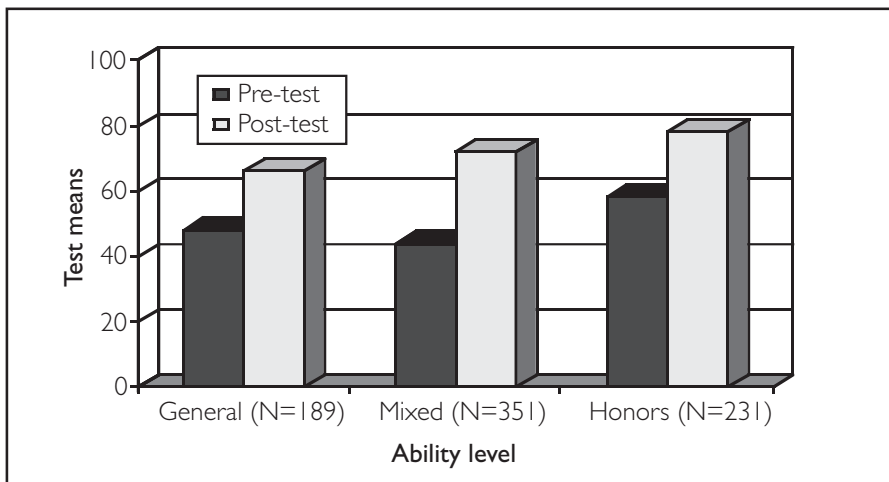


Figure 2 10th grade test score means by ability level

As part of a classroom-based study, student achievement was correlated with level of fidelity of teacher implementation. Based on classroom observations by BSCS staff, the external evaluator used an observation protocol with high inter-rater reliability to assess the degree of fidelity. Teachers demonstrating high fidelity of use of the instructional materials were considered 'high implementers'. Teachers who were teaching the materials with somewhat less fidelity or significantly less fidelity were considered 'medium' or 'low' implementers, respectively. After teachers were assigned to an

implementation category, their student test scores were correlated with the teacher's level of implementation.

The results indicate that both 9th and 10th grade students learned more from teachers who taught the materials with medium and high fidelity than from teachers who taught the materials with significantly less fidelity (Coulson, 2002). It is encouraging, however, that students still learned from the materials even when they were in classrooms with teachers identified as low implementers. This finding points to the quality of our student materials as well as importance of our in-depth materials for teachers.

The BSCS Science: An Inquiry Approach phase two field-test of the 10th grade curriculum was carried out in 8 states, with 10 teachers and their students. The field-test results yielded strong, significant gains ($p < .001$) on all items in all chapter tests. When items were combined to create a composite score for the chapter, the gains remained significant. In addition, when scores were disaggregated by gender and socioeconomic status (students receiving free or reduced lunch verse those not receiving free or reduced lunch); there was no significant difference between groups (See Figures 3, 4 and 5) (Stuhlstaz, 2006).

Similar results were noted during the phase one of the field test, where statistically significant gains were noted across both 9th and 10th grade paired pre- and post-test results from over 1500 students.

How teachers learn

So far my focus has been on the design and development of curriculum materials. It is the case that the optimisation of contemporary curriculum materials requires new and different approaches to teaching. Although the idea was not entirely new (Bruner, 1960), Deborah Ball and David Cohen (1996) made and elaborated connections between teacher learning and curriculum materials, especially for reform-oriented programs. The requirements for effective implementation of new programs requires more than an introductory workshop. Teachers must understand the science content of the curriculum, understand the importance of the instructional sequences, make use of different teaching strategies, as well as appreciate the subtleties of responding to students' preconceptions in order to facilitate conceptual change.

There is a need to complement professional development experiences

and teacher learning through carefully designed curriculum materials. Promoting teacher learning through instructional materials has been referred to as educative curriculum materials (Schneider & Krajcik, 2002; Davis & Krajcik, 2005). Beyond the components designed for students, curricular materials can be designed so they contribute to science teachers' development of science subject matter, knowledge and use of instructional models and strategies, and pedagogical content knowledge of science topics and inquiry.

It would be an overstatement to indicate that BSCS has achieved all it could in the design and development of science curriculum. I do believe, however, it is accurate to indicate we have continually evolved in directions that optimise curriculum materials for teachers' effective use.

Conclusion

I began with the question – How can curriculum materials enhance science teaching and student learning? Based on a contemporary understanding of how students learn science, I used the processes of design and development of curriculum materials at BSCS to answer the question. That answer can be summarised in the following way. First, pay close attention to the criteria for student learning and the appropriate translation of those requirements to curriculum materials. Second, use an instructional model that provides opportunities and time for conceptual change and development of cognitive abilities. Third, use 'backward design' for the process of designing and developing the scope and sequence of the curriculum. Finally, incorporate a means to enhance teachers' knowledge base, including subject matter, pedagogical content knowledge, and teaching strategies.

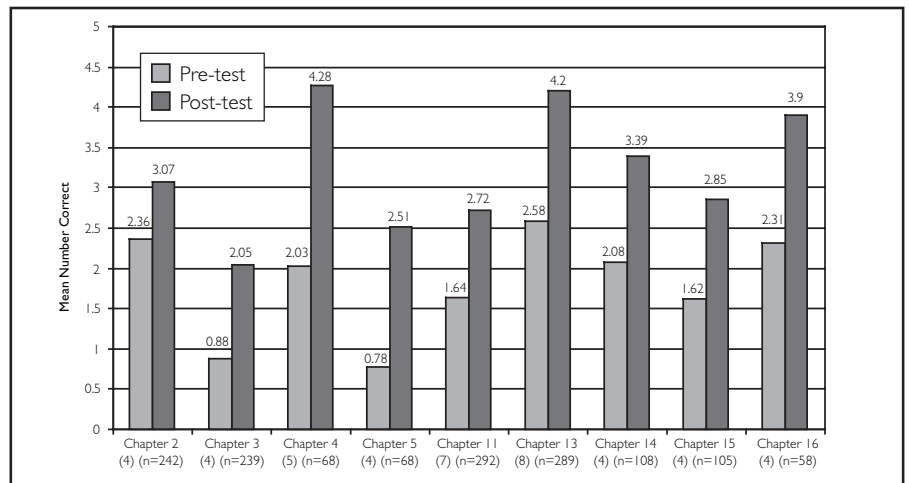


Figure 3

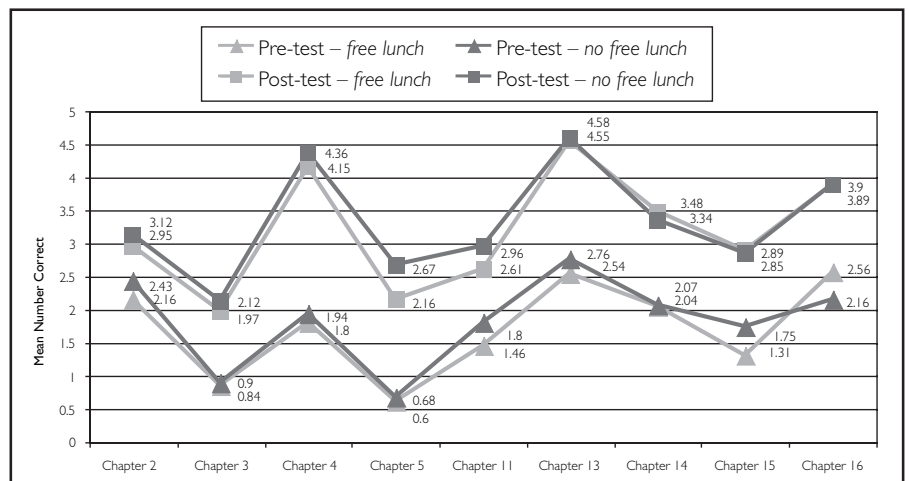


Figure 4

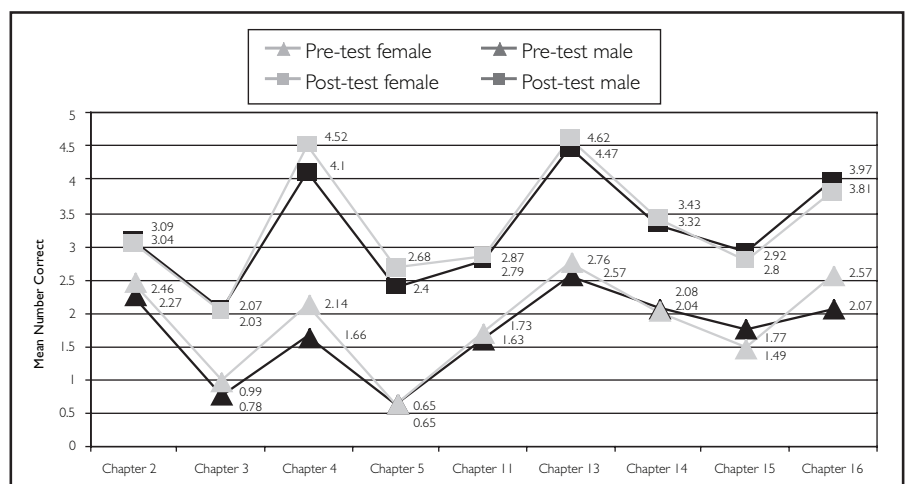


Figure 5

The complementarity of enhancing science teaching and student learning can be achieved through the design, development, and implementation of curriculum materials. Our work at BSCS provides a positive example of what it takes to make the potential of this statement a reality for teachers and students. I believe the BSCS experience can be generalised and applied by other curriculum development groups.

In the end, we want to provide curriculum materials that enhance science teaching and student learning.

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Concurrent papers

What science do students want to learn? What do students know *about* science?



Barry McCrae

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Barry McCrae joined ACER in 2001 as a Principal Research Fellow and leader of the Mathematics, Science and Technology test development team. Associate Professor McCrae was previously Deputy Head of the Department of Science and Mathematics Education at the University of Melbourne where he now holds an honorary appointment of Principal Fellow. At the University, Barry was involved with the pre-service and post-service training of mathematics and science teachers, both primary and secondary. During his career, Barry has made significant contributions at state and national levels in the fields of mathematics education and computer education.

At ACER Barry has undertaken key roles in a number of national and international projects, including directing state-wide assessments and producing the Australian report for the TIMSS 1999 Video Study of Year 8 mathematics teaching. Barry played a leading role in the PISA 2003 assessment of problem solving and managed framework and item development for the PISA 2006 assessment of scientific literacy. This included the conceptualisation and development of items for the optional computer-based assessment, and items to assess students' attitudes toward science. Barry is overall head of framework and item development for PISA 2009.

Abstract

In 2006, for the first time, science will be the major focus of the PISA assessment of 15-year-olds. A major innovation in PISA 2006 is that many of the science units contain one or two items designed to assess students' attitudes towards science – in particular, their interest in learning about science and their support for scientific enquiry. A second major innovation is that some of the items assess students' knowledge about science – that is, their knowledge of scientific methodology. This paper presents some field trial results that shed light on what science students want to learn, and how their knowledge about science compares with their knowledge of science (biology, chemistry, physics, Earth and space science).

PISA 2006 is the third cycle of the OECD Programme for International Student Assessment (PISA)¹ which is designed to measure how well 15-year-olds are prepared for life beyond school as they approach the end of compulsory schooling. PISA takes place every three years and covers the domains of reading, mathematical and scientific literacy. An ACER-led consortium has been responsible for the conduct of PISA since its inception in 2000. In 2006, for the first time, science will be the major focus of the assessment.

Reading literacy was the major assessment domain in PISA 2000 and mathematical literacy was the major focus in PISA 2003. PISA 2000 was conducted in 32 countries, including 28 OECD countries (OECD, 2001), and 41 countries participated in PISA 2003, including all 30 OECD countries (OECD, 2004).

A total of nearly half a million 15-year-olds representing 58 countries are being assessed in the main PISA 2006 study. A total of about 3000 students

from three of the countries (Denmark, Iceland and Korea) are also undertaking a computer-based assessment of science. In Australia, over 350 schools, drawn from both the government and non-government sectors in all states and territories, have been selected to take part in PISA 2006. During July and August, a random sample of up to 50 students from each chosen school will undertake the assessment – about 18,000 students overall.

PISA 2006 scientific literacy framework

In accordance with science's elevation to major domain status in 2006, the PISA science framework (OECD, in press²) has been significantly expanded over that used for the 2000 and 2003 assessments. The PISA 2006 Science Expert Group, chaired by Rodger Bybee, was responsible for the development of the framework.

PISA 2006 Definition of scientific literacy

For the purposes of PISA 2006, *scientific literacy* refers to an individual's:

- scientific knowledge and use of that knowledge to identify questions, to acquire new knowledge, to explain scientific phenomena, and to draw evidence-based conclusions about science-related issues;
- 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; and
- willingness to engage in science-related issues, and with the ideas of science, as a reflective citizen.

¹www.pisa.oecd.org

²The information in this paper about the framework is taken almost directly from the OECD publication.

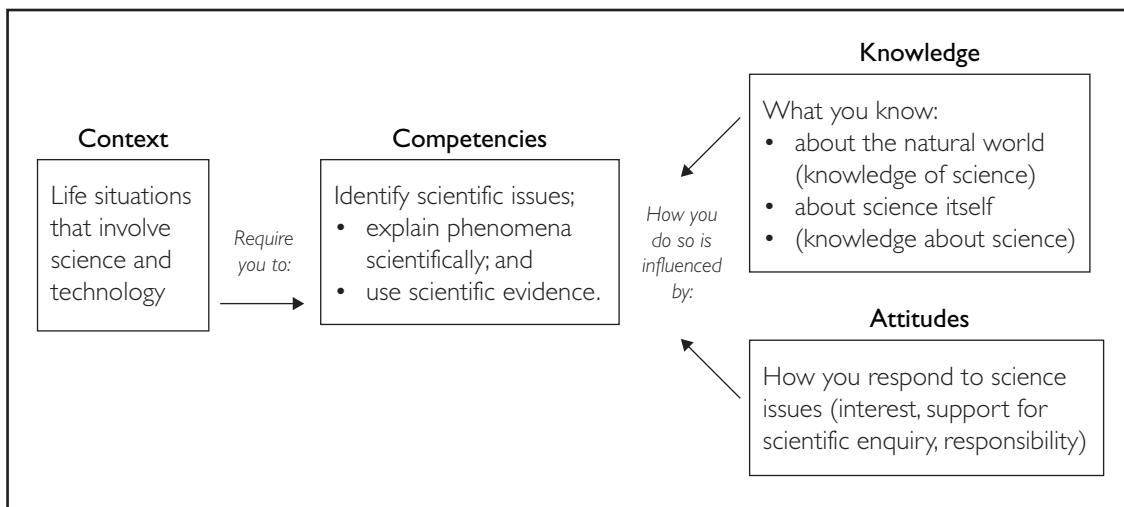


Figure 1 Framework for PISA 2006 science assessment

The previous PISA definition of scientific literacy has been enhanced to include aspects of individuals' attitudes towards science. The definition also gives more emphasis than before to an individual's understanding of the nature of science and to the role of science-based technology.

Organisation of the domain

For the purposes of assessment, the PISA 2006 definition of scientific literacy may be characterised as having the following four interrelated components as shown in Figure 1:

- Recognising life situations involving science and technology. This is the *context* for assessment.
- Understanding the natural world on the basis of scientific knowledge that includes both knowledge of the natural world, and knowledge about science itself. This is the *knowledge* component of the assessment.
- Demonstrating competencies that include identifying scientific issues, explaining phenomena scientifically, and using scientific evidence. This is the *competency* component.
- Indicating an interest in science, support for scientific enquiry, and

motivation to act responsibly towards natural resources and environments. This is the *attitudinal* dimension of the assessment.

Knowledge component

PISA 2006 will assess students' knowledge of science, selected from the major fields of physics, chemistry,

biology, and Earth and space science, and their knowledge about science. Knowledge about science refers to knowledge of the means ('scientific enquiry') and goals ('scientific explanations') of science. This is elaborated in Figure 2. Knowledge about science questions will constitute approximately 40 per cent of the cognitive assessment.

Scientific enquiry

- origin (e.g., curiosity, scientific questions)
- purpose (e.g., to produce evidence that helps answer scientific questions, current ideas/models/theories guide enquiries)
- experiments (e.g., different questions suggest different scientific investigations, design).
- data type (e.g., quantitative [measurements], qualitative [observations])
- measurement (e.g., inherent uncertainty, replicability, variation, accuracy/precision in equipment and procedures)
- characteristics of results (e.g., empirical, tentative, testable, falsifiable, self-correcting)

Scientific explanations

- types (e.g., hypothesis, theory, model, law)
- formation (e.g., data representation; role of extant knowledge and new evidence, creativity and imagination, logic)
- rules (e.g., must be logically consistent; based on evidence, historical and current knowledge)
- outcomes (e.g., produce new knowledge, new methods, new technologies; lead to new questions and investigations)

Figure 2 PISA 2006 knowledge about science categories

Attitudinal dimension

The PISA 2006 science assessment will evaluate students' attitudes in three areas: *Interest in science*, *Support for scientific enquiry*, and *Responsibility towards resources and environments* (see Figure 3). The student questionnaire will be used to gather data on students' attitudes in all three areas in a non-contextualised manner. Data concerning students' *Support for scientific enquiry*, and one aspect of their *Interest in science* (namely, their *Interest in learning about science*), also will be gathered by embedding Likert-style items in about two-thirds of the test units. The decision to assess students' attitudes towards science reflects the view expressed in the PISA science framework that they should be regarded as important *outcomes* of science education.

The 'scores' on the embedded attitudinal items will be used to construct scales for *Interest in learning about science* and *Support for scientific enquiry*. They will not be combined with the scores on the other test items to produce an overall score of scientific literacy.

PISA 2006 science test items

PISA science items are arranged in groups (units) based around a common stimulus. Two sample units, *Bread Dough* and *Health Risk?*, are included in the Appendix to this paper. The items shown were used in the field trial in 2005 as part of the item development process for the 2006 PISA main study but are *not* included in the final selection. Some of these items have undergone minor revision since the field trial and some of them have measurement properties that make them less than ideal for inclusion in an international test, but they are

nevertheless useful for illustrative purposes.

Question 1, 3 and 4 of *Bread Dough* assess the competency 'Explaining phenomena scientifically', and draw on students' knowledge of physical systems (in particular, chemistry). Question 2 requires students to recognise which variables need to be changed and which need to be controlled in an experiment and so it assesses students' knowledge *about science* (category: Scientific enquiry). The competency classification is 'Identifying scientific issues'.

The final item in *Bread Dough* (Question 5) is the only released item that was designed to assess students' *Support for scientific enquiry*. Like all attitudinal items, it is placed last in the unit in order that students engage with the context prior to providing an opinion on the three statements.

Attitudinal items are distinctively formatted to remind students that they have no correct answer and will not count in their test score. Question 3 of *Health Risk?* is an example of an item designed to assess students' *Interest in learning about science*. The other two items in *Health Risk?* assess students' knowledge about scientific enquiry. Question 1 requires students to make a judgement about the relevance of a scientific study and Question 2 requires the identification of relevant variables that were not controlled in the study. The competency involved in both questions is 'Using scientific evidence'.

Field trial results

During 2005, about 260 science items (70 units) were trialled for inclusion in the PISA 2006 assessment. The field trial was conducted in all 58 countries participating in PISA 2006 and involved over 95 000 students. In this section, some results of the field

trial are presented. Note, however, that convenience samples rather than random samples were employed in the field trial and so they cannot be regarded as representative samples of 15-year-old students. Accordingly, these results must be treated with caution and regarded as hypotheses to be investigated when analysing the main study results rather than as substantiated findings.

Students' attitudes towards science

Interest in learning about science: For the sample unit *Health Risk?*, above average interest was shown in the second and third statements of Question 3 but low interest was shown in the first statement. In general, students expressed most interest in learning about health or safety issues that they may encounter personally (e.g. 'Learning which diseases are transmitted in drinking water'), and least interest in learning about abstract scientific explanations (e.g. 'Learning about the different arrangements of atoms in wood, water and steel') and how scientific research is conducted.

This outcome is in agreement with that of Osborne and Collins (2001) who found that students are most interested in the aspects of science that they perceive as being relevant to their lives, and least interested in topics that they perceive as being of little relevance to themselves. Further support comes from the responses of students in England to the ROSE questionnaire³. Jenkins and Pell (2006) report that girls were most interested in learning about health-related issues, and that topics such as 'How crude oil is converted into other materials' held little interest for both boys and girls. However, the popularity of health-related issues was found to be not as strong for boys

³The Relevance of Science Education (ROSE) project is an international comparative study designed to gather and analyse information from 15-year-olds about their attitudes to science and technology and their motivation to learn about science and technology. See www.ils.uio.no/english/rose/

who expressed stronger interest in 'destructive technologies and events'.

Support for scientific enquiry: The 'personal relevance' influence was also the main factor here with most support being shown for investigation into health and safety issues (e.g. 'It is important to research how diseases are spread'), although a high level of support also was expressed for research that would assist the survival of endangered species. Least support was expressed for research that appeared to have little or no practical application (e.g. 'Studying fish in a tank is important even though the fish may behave differently in the wild').

Interestingly, students tended not to value scientists' explanations of everyday phenomena more than alternative explanations. For example, for *Bread Dough*, below average support was shown for the second and third statements and low support for the third statement.

Students' scientific knowledge

The field trial showed the six cognitive sample items included with this paper to be of moderate to high difficulty. The hardest items in the group were two of the three knowledge *about science* items, Question 2 of *Bread Dough* and Question 2 of *Health Risk?*. The easiest item, answered correctly by over 40 per cent of students, was Question 4 of *Bread Dough* which assesses understanding of the particle model of matter.

Internationally, no gender difference was apparent in the performance on the sample items or on the test overall. However, as shown in Figure 4, gender differences become apparent when performance is analysed according to the knowledge component of the items: physical systems (PS), Earth and space systems (ES), living systems (LS), and knowledge *about science*.

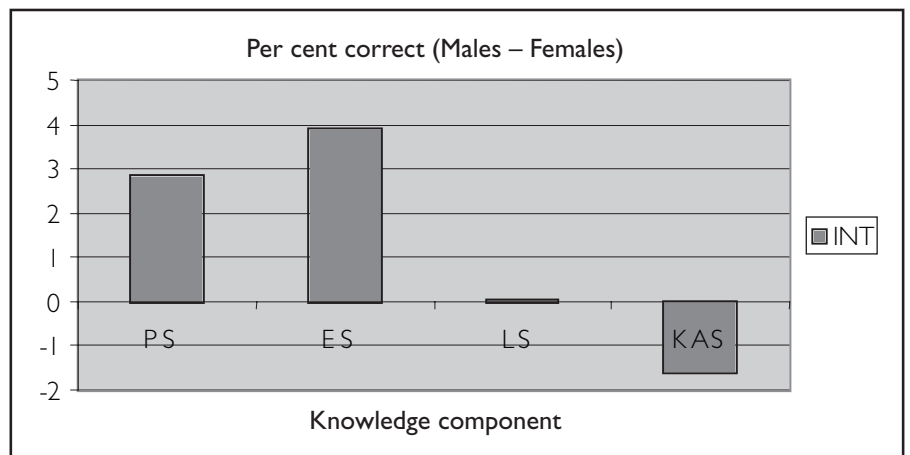


Figure 4 PISA 2006 field trial items per cent correct according to knowledge component

The gender difference pattern for the knowledge of science items is consistent with that found for Year 8 students in TIMSS 2002/03 (Martin, Mullis, Gonzalez, & Chrostowski, 2004). Of most interest, though, since this appears to be the first international assessment of students' knowledge *about science*, is that females outperformed males on these items.

Summary

Science is the major assessment domain for the first time in PISA 2006. The definition of scientific literacy has been expanded to include aspects of individuals' attitudes towards science and a much stronger emphasis than before is placed on individuals' understanding of the nature and methodology of science itself (their knowledge *about science*). An innovative aspect of the 2006 assessment is that items designed to assess students' 'interest in learning about science', and their 'support for scientific enquiry', are embedded in the test units.

The field trial conducted during 2005 in all 58 countries participating in PISA 2006 yielded some interesting preliminary results concerning students' attitudes and knowledge. Of particular interest is that girls outperformed boys on knowledge *about science* items. This and other field trial findings will be the

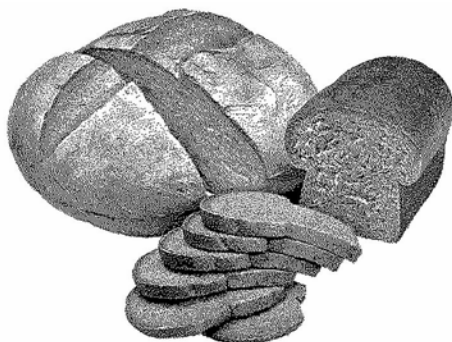
subject of closer scrutiny when the main study results become available throughout the second half of 2006.

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Appendix: PISA 2006 Sample Science Items

BREAD DOUGH



To make bread dough, a cook mixes flour, water, salt and yeast. After mixing, the dough is placed in a container for several hours to allow the process of fermentation to take place. During fermentation, a chemical change occurs in the dough: the yeast (a single-celled fungus) helps to transform the starch and sugars in the flour into carbon dioxide and alcohol.

Question 1: BREAD DOUGH

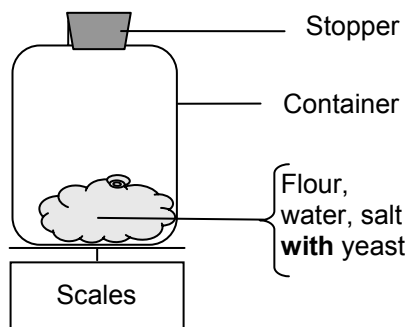
Fermentation causes the dough to rise. Why does the dough rise?

- A** The dough rises because alcohol is produced and turns into a gas.
- B** The dough rises because of single-celled fungi reproducing in it.
- C** The dough rises because a gas, carbon dioxide, is produced.
- D** The dough rises because fermentation turns water into a vapour.

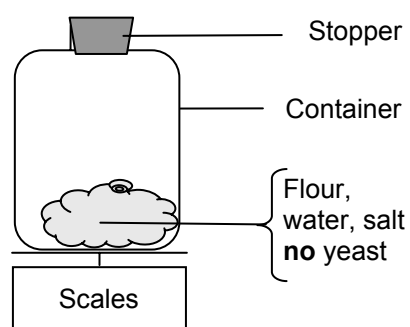
Question 2: BREAD DOUGH

A few hours after mixing the dough, the cook weighs the dough and observes that its weight has decreased.

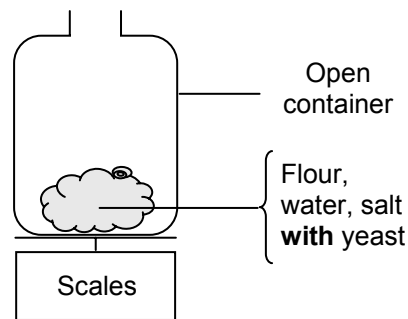
The weight of the dough is the same at the start of each of the four experiments shown below. Which **two** experiments should the cook compare to test if the **yeast** is the cause of the loss of weight?



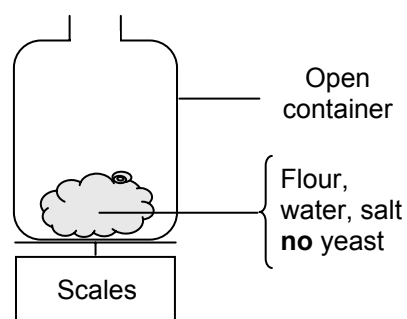
Experiment 1



Experiment 2



Experiment 3



Experiment 4

- A** The cook should compare experiments 1 and 2.
- B** The cook should compare experiments 1 and 3.
- C** The cook should compare experiments 2 and 4.
- D** The cook should compare experiments 3 and 4.

Question 3: BREAD DOUGH

In the dough, yeast helps to transform starch and sugars in the flour. A chemical reaction occurs during which carbon dioxide and alcohol form.

Where do the **carbon atoms** that are present in carbon dioxide and alcohol come from? Circle 'Yes' or 'No' for each of the following possible explanations.

Is this a correct explanation of where the carbon atoms come from?	Yes or No?
Some carbon atoms come from the sugars.	Yes / No
Some carbon atoms are part of the salt molecules.	Yes / No
Some carbon atoms come from the water.	Yes / No

Question 4: BREAD DOUGH

When the risen (leavened) dough is placed in the oven to bake, pockets of gas and vapours in the dough expand.

Why do the gas and vapours expand when heated?

- A Their molecules get bigger.
- B Their molecules move faster.
- C Their molecules increase in number.
- D Their molecules collide less frequently.

Question 5: BREAD DOUGH

How much do you agree with the following statements?

Tick only one box in each row.

	<i>Strongly Agree</i>	<i>Agree</i>	<i>Disagree</i>	<i>Strongly Disagree</i>
a) I would trust a scientific report more than a baker's explanation of the weight loss in dough.	<input type="checkbox"/> ₁	<input type="checkbox"/> ₂	<input type="checkbox"/> ₃	<input type="checkbox"/> ₄
b) Chemical analysis is the best way to identify the products of fermentation.	<input type="checkbox"/> ₁	<input type="checkbox"/> ₂	<input type="checkbox"/> ₃	<input type="checkbox"/> ₄
c) Research into the changes that occur when food is prepared is important.	<input type="checkbox"/> ₁	<input type="checkbox"/> ₂	<input type="checkbox"/> ₃	<input type="checkbox"/> ₄

HEALTH RISK?

Imagine that you live near a large chemical factory that produces fertilisers for use in agriculture. In recent years there have been several cases of people in the area suffering from long-term breathing problems. Many local people believe that these symptoms are caused by the emission of toxic fumes from the nearby chemical fertiliser factory.

A public meeting was held to discuss the potential dangers of the chemical factory to the health of local residents. Scientists made the following statements at the meeting.

Statement by scientists working for the chemical company

'We have made a study of the toxicity of soil in the local area. We have found no evidence of toxic chemicals in the samples we have taken.'

Statement by scientists working for concerned citizens in the local community

'We have looked at the number of cases of long-term breathing problems in the local area and compared this with the number of cases in an area far away from the chemical factory. There are more incidents in the area close to the chemical factory.'

Question 1: HEALTH RISK?

The owner of the chemical factory used the statement of the scientists working for the company to argue that 'the emission fumes from the factory are not a health risk to local residents'.

Give one reason, other than the statement by scientists working for the concerned citizens, for **doubting** that the statement by scientists working for the company supports the owner's argument.

.....

.....

Question 2: HEALTH RISK?

The scientists working for the concerned citizens compared the number of people with long-term breathing problems close to the chemical factory with those in an area far away from the factory.

Describe one possible difference in the two areas that would make you think that the comparison was not a valid one.

.....

.....

.....

Question 3: HEALTH RISK?

How much interest do you have in the following information?

Tick only one box in each row.

	<i>High Interest</i>	<i>Medium Interest</i>	<i>Low Interest</i>	<i>No Interest</i>
a) Knowing more about the chemical composition of agricultural fertilisers	<input type="checkbox"/> ₁	<input type="checkbox"/> ₂	<input type="checkbox"/> ₃	<input type="checkbox"/> ₄
b) Understanding what happens to toxic fumes emitted into the atmosphere	<input type="checkbox"/> ₁	<input type="checkbox"/> ₂	<input type="checkbox"/> ₃	<input type="checkbox"/> ₄
c) Learning about respiratory diseases that can be caused by chemical emissions	<input type="checkbox"/> ₁	<input type="checkbox"/> ₂	<input type="checkbox"/> ₃	<input type="checkbox"/> ₄

Inquiry in science classrooms: Rhetoric or reality?



Denis Goodrum

University of Canberra

Denis Goodrum has been involved in many national and international activities in science education. In 1998, Professor Goodrum was a visiting scholar at the National Research Council in Washington DC working on a project examining inquiry and the National Science Education Standards.

During the 1990s, he was Project Director of the National Primary School Project that was underwritten by the Australian Academy of Science. This project resulted in the curriculum resource *Primary Investigations* and an associated professional development model and package.

In 2000, he led a research team that completed a significant and extensive national study for the Federal Government into the status and quality of teaching and learning of science in Australian schools. Recently he was Project Director of the *Collaborative Australian Secondary Science Project (CASSP)* which evaluated a teacher change model through the development of integrated curriculum and professional development resources. Presently he is responsible for two national projects *Science by Doing* and the *Australian Science Education Framework*.

He has extensive administrative experience in so far as he has carried out the roles of Head of Department, Head of School, and Dean of Faculty within the university sector. He has served on numerous state and national Boards including Board of the Australian Deans of Education, Scitech and the ACT Curriculum Renewal Taskforce.

Besides managing large national projects, he has also been responsible for a variety of international projects including a Mauritius teacher education project. Other countries with which he has had professional involvement include Thailand, China, Malaysia, Singapore, Nigeria, the Seychelles, Burma, the USA, the Maldives, the Philippines, Botswana, Canada and the UK.

Abstract

If one scans the science curriculum statements of the Australian States and Territories, one will find a consistent theme of inquiry and inquiry pedagogy pervading these documents. With the rhetoric of these policy documents and our sense of science education history, one would expect to see inquiry as an integral part of our secondary science classrooms. Unfortunately, this is not the case. Many secondary students are taught science that is perceived by them to be neither relevant nor engaging. Furthermore, traditional didactic teaching methods that offer little challenge, excitement or opportunities for engagement are common. There is a considerable gap between the intended curriculum as described in the various curriculum documents and the actual curriculum experienced by students. This presentation describes a national pilot study, the *Collaborative Australian Secondary Science Program (CASSP)*, which attempts to provide better information for responding to the challenge of converting the inquiry rhetoric into classroom reality.

Introduction

If one scans the science curriculum statements of the Australian States and Territories, one will find a consistent theme of inquiry and inquiry pedagogy pervading these documents. This theme is also strongly reflected in the new national Science Statement of Learning. Such a fact should surprise no one, since the importance of inquiry has resonated through Australian science education circles for the past 40 years. The curriculum resources of the 1970s like *Web of Life* and *ASEP* were developed from an inquiry pedagogical perspective.

With the rhetoric of these policy documents and our sense of science

education history, one would expect to see inquiry as an integral part of our secondary science classrooms. Unfortunately, this is not the case. In the 2001 review of science teaching and learning in Australian schools, a disappointing picture of secondary science is described (Goodrum, Hackling, & Rennie, 2001). Many secondary students are taught science that is perceived by them to be neither relevant nor engaging. Furthermore, traditional didactic teaching methods that offer little challenge, excitement or opportunities for engagement are common. There is a considerable gap between the intended curriculum as described in the various curriculum documents and the actual curriculum experienced by students.

How do we convert rhetoric into reality?

The key to educational innovation, reform and improvement is the teacher. It is now generally accepted that to improve learning in our schools we need more and better teacher professional learning.

Professional learning and development cover a wide range of courses and training activities as well as a variety of 'on the job' experiences. Loucks-Horsley, Hewson, Love and Stiles (1998) in their book, *Designing Professional Development for Teachers of Science and Mathematics*, outline 15 different strategies that are used to undertake professional learning.

Using a meta-analysis approach Tinoco, Lee, Fletcher and Barufaldi (2004) suggest that the professional learning strategies outlined by Loucks-Horsley et al. (1998) impact on science student learning to different degrees. On the basis of an analysis of 37 professional learning studies, there was evidence of different effects on student learning of

science. The results of this research are summarised in Table 1.

High impact strategies on student learning were those associated with Curriculum Replacement and Curriculum Development, while medium impact approaches involved Curriculum Implementation and Partnerships. A range of strategies appeared to have a limited impact on student science learning including projects associated with Partnerships with scientists.

Table 1 Impact of professional learning on student learning

High Impact	Curriculum Replacement Curriculum Development
Medium Impact	Curriculum Implementation Partnerships
Low Impact	Workshops, seminars Partnership with scientists Case discussion Inquiry
No impact	Action research

Source: Tinoca (2004)

Perhaps the most surprising result was that the Action research strategies had no impact on student learning. In Australia, considerable funds have recently been invested in this approach through programs like the Quality Teacher Program. The important implication is that we need to investigate more fully the impact of these approaches before allocating substantial funds.

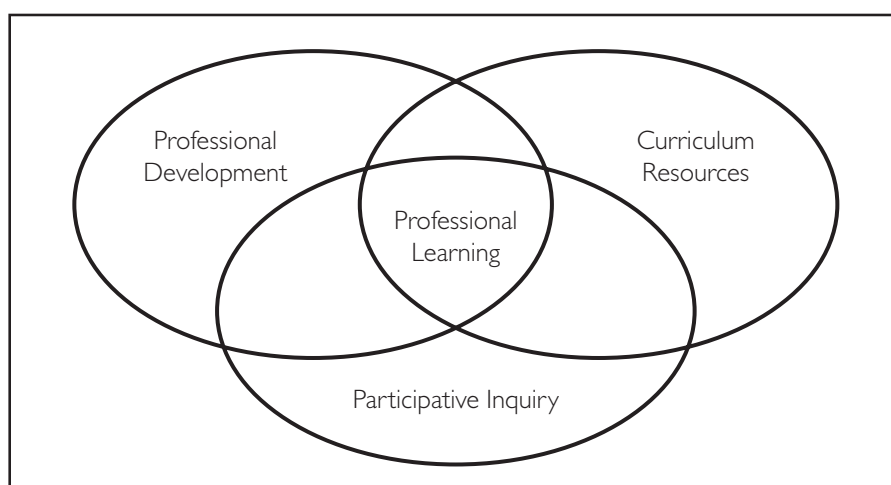


Figure 1 The role of professional development, curriculum resources and participative inquiry in professional learning

Collaborative Australian Secondary Science Program (CASSP)

One attempt to gather better information and respond to the challenge of converting rhetoric into reality was the pilot study, Collaborative Australian Secondary Science Program (CASSP). CASSP was developed through considerable national discussion among researchers and stakeholders over a number of years. It is based on a simple model.

The unique feature of CASSP was to facilitate professional learning by the implementation of an integrated set of curriculum, professional development and participative inquiry resources (see Figure 1). These resources provided a concrete basis for illustrating the methods by which a teacher could teach science in an inquiry-based manner, engaging students in relevant and engaging experiences of science and developing scientific literacy. The Australian government funded the extensive national pilot study. The project was managed by Curriculum Corporation in collaboration with

the Australian Science Teachers' Association, the Australian Academy of Science and Edith Cowan University with the support of the state and territory education departments.

The CASSP project is an example of both Curriculum Replacement and Curriculum Development as outlined by the framework of professional learning constructed by Loucks-Horsley et al. (1998).

Purpose and design of CASSP project

The purpose of the pilot project was to:

- demonstrate that national collaborative procedures and processes could be used effectively to develop resources and implement them through the structures and processes in place in each of the States and Territories;
- evaluate the effectiveness of the CASSP model in changing and improving teaching and learning in science.

To meet this purpose, it was decided to develop an *Energy and Change* unit with three modules of *Light, Electricity*

and *Energy* with a flexibility of structure and content that enabled teachers to choose from these modules. It was also decided that the focus of the pilot project would be:

- student-centred approaches to learning;
- inquiry and investigative approaches; and
- formative and authentic approaches to assessment.

The pilot program was designed for implementation over a time scale of one school term with a whole-of-department approach to professional development. Each State identified the schools within that State that should be considered for involvement in the project. The project took place in term three of 2002 with 28 schools from six States involving 122 teachers and approximately 3,000 students.

There were three face-to-face professional development sessions during the course of the project. The initial professional development activity took place over two days towards the end of term two in each State, with the exception of Tasmania which has a three-term year and therefore undertook the initial PD activity in the middle of term two. The aim of these sessions was to acquaint the teachers with the teaching practices that were the focus of the pilot and with the resources and the skills necessary to implement these changes in teaching practice.

The second PD session occurred mid-term with an emphasis on assessment and developing skills for assessing student work in terms of conceptual development. The full day of activities also provided an opportunity for teachers to examine common concerns and devise strategies for meeting these concerns. A final half-day debriefing session was held in the last week of term three.

Evaluation and results

At the beginning of each of the three professional development sessions a questionnaire was completed by the participating teachers. A simple questionnaire was also completed by students at the end of the unit. In Western Australia, four teachers agreed to allow a researcher to observe their lessons throughout the trial.

Data from the first questionnaire suggested that the initial response to the project by the majority of teachers was positive. As in all innovations, there are inevitable concerns but these seemed to be balanced by the perceived potential benefits. Approximately one-fifth of the teachers appeared to hold traditional views about science teaching. These views included didactic approaches to teaching, significant amounts of memorisation of facts and explanations, and a concentration on summative forms of assessment.

The driving forces for change were identified as the initial professional development sessions and the student resource. A number of teachers, however, felt that the student resource required more theoretical or factual information. The teacher resource was considered less useful with a quarter of teachers not using the book at the initial stages of the project.

The project generated much discussion and collegial interaction among teachers at an informal level, however, the suggested formal participative inquiry sessions did not occur in many schools because of the pressures of time. Where formal participative inquiry discussion occurred, they were very useful in supporting teachers to resolve difficulties.

Data from the questionnaires indicated there was a change from teacher-directed teaching to more student-centred learning:

- 50% of teachers said that their students copied less notes from the board; and
- 33% of teachers spent less time on teacher explanation.

The decrease in teacher-directed activities was offset by an increased use of student-centred strategies initiated by the teachers. These included:

- small group work and discussions (63% of teachers);
- cooperative learning groups (53%);
- open-ended questions and wait time (51%);
- conceptual explanation after activity and experience (57%);
- investigations (53%);
- more exposure to fewer concepts (55%) and
- greater use of formative (39%) and diagnostic assessment (61%).

The response of the teachers was very positive with 90 per cent wanting to see the project continue. A large majority (88%) wanted curriculum resources developed for other topics. From discussions with teachers, it was obvious that the project was demanding both in terms of time needed to develop student understanding and the added stress of classroom management in unfamiliar student-centred activities.

Most teachers expressed a preference for the traditional print form for student resources and were less inclined to use electronic forms of delivery. This was mainly due to the fact that many schools did not have adequate computer hardware or facilities to handle electronic delivery of curriculum materials.

Data from the student survey indicate that one-third of students reacted very positively to the science they experienced during the trial while half the students were ambiguous in their responses and the final sixth of the students were negative. In the national

review of science teaching and learning, only about 20 per cent of secondary students reported that their science was relevant or useful to them. The results of the trial would suggest the trial students' interest in science was greater than the students surveyed in the national survey.

For the four case study teachers, observations suggest the teachers and their students gained from the project. The teachers felt they had the opportunity to reflect on their classroom practice and refine their teaching skills to varying degrees. Again these feelings were borne out by the classroom observations.

The results and experiences of this study highlight a number of issues.

Collaboration

All six States successfully participated in the implementation of the project. The States, through consensus, determined the specific priorities of the professional development program and the nature of the curriculum resources. At each stage of development of the pilot materials, all the States and Territories were provided with draft materials and with the opportunity to provide feedback. Changes were made as a result of feedback. In the early part of the project this feedback resulted in a new approach to the development of the curriculum resources. This new approach caused a delay in the implementation of the program but schools and States were able to accommodate the delay. The program was successfully implemented in all States. No teachers in any of the States indicated that the resources were inappropriate or not compatible with what was happening within their State.

Effectiveness of the CASSP model

The results from the study showed that the trial had a significant impact on teacher behaviour with respect to

the project's focus: student-centred approaches to learning, inquiry and investigative approaches, formative and authentic approaches to assessment.

The data showed that change occurred in teachers' pedagogy when they were supported with an integrated program professional development and exemplar curriculum resources and used a collegial team problem solving approach. Despite the limited time for the trial, the results indicated the value of the approach. Due to the limited time one would, however, question the sustainability of these changes and their transferability to other units.

The question of covering content versus developing understanding

There was an issue concerning, in simple terms, the perceived need to memorise content in some classes considered to be composed of identified high-achievers. Many high-achieving students felt comfortable with memorising clearly delineated science content because under current assessment regimes this could result in high grades from examinations. The less structured inquiry and investigative approach did not necessarily generate bodies of information that could be memorised. Consequently, some of these students did not believe they were learning, because they equated learning with memorisation of content.

Besides the differing views on the nature of science and science teaching that such an attitude reflects, one also needs to consider the level of skills required for student-centred conceptual learning. To synthesise the ideas that arise from student activity through questioning is a challenge. A teacher needs to bring together the understandings that emerge from inquiry through summarising class

discussion and be able to generate summary statements that are meaningful to students. Such a skill is challenging but critical for making inquiry approaches effective.

While feedback suggests the project was viewed as being successful in typical classes, the perceived success was diminished in some classes of identified high-achieving students because of the preference for memorising information for exams. The dilemma between learning for memorisation and learning for understanding needs to be thought through carefully especially in terms of how a change in attitude can be achieved in classes for the high-achieving student.

The resources

All teachers in the project used the student resource that was supplied in hard copy to every participating student. Some teachers followed it without variation while most adapted it and in some cases added to it. Some teachers indicated that they seldom used the teacher resource book, which was also provided in hard copy to participating teachers. It would appear that the website was used least of all the resources. The website was mainly used to access the assessment items that were only provided electronically. The evidence would suggest that the student resource was a powerful driver of teacher change. It enabled teachers to implement and experience changed practices that were the focus of the professional development program.

The feedback from teachers indicated that 90 per cent of teachers wanted the student resource in print form while 76 per cent also wanted the teacher resource in print form. The dilemma facing those who make decisions about the format of student and teacher curriculum resources concerns the question of how long the reliance on print form will continue. Many schools

indicated that they did not have adequate computer hardware or facilities to handle electronic delivery of curriculum resources. This technological lag will change over time but it may take 5 or even 10 years before digital curriculum resources will be commonly accepted.

Leadership

Heads of departments have, in most schools, a significant influence over what happens in the school. The experiences of this project reinforced that important principle. One of the disappointing aspects of the project was that few schools undertook formal participative inquiry sessions. One of the suggested reasons was the time pressure that teachers were experiencing. The project was an extra demand on teachers who were under stress because of the numerous demands and expectations made of them. Another contributing factor was the role of the head of department. Valuable formal participative inquiry discussion occurred in one of the case study schools, as a result of leadership at the school.

Future directions

As a result of this study and other research, there is a new major project being planned. The proposed secondary science project is called *Science by Doing*. The planning is occurring during 2006 and is being managed by the Australian Academy of Science with funding by the Federal Government. With hope and a great deal of cooperation and insight, perhaps, the rhetoric may eventually become reality.

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Addressing the looming crisis in suitably qualified science teachers in Australian secondary schools



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Kerri-Lee Harris is a higher education researcher at the Centre for the Study of Higher Education (CSHE) at the University of Melbourne. Dr Harris is the principal author of *Who's Teaching Science?*, and has recently completed a related, national study of mathematics teaching for ACDS. Currently co-director of a national project on assessment in the biological sciences, Kerri-Lee is also directing an evaluation study of the Science and Technology Awareness Raising (STAR) Peer Tutoring Programme, which is run from Murdoch University in Perth. Kerri-Lee joined the CSHE in 2004, having previously held an academic position in the biological sciences at the University of Melbourne.

Abstract

With the academic preparation and future supply of science teachers an issue of national interest, there is a need for more detailed information on the working lives of practising science teachers. In response, we conducted a nationwide survey of science teachers and teaching in 2004–05. The resulting report, *Who's Teaching Science?*, highlights the current and growing shortage of science teachers with the disciplinary background needed to teach the physical sciences. Heads of science departments defined the level of discipline-specific preparation they believed was necessary to teach science well. The results of this study provide valuable insights for universities and education authorities involved in teacher education and accreditation, and governments involved in workforce planning.

We hear much about students' flagging interest in science. The proportion of Year 12 students studying physics, chemistry and advanced mathematics subjects has declined in recent years (DEST, 2003; Barrington 2006). A 'flow-on' effect has been described, reflected in the decline in enrolments in science and mathematics at university, raising concern among business, research and educational organisations (ETC, 2006). These concerns are focusing attention upon science teaching in schools – the curricula, resources, standards, teaching practices, and upon teachers themselves.

Science teachers play a key role in engaging students in science learning. Enthusiastic, knowledgeable and skilled teachers motivate students' interest in science, encourage them to achieve

their best, and influence their future study and career choices. Ensuring a scientifically literate society is therefore reliant upon ensuring that school science teachers are themselves both motivated and suitably qualified to teach science well.

In 2004–05, the Centre for the Study of Higher Education undertook a study of Australia's secondary school science teachers (Harris, Jenz, & Baldwin, 2005). We sought information on the demographics, tertiary preparation, teaching responsibilities, attitudes and career plans of the nation's teachers. From heads of science departments in schools, we sought information on staffing issues and the views of heads on what constitutes suitable preparation for teaching science. Titled *Who's Teaching Science?* and commissioned by the Australian Council of Deans of Science (ACDS), the resulting report sparked considerable interest. The data presented in the report disaggregated 'science' into the core disciplines of biology, chemistry, physics and earth sciences. Such data was not previously available at a national level. The results highlight the current and growing shortage of teachers suitably equipped to teach the physical sciences, particularly at senior school level.

The study involved a nationwide questionnaire-based survey of secondary schools. A sample of 629 schools was selected for the survey, representing all states and territories, school sectors and geographical locations. Each school received two different questionnaires: one for the head of science teaching, and multiple copies of a second questionnaire for teachers of science subjects. Responses

¹We have recently completed a similar study of mathematics teachers, in which all Australian secondary schools were surveyed and a total of 3545 responses received. The findings from that study are soon to be released.

were received from 266 heads of science and from 1207 teachers¹.

This paper draws upon the data presented in *Who's Teaching Science?*, and highlights the reasons for the ACDS's call for urgent action on workforce planning and high quality teacher preparation (Harris, Jenz, & Baldwin, 2005, p. viii). The nature of the current teacher shortage is described, and the factors that suggest the situation will soon worsen are presented. The requirements of heads regarding discipline-specific tertiary study is compared to the actual qualifications of practising teachers. Finally, a case is made for science teacher recruitment strategies that focus on current university science students. As science teachers need both a strong grounding in their discipline and an enthusiasm for science learning, where better to find candidate science teachers?

The current and growing shortage of science teachers

Most schools reported difficulties recruiting suitably qualified science teachers. There is no shortage, however, of teachers with strong backgrounds in the life sciences. The problem schools face is with the availability of teachers with knowledge of the physical sciences. Forty per cent of schools experienced difficulty adequately staffing physics classes, and one-third reported similar problems for chemistry. These shortages also affected staffing of junior and middle school science, and heads reported lower levels of satisfaction with the quality of their schools' teaching at these year levels than at senior school level.

Shortages were reported for all states and territories, and by both metropolitan schools and those in more remote regions. Many heads of science

described problems filling short-term vacancies, such as those created when teachers take extended family or long-service leave. While a staffing shortfall of three to six months is manageable in some businesses, this is not the case for schools. Such a 'gap' in students' schooling is likely to have significant and lasting consequences.

Three factors indicate that the demand for teachers with strong backgrounds in the physical sciences is set to increase – the large proportion of teachers nearing retirement age; the disillusionment and uncertain career plans described by many younger teachers; and the fact that early career teachers are predominantly biologists, with limited background in physics.

An aging teaching workforce

The age profile of science teachers shows a large 'bulge' above 45 years of age. Nearly 30 per cent of the science teachers surveyed were at least 50 years of age, and another 14 per cent were between 45 and 50 years of age. There is a pronounced difference in the age profile of male and female teachers. Male respondents were older, dominating the 45+ years of age group and under-represented in the 'under 30 years' age group.

Uncertainty among young teachers

Nearly half the teachers surveyed were not sure that they would be still be teaching in 2009. While this group included older teachers planning to retire, many were younger, early career teachers. Teachers cited the pressures of a high workload and long hours as a negative aspect of their working life. This was particularly an issue among female teachers.

A second major concern of teachers, and a source of obvious frustration, was poor student behaviour and lack of student interest in science. This was of particular concern among teachers from government schools, rivalling workload as the most commonly cited challenge they faced.

Physics expertise concentrated among older teachers

Younger, early career teachers were less likely than their more experienced peers to have studied physics at university – a trend set to exacerbate the current shortage of physics teachers as older teachers of physics retire. Half the science teachers under 35 years of age had studied no physics at university. The same was true for teachers with less than five years' teaching experience.

Science teachers need a strong, discipline-specific science background

The diversity of educational pathways leading to a career in secondary school science teaching (Lawrence & Palmer, 2003) is reflected in the diversity of disciplinary backgrounds among science teachers. Some of the teachers surveyed had studied no tertiary science at all, while others held majors in multiple science disciplines.

In the absence of prescribed standards for the minimum level of science background for secondary school science teachers, we asked teachers and heads to provide insight into current practice and perceptions in schools. Teachers were asked to describe both their pattern of tertiary science study and their current teaching responsibilities. Heads of science departments were asked for their views

regarding the minimum level of science study necessary to prepare teachers for school science teaching.

Junior and middle school science teaching

Half the teachers surveyed taught junior school science², typically in combination with later-year science classes. Three in five teachers taught middle school science and, as for teachers of junior school, usually in combination with other year levels. Half taught senior school science. Their disciplinary backgrounds were predominantly in biology and, to a lesser extent, chemistry. Only a minority of junior–middle school teachers had studied physics beyond first year at university.

Ten per cent of all respondents taught science at junior school level only. This group was typically early-career teachers. They also made up the group of respondents with the lowest levels of tertiary science preparation – 22 per cent had studied no science at university.

Half the heads of science expressed the view that some first year science study at university was adequate preparation for teaching science at junior school level. One in ten, however, favoured a major (study to at least third year level) in at least one science discipline. Overall, heads were less satisfied with the qualifications of teachers of junior school than they were of other year levels.

Heads expected teachers of middle school to have studied science subjects to at least second year at university, and some required a science major. While most middle school teachers held either a minor or major in at least one science discipline, 12 per cent did not and 6 per cent had studied no science at university.

Senior school science teaching – biology, chemistry and physics

The 649 teachers who taught senior school science were typically male and older than colleagues who taught only junior-middle school. In particular, many senior school chemistry teachers were approaching retirement age.

Senior school teachers displayed the most 'specialised' patterns of teaching. Forty per cent taught only senior level science subjects, and most taught only one science discipline at senior level. Biology teachers were the most 'restricted' in discipline range.

Biology teachers were also the most highly trained in their specific discipline – 86 per cent held a major in biology, and 28 per cent had studied the subject beyond third year. In contrast, teachers of physics were likely to be far less qualified. While 57 per cent held a physics major, one in four had not studied physics beyond first year at university. This is of considerable concern, as most heads stated that senior school teachers need to hold a discipline-specific science major, and the overwhelming majority believed that study beyond first year university was essential.

Attracting and retaining suitably qualified science teachers

The results of the *Who's Teaching Science?* study support assertions and predictions made elsewhere: that Australia needs to be attracting more people to science teaching, and needs to ensure that these teachers have both the disciplinary knowledge and communication skills necessary to teach science well. The study also identified

levels of disillusionment among current science teachers that should be of grave concern to schools and education authorities.

A range of complementary strategies will be needed to address these challenges.

- Identified disincentives need to be removed or managed, in order to attract more people to science teaching.
- Additional measures are needed to support practising science teachers, both to enable them to do their jobs well, and to encourage them to remain in the teaching profession.
- Aspiring science teachers need tertiary preparation that provides them with the disciplinary knowledge appropriate to the teaching that they will do.
- More young people need to be encouraged to pursue a career teaching science in secondary schools.

I do not suggest that these concerns are new. Governments, universities and science organisations have developed a range of policies and strategies along these lines, and many are ongoing. However, the looming shortage of teachers in the enabling sciences calls for renewed efforts and, arguably, innovative approaches.

The need to attract 'stronger cohorts of strong students' (Lawrence & Palmer, 2003, p. xviii) to secondary science teacher education programs has been stressed in earlier studies. The findings of our study suggest that recruitment strategies would do well to target current university students studying in the sciences. University students typically choose to study science because they have a passion for it. This passion can feed back into schools if more university science students are

²Junior school: Years 7 and 8. Middle school: Year 9 and 10. Senior school: Years 11 and 12.

encouraged to consider careers in science education. Indeed, a majority of the teachers surveyed cited their own enthusiasm for science as a motivation for becoming science teachers.

In concluding this brief paper, I contribute to the following suggestion – universities reviewing teacher education programs should seek to create pathways between science and education that are attractive to all science students, not only to those students with an identified interest in teaching. For example, the creation and promotion of science communication subjects would be one approach. Science communication is already an area that has appeal among science students. If the curricula of such subjects were built around communication for different audiences, and if ‘school students’ was identified as one such audience, university students who had not previously considered teaching might well be both encouraged and, in part, prepared to become science teachers.

Acknowledgments

The report upon which this paper is based:

Harris, K-L., Jensz, F. & Baldwin, G. (2005) *Who's Teaching Science? Meeting the demand for qualified science teachers in Australian secondary schools*. Report prepared for Australian Council of Deans of Science. January 2005.

The full report is available at: <http://www.acds.edu.au/>

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Boosting science learning – what will it take?



Russell Tytler

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Russell Tytler, Professor of Science Education at Deakin University, Melbourne has been involved over many years with Victorian curriculum development and professional development projects. He was principal researcher for the highly successful School Innovation in Science initiative, which developed a framework for describing effective science teaching and learning, and a strategy for supporting school and teacher change. His research interests also include student learning, student reasoning and investigating in science, and public understanding of science.



David Symington

Deakin University

David Symington spent 14 years as a teacher in Victorian schools followed by several decades engaged in the education of teachers and in research in science education. Adjunct Professor Symington later worked for 8 years at the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in several positions, where he learned a good deal about the path from the laboratory bench to the marketplace. Presently, he is engaged with Russell Tytler and others in a number of research and development activities at Deakin University.

Abstract

In this session Russell Tytler and David Symington will present some data they have gathered from three sources: scientists working in some of Australia's Research Priority Areas, science graduates working in positions outside their discipline specialisation, and students studying sciences at Year 11. The presenters will explain why they chose to interview these quite different groups of people and give some indication of why they believe the data is relevant to the question driving the conference: Boosting science learning – what will it take? There will then be group discussion drawing on the views and experiences of the group members and the data to suggest ways to boost science engagement and learning.

There is growing concern in Australia, and in post-industrial countries generally, about a perceived crisis in science education. This relates to lack of engagement of school students with science and claims of diminished learning outcomes; a decreasing proportion of students taking post-compulsory science; low levels of participation in tertiary courses in physics and chemistry and higher mathematics; a shortage of graduates and research students in key areas; and a shortage of science teachers. The question for us, then, is how do we boost student engagement, learning and participation in science?

The starting point for any discussion on this topic is to recognise that there will be no simple answer to this question. Nor will it be possible to sheet home responsibility for addressing the problem to any one group, teachers, educational administrators, government, university lecturers, or students. It is going to require action by all of these groups acting on many fronts to make progress. It may well require a rethinking of the nature and purpose of science education in a post-industrial world.

However, by examining evidence together in this forum, including pooling our experience of successful practices in school science, we believe that we will be able to identify some promising leads and suggest how we could build on what we do know to boost science learning. The speakers at this conference will be bringing research evidence they and colleagues have generated to cast some light on this issue of learning and engagement. We will also present, for consideration by the group, data we have gathered that we believe suggests some exciting possibilities. This was research done in an attempt to rethink science teacher education.

Our data came from three sources.

The world of science

First, we gathered information about what is happening in the world of science. We ran focus groups involving mainly scientists working in areas identified as Australia's Research Priorities, such as 'frontier technologies' and 'protecting our borders from infectious diseases and pests' and 'climate change'. One clear and compelling point emerging from these focus groups was the importance of public perspectives and understandings to the advancement of science and technology. It is really important that educators know how passionately people working at the frontiers of science and technology feel about this.

A second thing we learned from these groups was the extent to which a common set of competencies required of people working in these science fields could be established. Further, these are capabilities that can easily be stimulated by appropriate science education at all levels of education. They include being able to communicate effectively with multiple audiences, having well-developed analytical thinking and problem-solving

skills, and being able to work in teams across disciplinary boundaries. We need to explore the implications of this for the curriculum and for teaching.

Although we didn't intend to engage these people in discussion of school science, they brought it up. Many had experience of school science through their children, or through working with schools on science-related projects. So what did they say about school science? A number of the focus groups noted a disjunction between traditional images of science, particularly represented in science education, and the way contemporary science operates, and the abilities required of those working in the field. They argued for a science education less focused on knowledge structures, and more on skills, thinking, preparing for lifelong learning and engagement with science.

The world of work for many science graduates

We conducted interviews with science graduates not working in their specialist fields – some are employed in science-based enterprises, others are not. Why would we want to do that? Most commentators and politicians are worried about the lack of people moving into the more traditional science positions. This is certainly a cause of major concern, but the problem is wider than this. We believe that in the present science-based world there is also a need for more science-educated people in decision-making positions in government and industry. At present about 40 per cent of science graduates are employed in positions that are not specific to their discipline specialisation. Accordingly, we wanted to find out what insights people in such positions could bring to our considerations of science education. As it turned out, they had much to say that we believe to be of relevance to our discussions. Some of these

data will be shared to stimulate our thinking. Interestingly, and encouragingly, we found that this group of people stressed the importance of many of the same capabilities identified by the scientists in the focus groups.

The world of school students thinking about further studies

Our third source of data was students doing science studies in Year 11. We explored what would encourage them to enrol in a science degree at university. From them, we gained insight into how they regard science particularly in relation to career options. For example, the feature of a science degree course most likely to encourage more students to enrol is that, at the completion of the course, they would have a chance to pursue a variety of career possibilities and get a job where they will be working with people. The features least likely to encourage student entry are that the degree leads you to become a science researcher, work in a laboratory, or become a science teacher.

The data challenge us on a number of fronts. First, there is the image of science generated at school. Then, there is the information students have about science careers. The data also have implications for the way school and university systems market science degrees. Finally, of major concern, in an era when a significant shortage of appropriately qualified science teachers is looming is the lack of appeal of science teaching. Within the forum we will have the opportunity to discuss some of these issues.

Possible questions to be discussed in the forum include:

- How can we ensure that school science programs reflect contemporary science?
- How do we ensure that citizens are able to engage with, and are interested in engaging with, social and ethical issues around applications of science?
- What image of potential careers do our science programs present? Is this an issue we should think about? What should be done?
- Given the issues and perspectives raised at this conference, how might we boost student engagement and learning in science?
- What are the key points at which we need to exert pressure for change?
- What examples can we find in current practice that might give us directions for ways forward?

How can professional standards improve the quality of teaching and learning science?



Lawrence Ingvarson

Australian Council for Educational Research

Lawrence Ingvarson began his career as a science and mathematics teacher in WA, then taught in the UK, before undertaking further studies at the University of London and lecturing at the University of Stirling in Scotland. Prior to taking up his current position at ACER early in 2001, he was an Associate Professor at Monash University in Melbourne.

Dr Ingvarson is internationally recognised for his research on professional development in the teaching profession. He has worked closely with teacher and principal associations in the development of professional standards as a means of strengthening the important role they play in relation to professional development and the provision of recognition to teachers who attain high standards of practice. With members of these associations, he has pioneered the development of new standards-based methods for the assessment of teacher and school leader performance and laid the foundations for a national, voluntary system for advanced professional certification in the teaching profession. Recently, he has been a member of Ministerial Advisory Committees for the Victorian Institute of Teaching, the TAFE Development Centre and the National Institute for Quality Teaching and School Leadership.



Anne Semple

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Anne Semple was a teacher of science for over 30 years prior to becoming a Science Project Officer at the Victorian Curriculum and Assessment Authority (then the Board of Studies), a Research associate at Monash University and a Research fellow at ACER (Teaching and learning research program and Assessment and reporting research program). She has extensive experience in the development of curriculum and teacher and students materials (print and online) and has conducted many professional learning programs and sessions on a variety of themes. She is a past president of the Australian Science Teachers Association and has a strong and ongoing commitment to the teaching profession. Currently, Anne is an independent education consultant.

Introduction

After extensive national consultation, the recent Review of Teaching and Teacher Education (DEST 2003) announced an 'agenda for action' in its report, *Australia's Teachers: Australia's Future*. One of its central themes was a call to 'revitalise the teaching profession'. The report recommended that:

- National standards for different career stages should continue to be developed by the profession.
- A national, credible, transparent and consistent approach to assessing teaching standards (should) be developed by the teaching profession with support from government.
- Teacher career progression and salary advancement (should) reflect objectively assessed performance as a teaching professional.
- Recognition, including remuneration, for accomplished teachers who perform at advanced professional standards and work levels (should) be increased significantly.

In making these recommendations, this Review was consistent with many reports over the past 30 years related to the teaching profession. Examples include the Karmel Report in the early 1970s; the NBEET reports on teacher quality and award restructuring in the late 1980s; *A Class Act*, the report of the Senate Inquiry into the Status of Teaching (1998); the *National Statement from the Teaching Profession on Teacher Standards, Quality and Professionalism* (2003); and the report *The Status and Quality of Teaching and Learning of Science in Australian Schools* (Goodrum, Hackling & Rennie, 2000).

These reports recognised that teacher quality is critical to school and student success. A common theme, therefore, was the importance of strengthening the capacity of the profession to

develop and apply its own standards because this was regarded as the foundation for attracting, developing and retaining effective teachers.

For example, to improve the status of teaching, the 1998 Senate Inquiry called for a national system for professional standards and certification for teachers based on the achievement of enhanced knowledge and skills to retain the best teachers at the front line of student learning. The Goodrum report recommended that incentives be provided to attract larger numbers of quality students into science teaching and to retain experienced teachers in the classroom.

However, the evidence is clear that shortages of mathematics and science teachers continue. Higher earnings are required not only at the start, but throughout career paths to retain highly qualified and effective teachers. One-off recruitment schemes with golden handshakes and various incentives and bonuses are unlikely to have sustained effects (Webster, Wooden, & Marks, 2004). Any serious attempts to improve the quality of teaching and learning in science will need to improve both relative salaries and incentives to reach high professional standards if these perennial problems are to be overcome.

The success of such reforms, however, will depend fundamentally on research that informs the development of valid methods for evaluating the capacity of teachers to provide their students with high-quality opportunities to learn science. Without the capacity to evaluate teaching, it is difficult to place more value on good teaching. An important research challenge is to learn how to reform pay systems for teachers in ways that attract and retain effective teachers, without the negative effects of previous approaches such as merit pay.

In this vein, the purpose of this paper is to provide a brief review of

preliminary work at ACER, conducted in collaboration with the Australian Science Teachers' Association, to develop a standards-guided professional learning system that would lead to professional certification for highly accomplished teachers of science.

Background

The Australian Science Teachers' Association (ASTA) has long held a vision for improving the teaching of science in Australian schools. Twelve or so years ago ASTA recognised the need for articulating clearly what teachers of science should know and be able to do as they gain experience and advance in their career. It recognised the imperative for the association, as the peak body representing teachers of science across Australia, to develop and demonstrate its capacity to give professional recognition to teachers of science who achieve against these standards.

ASTA believed that such a system would provide the public and employing authorities with the assurance of quality. ASTA believed that engaging in this process would at the same time provide opportunities for deep, significant and ongoing professional learning guided by standards of practice that were directly connected to the specialised work of teachers of science. ASTA believed that improving the quality of teaching science would improve the quality of student learning. How could ASTA achieve its vision and were its beliefs justified?

This paper describes ASTA's progress towards developing a system of certification, beginning with the development of standards of practice. It describes the opportunities for professional learning that the process afforded and the effect on teachers who participated in the process. It summarises the status of development

and identifies some of the key issues that the association has to resolve if it is to continue to move forward.

The challenges facing the association were considerable. In the early 1990s, little was known or understood in Australia about how a professional teachers' association could go about developing a voluntary system of professional certification that was underpinned by an infrastructure for professional learning. Surely it was up to employing authorities to set standards of teaching practice and to provide professional development activities?

There is no doubt about the need for employing authorities to ensure that suitably qualified teachers are employed in their schools and carry out the duties expected of them. Similarly, medical authorities have to ensure that suitably qualified practitioners are employed in hospitals and other medical facilities. Where the teaching profession differs from the medical profession and others is that it lacks a process of certification that recognises advanced or accomplished practice based on meeting high and rigorous standards set by the profession.

Developing a professional certification system

The first step ASTA took was to inform itself of international experiences in the establishment of professional teaching standards and issues linking professional standards to recognising highly accomplished practice through a process of certification. In 1994, the Council commissioned such a study (Ingvarson, 1995).

After examining several models of professional certification or credentialing, the one that ASTA favoured was that of the National Board for Professional Teaching

Standards (NBPTS) of the USA for the following reasons:

- ASTA shared belief in the five core propositions that provided the philosophical context for the work of the NBPTS²;
- ASTA was impressed by the NBPTS standards of what accomplished teachers of science should know and be able to do, and by the innovative approach to developing performance assessments for teachers that were firmly grounded in the context of the work of teachers of science;
- ASTA could see the potential for professional learning during the process of completing such performance assessments;
- The National Board is an independent organisation whose governing body consisted largely of classroom teachers; and
- The NBPTS (then) had about seven years of experience in research and development in this area with a budget far beyond what ASTA could raise if it were to begin from scratch.

Components of a certification system

As ASTA's financial resources depended largely on a per capita levy on state and territory association members, Council agreed that it should seek additional funding and partnerships to further the process of developing its own certification system that would better suit the Australian context. It was not until 1999 that ASTA and Monash University won a grant from the Australian Research Council of the Department of Training and Youth Affairs Strategic Partnerships with Industry, Research and Training Scheme (ARC/SPIRT) to enable it to do so.

ARC/SPIRT grants were also obtained by Monash and three other professional associations to develop professional standards in the fields of English and Mathematics.

ASTA's research project incorporated three components that reflected the elements of a credible national voluntary system of professional certification:

1. the development and validation of standards for highly accomplished teachers of science;
2. development of performance tasks that would provide vehicles for teachers to show how their teaching met the standards; and
3. research on the reliability and validity of these tasks for wider use in a national certification system.

Development and validation of standards of practice for highly accomplished teachers of science

In 1999, ASTA established a National Science Standards Committee (NSSC) with responsibility to develop the ASTA standards. Expressions of interest were called for and highly respected teachers of science and educators were selected from all levels and all sectors across Australia. A series of intensive meetings of the 15 members of the NSSC was held in 2000 and 2001 to draft the standards. All members of the Committee agreed that developing the standards was an extraordinarily rewarding process of professional engagement, reflection on practice, and professional learning.

As teaching is such complex work, the Committee was faced with the challenge of teasing out and articulating the elements of that work without developing a mere checklist that would lose sight of teaching's holistic nature. The Committee recognised that the knowledge and skills of highly

accomplished teachers of science differed from those of novice teachers and also differed fundamentally from the knowledge and skills of teachers of other subject areas. The standards had to reflect this.

The standards also had to be achievable, measurable and context-free if they were to be the basis of a high stakes national certification system, in addition to being valuable reference points for individual or group professional learning.

The process of validating the standards involved extensive consultation with ASTA members through its state and territory associations. Professional and public comment and critique were sought from a wide range of stakeholders, including the Federation of Australian Scientific and Technological Societies, the Australian Academy of Science, state and territory departments of education, the independent and Catholic sectors, and unions. Following review and revision, the standards were published in February 2002 (National Science Standards Committee, 2002).

The 11 professional standards for highly accomplished teachers of science are grouped in three categories:

1. **Professional knowledge:** Highly accomplished teachers of science have an extensive knowledge of science, science education and students (3).
2. **Professional practice:** Highly accomplished teachers of science work with their students to achieve high quality learning outcomes in science (6).
3. **Professional attributes:** Highly accomplished teachers of science are reflective, committed to improvement and are active members of their professional community (2).

²Five core propositions of the NBPTS [<http://www.nbpts.org/about/coreprops.cfm>]

Each of the 11 standards consists of a short statement that distils the essence of the standard, followed by an elaboration that paints a word picture of the practice of a highly accomplished teacher of science in relation to the standard. The full set of ASTA standards is over 20 pages long and can be found on the ASTA website.

Development of performance assessments based on the standards

A certification system not only involves the development of professional standards but also the development of tasks that provide authentic evidence of performance of teaching practice that can be assessed against the standards. This stage of the ASTA/Monash project commenced in 2000 and consisted of two phases.

Phase 1: 2000 – Trialling of NBPTS portfolio entries

The NBPTS had commissioned considerable research and engaged many leading figures in educational measurement in developing methods for gathering and assessing evidence about teacher performance. Based on ASTA's earlier 'in principle' acceptance of the NBPTS model, and rather than reinventing the wheel, teachers were invited to trial the five NBPTS 'entries' or tasks that comprised a complete portfolio, and to evaluate them in terms of:

- how appropriate the NBPTS portfolio tasks were for providing evidence of accomplished practice in the Australian context, and
- how appropriate the NBPTS portfolio tasks would be as a means

for assessing performance against the ASTA professional standards

Portfolio Evaluation Teams (PETs) were established in Victoria, Western Australia, New South Wales and South Australia. As part of the research project, each teacher was asked to trial and evaluate one of the five entry tasks that would constitute a complete portfolio. Due to competing demands for their time and other mediating factors, the attrition rate of members of PETs was high. This highlighted the need for a high level of national, structured collaboration and a supportive infrastructure, particularly at school level, to facilitate such a process.

Nine individual PET members were able to complete and submit their entry and the evaluation questionnaire. Group responses were received from two Portfolio Evaluation Teams. All agreed strongly that:

- overall the portfolio tasks were authentic for the Australian context – the tasks were asking for evidence of what should normally be part of the work of a teacher of science in Australia
- the tasks would discriminate between novice and highly accomplished practice
- teachers would be able to use their own styles and strategies of teaching to meet the needs of their students
- the tasks were clear and fair and designed appropriately for them to be able provide evidence for assessment against the standards³.

Apart from evaluating the portfolio tasks, teachers were invited to reflect on their experience. The following is a representative sample of teachers' views.

Putting together a portfolio entry (video) certainly was a challenging and

time-consuming experience. However, the benefits for me as a professional were far greater. The chance to see myself teach and reflect upon my practice, although daunting, enabled me to look closely at the things that I did well, as well as look at the things I could improve on. This had obvious benefits for my class. I was able to sit back and watch my own lesson from a distance and see if my teaching methods really did support my beliefs. I was able to view the Science lesson from the student's perspective rather than simply from my own.

Phase 2: 2001 – Developing the ASTA portfolio tasks

ASTA Council had established an Assessment Reference Group (ARG) to provide advice about developing assessment tasks. It consisted of members of PETs and the NSSC and educators who had undertaken assessment training and benchmarking with the NBPTS in the USA.

The findings of the PETs and advice from the ARG informed the writing of the ASTA portfolio entries. Writers included well-respected teachers of science, teachers who had trialled NBPTS portfolio entries and those who had undertaken assessment training. As with the development of the standards, the process offered opportunities for significant professional learning.

Five portfolio entries were modelled on the NBPTS framework.

1. *Teaching a major idea of science over time*: teachers provide evidence of how they design a teaching and learning program or unit of work centred on a major scientific idea that enables students to develop associated skills.
2. *Assessing students' work*: teachers provide evidence of how they use

³Semple, A. (2001). *ASTA evaluation of NBPTS portfolio entries: Report of Portfolio Evaluation Teams* (unpublished), ASTA.

assessment to evaluate students' progress and further students' learning in science.

3. *Probing students' understanding:* teachers provide evidence of how they engage students in probing their prior understanding of a major scientific concept and how they modify their teaching in response.
4. *Active engagement in investigation and inquiry:* teachers provide evidence of how they engage students in discussion that involves the interpretation of data collected during an investigation of an important scientific concept.
5. *Leadership and collaboration in school and professional communities:* teachers provide evidence that their contribution extends beyond the classroom to the school and the wider professional community. They show how interactions with students' families/caregivers and the local and professional communities have contributed to their students' learning in science.

Portfolio entries 1 and 2 each required detailed critical analysis of and reflection on student work samples; each of entries 3 and 4 required detailed critical analysis of and reflection on an unedited 20-minute video recording of class interactions. The Portfolio 5 entry required verified evidence of active leadership and a written reflection on the effects of such professional activity on their students' learning in science.

Portfolio entries, based on the NBPTS framework, were designed to make it clear *what* kind of evidence teachers had to provide and how the evidence would be assessed, but to leave open *how* teachers fulfilled the requirements. This format reduced the chance of ambiguity in interpreting expectations (and therefore were legally defensible), yet took account of the different contexts in which teachers work. It was important for teachers to realise that

having standards of practice did not mean standardisation of practice. Each portfolio task is structured so that it provides evidence relevant to several standards and retains the wholeness of teaching. And, the portfolio entries, as a set, provide several independent pieces of evidence about each of the standards, increasing the reliability of the assessment.

Despite teachers initial concerns that they were able to submit everything that they thought relevant, there was general agreement that the structured format with guideline questions helped them to represent their teaching in the best possible light. There was:

'relief that there **were** boundaries! The imposed word limit meant you had to remain quite focused and really home in on the key ideas. Having set standards meant that everyone else would face the same constraints.'

Research on the reliability and validity of the assessment tasks (portfolio entries)

The next phase of the research project required larger numbers of teachers to complete portfolio entries so that their measurement properties could be evaluated, such as their ability to be assessed reliably by trained peer assessors. The next phase also required the development of a support structure to help teachers to prepare their entries.

In total, 45 teachers completed one of the ASTA developed portfolio entries in 2001 and 2002. After they had completed the entry, teachers were invited to assess:

- whether the draft tasks were appropriate for assessing practice against the ASTA draft standards

(i.e. were they authentic, assessable and feasible?); and

- the effects that completing a portfolio entry had on their professional practice and professional interactions with colleagues.

A brief description of the support program follows.

Setting up an infrastructure for professional learning

Research findings of the NBPTS and the experience of members of the Australian PETs (2000) indicated strongly that teachers wanted, and benefited from, collaborative and ongoing support and interaction through the process of preparing portfolio entries. In collaboration with the Australian Council for Educational Research (ACER), a six-session professional learning program, *Relating professional standards to practice*, was designed based on the ASTA standards and what research at the time revealed about best practice in professional development (Hawley & Valli, 1999; National Academy of Science, 1995).

Funding to assist teachers through the trialling process was obtained from education departments in South Australia, Victoria and New South Wales, the Catholic Education Commission in Victoria and by individual schools through the Association of Independent Schools in South Australia. Some independent schools in Victoria covered the cost of their teachers' participation. Member associations of ASTA collaborated in the delivery of the program and university credit was arranged for teachers who wished it. One teacher took advantage of this opportunity.

Gathering the evidence to complete their portfolio entry over a period of up to eight months engaged teachers in authentic problems of teaching and

student learning. Facilitated learning, sharing practice and discussion with peers supported teachers through the process of viewing, analysing and reflecting on their work that involved tracking the progress of students' learning in a variety of contexts.

Participants were asked to complete two questionnaires, one to evaluate the nature and process of completing the portfolio entries⁴ and the other to evaluate the professional development program that supported them in the process.

Findings

Portfolio tasks

In summary, all participating teachers agreed or strongly agreed that each of the five portfolio tasks was authentic, assessable and feasible. About a third of the teachers who completed an entry requiring videotape of their lessons found some difficulties in arranging for videotaping and using video cameras. Despite initial concerns, teachers valued the experience of seeing themselves and others in action.

'Seeing yourself (and hearing) on video shows certain flaws and, although you may think you cover something well, the video will/may show something different. I thought I cover asking every one in the class well – but not at all! The video also shows members of the class and their levels of participation, especially when you are not asking them information – but the video is still on them.'

The opportunity to analyse and reflect on their practice provided powerful learning opportunities for all respondents.

'When I finally finished the entry, I looked back on my endeavours with pride. While it was far from

perfect, I gained many ideas for improvement. I am more confident about sharing my practice with others. There is value in having a formal structure on which to compare practice with others. This opportunity to reflect on teaching and consider ways of improving practice should be available to others. I certainly found it to be a worthwhile exercise. It gives teachers something to aspire to and work towards achieving specific standards. There is a tangible purpose to improving practice and the possibility of developing a reward system for achieving those standards.'

Another teacher commented:

'The process allowed me to reflect upon the manner in which my activities outside the classroom impact on successful study of science by all students in my school. This has allowed me to refine aspects of my management and reinforced my commitment to this aspect of my role.' (Entry 5)

Some teachers referred to the value of having professional standards to guide them in their teaching and in their professional learning.

'I now have a set of standards which I can adhere to throughout my teaching ...'

'For the first time in many years I have had a structured way of analysing and reflecting on my science teaching. I have successfully completed AST 1 assessment and the application/selection process for promotion. However, my classroom teaching in the specialised area of science has not been specifically analysed. I believe that long-term, this process will significantly benefit my teaching of science and my input into discussion of effective teaching at school.'

Professional learning program

Finding and managing time to participate in the program and complete a portfolio task in a busy teaching schedule, and the degree of support offered at the school level were problematic for some teachers.

'It's difficult finding time for sessions and to do work in between ... because it's worthwhile doing it – it's fantastic, I'm glad I went. The cost of the program makes it difficult to take part. If the budget is slashed, PD is the first to go.'

However, teachers valued the opportunity to discuss their work.

'... getting together with others; the focus on teaching; it's able to be used in the classroom – it's relevant and therefore more effective. It's highlighted the ways students learn and made me look deeper into the learning environment and how they learn. It's been an incredibly invaluable experience for me – access to people, hear how they function, curriculum and so on ... it's benefited me early in my career.'

In all, about 80 teachers have taken part in these programs of professional learning strongly linked to their work. Approximately 40 entries, distributed across the five components of a portfolio, were submitted by primary and secondary teachers of science. Generally, participants agreed that they had been challenged, that their professional knowledge had expanded and deepened, their practice improved – even revitalised in some instances – and in the majority of cases, their professional interactions had benefited.

Though evidence of the direct and measurable effect of these changes on student learning has yet to be established, many teachers reported on improvement in their students'

⁴Seiple, A. (2001). *Developing standards-based performance assessments for teachers of science*. (unpublished) ASTA/ACER.

attitude and interest in learning science, that they generally had a clearer understanding of their learning and that they were better able to judge their progress⁵.

ASTA's vision: What has been achieved?

The work reported here has been guided by a vision in which teacher organisations like the Australian Science Teachers' Association would play a stronger role in developing profession-wide standards for highly accomplished practice and providing certification to teachers who reached those standards. A full set of standards points to how evidence about capability and performance will be gathered, and how decisions will be made about whether the standards have been met.

This paper has summarised preliminary research at ACER, conducted in collaboration with ASTA, to develop new methods for gathering evidence about teaching performance that might be used in a system for providing recognition to highly accomplished science teachers.

The work reported here indicates that ASTA has made considerable progress towards developing a professional certification system. It has also described how the process of working towards standards for highly accomplished science teaching and assembling evidence in relation to those standards provides significant professional learning opportunities for teachers of science. The shared process of describing, analysing and reflecting on how one's teaching compares with professional standards engages teachers in effective processes of professional learning.

Improving the quality of science learning in our schools will undoubtedly require

more effective policies and career pathways for attracting, developing and retaining effective science teachers. For these policies to work, we will have to find credible methods not only for defining what we think good science teachers should know and be able to do, but also for gathering evidence about performance and assessing whether that evidence indicates that the standards have been met. We need to get better at evaluating teaching if we are to find acceptable methods for giving recognition to teachers who reach high standards of practice.

In other words, this paper makes clear that the teaching profession is beginning to build its own infrastructure for defining high quality teaching standards, promoting development toward those standards and providing recognition to those who meet them. The ASTA initiative, and others like it, such as that of the AAMT, is demonstrating that the teaching profession has the capacity to build a standards-guided professional learning system that will strengthen the quality of science teaching and learning in our schools. These initiatives are very much in the interest of governments and other employing authorities and therefore to be encouraged through better remuneration and career paths that better reflect what a highly accomplished science teacher is worth, not only to their school, but to our society and our economy.

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No wonder kids are confused: the relevance of science education to science



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Deborah Corrigan is a Senior Lecturer in Science Education and Associate Dean (Teaching) at Monash University, Australia. After working as a Chemistry and Biology teacher for 10 years, Dr Corrigan has worked at Monash University for 15 years in Chemistry and Science Education, particularly in teacher preparation. Her research interests include industry and technology links with chemistry curricula, which has included an active involvement in many vocational educational programs for students and teachers. However, her main research interests remain improving the quality of chemistry and science education so that it is relevant to students, and improving the professional practice of teachers and other industry professionals.

Abstract

My experiences in science have left me wondering if we know what we want to achieve when educating students in science. An important question for science educators is: how authentic is the science presented in science classrooms? To answer this, science educators need a clear idea of what is they believe to be the purpose of science and then how they can portray that in their classrooms. This paper represents my journey in thinking about and researching of these ideas. It is my belief that, if we are to engage students in science, then science education has to be far more authentic than it has been in the past. In this sense, the title is apt – it is no wonder students are confused as I believe that, as educators, we have not been successful in creating the bridge between science and science education.

Introduction

My experiences in science have left me wondering if we know what we want to achieve when educating students in science. An important question for science educators is how authentic is the science presented in science classrooms. To answer this, science educators need a clear idea of what it is they believe to be the purpose of science and then how they can portray that in their classrooms. This paper represents my journey in thinking about and researching these ideas. It is my belief that, if we are to engage students in science, then science education has to be far more authentic than it has been in the past. In this sense, the title is apt – it is no wonder students are confused as I believe that, as educators,

we have not been successful in creating the bridge between science and science education. In this paper, I will make a number of assertions that are a consequence of my journey in science and science education. However, to begin I will start with a story about the experiences of some teacher colleagues of mine – Rebecca and Vojtech.

Year 9 Big Picture Science Unit

Rebecca and Vojtech have developed a unit of science called 'Big Picture Science'. The idea for this was taken from a collaborative workshop run by science educators at Monash University and their partner schools in an ASISTM (Australian School Innovation in Science, Mathematics and Technology) project.¹ The focus of this unit was the ethical issues in Science, Medicine and Technology and who makes the decisions.

An initial prompt was provided for students through the viewing of a television program – *Grey's Anatomy*², in which an ethical decision was posed about which one of two accident victims should be saved. Students were then asked to form groups to research answers to a series of questions based on assigned roles of a doctor, a pharmaceutical research scientist, the government, a relative, and a member of a 'Right to Life' group. Examples of questions that were posed included: Russell Tytler, Professor of Science Education, Deakin University, Melbourne has been involved over many years with Victorian curriculum development and professional development projects. He was principal researcher for the highly successful

¹Australian School Innovation in Science, Mathematics and Technology Project is a DEST funded project. Details can be found at <http://www.asistm.edu.au/>

²*Grey's Anatomy* (Episode 6 in Season 2) 'Into You Like a Train' in which several seriously injured patients, including Bonnie and Tom, a pair of passengers who have been impaled on a pole, are brought to hospital following a train crash.

School Innovation in Science initiative, which developed a framework for describing effective science teaching and learning, and a strategy for supporting school and teacher change. His research interests also include student learning, student reasoning and investigating in science, and public understanding of science.

Who has the final say on a medical procedure?; What laws might govern the type of research a scientist can do?; and Can scientists research whatever they wish? All roles also had a requirement to find real-life examples or recent examples from the media.

Rebecca and Vojtech had clear purposes for this project. They wanted to explore how their own knowledge and teaching practice might develop, and what promoted such development over the course of the project. They also wanted to see if and how students' learning might be challenged, reshaped and/or enhanced through such an approach. Decision making was an important focus of the project at two different levels; first at the level of deciding on the work itself (the topic); and second, the work the students will do (and their decision about how to do the task).

Student responses were gathered as the project progressed and it became obvious that the students felt quite strongly that the topic had some meaning for them and was relevant to them. They also saw that the content they were covering was clearly science, but the decision making that occurred in science, they believed, went far beyond the boundaries of science.

After 4 weeks on the project (one hour a week while 'normal' science classes continued for the other two lessons a week), Rebecca and Vojtech raised a number of questions about their experience from doing this project.

Where does science fit into society? How much 'say' does science have in issues that arise in society? How much credence is given to science when it comes to various aspects of society? How much of an influence does science have on the daily lives of people in our society? How relevant is science to the students' daily lives? Have we given students the tools to make responsible decisions in the future? Have students made a link between the decision making and the presence of science? We've amalgamated science with ethics, legalities and politics, but is there science in all of these areas? Have we emphasised that there is a link between decision making and science? Should we have made it more explicit? How do we get them [the students] to establish links between science and what they're actually doing?

Not only have Rebecca and Vojtech been concerned about their teaching and the learning going on in their classrooms, they have also raised some issues related with their curriculum planning:

Can you run a science curriculum at Year 9 that is solely based on our Big Picture Science? Why wouldn't we make this part of the science curriculum? We are thinking more and more that this is something that should be just like any other topic. During this unit there has been no emphasis on content. The content has been left up to the students to explore. If your curriculum was like this for an entire year, would the link between science and society be more observable for the students?

This experience has led Rebecca and Vojtech to rethink their own notions of science and science education:

We feel that it is science simply because decisions are made in science and a large aspect to this assignment was decision making. We view science as having two aspects: content and application. In terms of what is science and

what we teach in science, we as teachers make a decision about what is science content and what is application. You could therefore teach a unit that is all content without necessarily considering the applications of the science within society. Do the students view science as all content? How familiar are students with the fact that science has content and a role in society? It is obvious that for students to appreciate science's role in society they need to be familiar with some scientific content. Thus, we ask the question: Is teaching science's role in society teaching science?

This story highlights a number of important issues that we face as science educators: what is science, and what is the difference between science and science education? As science educators, we need to re-examine our own notions of science as we need to think about how our ideas of science influence what happens in the science classroom. Rebecca and Vojtech have begun this process as indicated above. They felt they were taking a huge risk in proposing such a unit of work. They did not know if their students would like this unit or consider it science, let alone whether their parents would approve and parent/teacher interviews were looming. This unit was very different to anything they had done previously and they did not know what the outcomes would be. As indicated in their comments above, they did not know what science students would learn and if what they learned was legitimate science.

I chose this story from our ASISTM research project as I think it provides a good example of the journey that I have been travelling for a number of years, as a student of science, a teacher of science, as a parent, and as a researcher in science education. In writing this paper I realise I have not thought much about science in terms of my role as a member of

the community, or at least not in the explicit way I would think of science in any off the other roles mentioned.

A journey of science experiences

From a constructivist viewpoint, my experiences have influenced my concept of science and why we should learn science. Science should help us make sense of what is around us. If this is what science is about, what does it mean for what we teach in science? My experiences (and I will not detail them all here, only highlight a few) have led me to frame a number of assertions. These include:

- The context matters and it needs to be meaningful;
- Purposeful learning and the applications and use of knowledge in different ways matters;
- Purposeful teaching matters;
- Doing science matters; and,
- Science is making sense of what's around you, using your knowledge, skills and abilities to create meaning.

I believe that we, as science teachers, can do so much more for our students as they learn science. Some of the research that I, and others, have done which highlights some findings that support this belief follows. Science educators need to provide a bridge between science and science education if students are to appreciate what science can offer in a number of roles such as a scientific worker, a consumer and as a responsible citizen. It is my belief that science educators have not understood this responsibility very well and are confused by what science is and how science education is linked to it. It is therefore not surprising that students are confused.

Meaningful contexts

Research from my PhD (Corrigan, 1999) indicated that when technology and industrial tasks were introduced into chemistry curricula (VCE Chemistry as a specific example) with the purpose of introducing contexts that were relevant and meaningful to students and part of their real world, their success was limited for a variety of reasons. Chemistry teachers' own experiences of technology arose from a largely science-dominated curriculum (Fensham, 1988). The shift in curriculum emphases (Roberts, 1982) in this instance meant they were now asked to teach from a technology-dominated curriculum. Consequently, teachers were being asked to teach using contexts that were largely unfamiliar to them. Their response to this situation was to focus on the task itself rather than providing an opportunity for students to experience the work of a chemist.

In addition, this research highlighted how problematic it can be to introduce contexts that are meaningful and indeed what makes contexts meaningful. For a context to have meaning implies that there is a sharing of understanding, between all involved, of the context. If the contexts used to create meaning are not familiar, such as the chemical industry for many chemistry teachers, then teachers in developing their own limited understanding of such contexts, often act as filters to help create meaning for their students. In some instances, teachers provided students with structural frames, such as through an issues-based or a community-based approach (Ziman, 1994), and provided mechanisms for developing contexts that were meaningful for students across settings such as school, home and industry. Ziman, proposed a multiplicity of approaches that can be adopted that may help to extend and complement the exploration of the domain of valid science. Such approaches include:

- the approach through relevance where attention is drawn to the relevance of science to everyday life and its social role;
- the vocational approach where attention is given to the professional and social roles science plays in a person's career path;
- the transdisciplinary approach where science is considered across discipline areas rather than as a discrete discipline on its own;
- the historical approach which recognises the historical activity associated with research;
- the philosophical approach which recognises that science should be presented as a more or less coherent body of knowledge, organised logically around theoretical principles and validated through observation and experimentation;
- the sociological approach which recognises science (and technology) as social institutions, internally organised to produce knowledge and know-how, externally linked to and embedded in society at large; and
- the problematic approach where attention is given to the problems of our time, e.g. overpopulation, and present science in an interrelated way to the rest of society.

Purposeful learning and the application and use of knowledge

Science educators need to have a clear purpose of what they hope their students will learn. In order to do this, they also need to have a clear personal idea of what they believe to be knowledge worth learning and the nature of science itself. There has been much research into this and I will not detail this here. Grandy

and Duschl (2005) suggest that the nature of science has shifted to the present model-based explanations where science is seen as a cognitive, social and epistemic practice. That is, science is about the thought and skill processes involved in acquiring knowledge and skills of different types that are embedded in our society. The knowledge types here should not be limited to traditional academic or conceptual knowledge (knowing science) but should also include, for example, vocational-based knowledge (knowledge to be able to do) as Peter Fensham and myself have detailed previously (Corrigan & Fensham, 2002). Or knowledge should include knowledge represented in some curriculum with an STS emphasis which 'emphasize the basic facts, skills and concepts of traditional science, but do so by integrating the science content into social and technological contexts meaningful for students' (Aikenhead, 1994, p. 59).

Other research I have been doing (Corrigan & Gunstone, 2006) has explored the values within science and science education (and maths and mathematics education). In exploring values, we used Halstead's (1996) description of values:

The principles, fundamentals, convictions, ideals, standards, or life stances which act as general guides or as points of reference in decision-making or the evaluation of beliefs or actions and which are closely connected to personal integrity and personal identity. (p. 5)

In this research we have been working from the premise that there are inherent values embedded in a person's ability to distinguish and discriminate between knowledge claims. The knowledge claims in science are clouded by the need to bridge the world of science and the world of school science. Rennie (2006) distinguishes between Science,

shown with a capital S, that is familiar to scientists as it is the product (and process) of scientific research, as opposed to science that requires some interpretation of Science if a layperson or student is able to access

it. This interpretation may include encoding, but requires deconstruction and reconstruction of the Science information into a science-related story. Rennie proposes the use of the word 'story' here as according to

Science as process (Scientific inquiry – note science as an adjective which turns it into something that's not exclusively science)
 experimental method
 being able to investigate
 asking questions
 using evidence to (attempt to) explain things around us
 communication of results, ideas (within and outside team) and the language of science compared with communication of scientific ideas in popular culture
 working in a team
 the nature of the evidence, e.g. respect for data and work

Human qualities (Private vs public understanding)
 passion
 honesty
 integrity
 fairness
 curiosity
 sharing
 ethical
 openness to change (including change in behaviours)

Cognitive
 Challenge current theories and practices (includes other knowledge claims, e.g. science and religion)
 Not constant, changing, developing

Theories
 Intellectual rigour (logic, creation, elegance); How do we know?
 Science makes mistakes; there are no absolutes (e.g. controversial issues such as genetic cloning); can be interpreted in a variety of ways

Societal
 Value of contributing to society
 Science has and will impact on society (including its problematic nature)
 Where does it exist in real life?
 Science is wide ranging/universal/applies in numerous contexts
 Science's ability to (assist in) solve(ing) problems

School Science
 Learning tools, e.g. research skills
 How students learn science, e.g. kinaesthetic
 The skills we want including science literacy
 * Groupings and labels for these generated by author.

Figure 1 Teachers responses to the question 'If you were working with other scientists, what would you value?'

Milne (1998) 'once ideas are presented selectively in science we are no longer telling the facts. We are instead telling a story' (p. 176). So science education must be telling a science story, but how close to the original Science are these stories?

The model of the nature of science as proposed by Grandy and Duschl (2005) appears to fit more closely with teachers' views gathered from a science professional development activity exploring their ideas of 'Big Ideas in Science' where they were asked: 'If you were working with other scientists, what would you value?' While the expectation was that teachers would come up with more obvious values such as logical thinking and experimental evidence, the list they produced was somewhat richer than anticipated, as indicated by the summary of their responses generated at the professional development sessions, and reproduced in Figure 1 (left).

The list in Figure 1 demonstrates that these teachers consider a wide range of values to be associated with the science they teach. Expected values such as the cognitive dimensions were present, but also present were values associated with science as a process that can also be used in ways that are not clearly identified as scientific. For example, being able to ask questions is seen as important in the scientific process, but is also central in many other pursuits. Science was clearly seen as a human endeavour, with human qualities featuring in the list, and a human endeavour that is embedded in society. The category of school science that emerged from the teacher responses was also an important one as it implies that school science by its very nature must be different from science and have different values associated with it.

The list in Figure 1 is an example that there is acceptance, among teachers at least, of values in science education, but it appears that there remains

very broad and vague perceptions by teachers of what values are.

Doing science matters

My PhD research (Corrigan, 1999) found that secondary school chemistry teachers have well-developed notions of the nature of scientific knowledge, a realistic perspective of the role science plays in society, the authority of science in society and scientific research being purposeful. However, their notions on the way scientists work, the reward system that operates for scientists and the communal nature of scientific work remained relatively naïve. This has implications for the teaching of chemistry as the societal aspects of chemistry will be represented largely by the authority role science has in society in developing content knowledge that has purpose. It will not include the activity of scientists in creating an acceptable body of knowledge, or the procedure of obtaining recognition in science through research and the publication of research – the practice of chemistry was absent!

The practice of science is not bound by regimes such as in the Scientific Method, which I believe only exists in school science and not in Science. There is research around the work of scientists (Latour & Woolgar, 1976) and what can be recreated, modelled and considered in the science classroom. Osborne (2000) has talked about the role of argument in the science classroom, Hart et al. (2002) have talked about the role of practical work to name a few. The shift in more recent times to scientific investigations is responding to a need to engage students in more authentic approaches to the way scientist's work and communicate their ideas. Hence the role of discourse and argumentation become crucial in developing more authentic work practices within the science field. But these approaches do

not capture the large field of vocational science, which is more competency-based and sometimes about mastery. Coles (2002), Gaskell (2002) and Corrigan (2002) have outlined how the practice of science in these contexts can take many forms. For example, a lithographer requires quite sophisticated chemistry knowledge, but this knowledge is only known in order to master techniques of etching.

Purposeful teaching

One of the most difficult things to do as a teacher is to have a clear purpose for why you are doing something and plan ways to provide evidence that you know this has been achieved. It is something I try to model in my own teaching and a constant plea that I make to pre-service teachers and experienced teachers alike. Over the last couple of years, I have been focusing more on two things – tracking the learning of my students and myself, particularly through learning logs (Korthagen, 2001) and re-examining both my own (and also as a teacher educator, my students') development of pedagogical content knowledge or PCK. Shulman (1986) conceived that PCK acknowledged the importance of the transformation of subject matter knowledge into subject matter knowledge for teaching. PCK is the knowledge of how to relate specific content in a way that all students can learn it. There is an increasing number of research studies in this area in science (for example, Loughran et al, 2006) and, while many of these studies explore traditional science content such as Forces, The Particle Model and Cells, I believe PCK has the potential to explore science knowledge of different types and in multiple contexts. For example, what, if any, is the PCK that a master lithographer uses to pass on his skills and knowledge to an apprentice. These are areas yet to be explored. However, the benefit of PCK is that

the teacher must critically examine what, why and how they are teaching something and provide evidence of what learning has been achieved if they are to develop their PCK further.

Rebecca and Vojtech's Story – making sense of our world using science

Rebecca and Vojtech's story has raised a number of questions. For example, the question 'Is teaching science's role in society teaching science?' might be answered by explaining that I believe they have it the wrong way around. Since science is a creation of society, embedding it in a social construct should be science. However, I believe that the power in Rebecca and Vojtech's story is more about raising questions and taking a value position of one's own on a range of things that are important in teaching and learning science than actually answering these questions – context, purposeful learning and the application and use of knowledge, doing science, and purposeful teaching that can help lead to using science to help make sense of your world. Values are a fundamental part of science (and many other areas) and should be a fundamental part of science education. Unfortunately, they are often left out of science education. I think what Rebecca and Vojtech are doing is putting them back in and consequently, the science education in this instance is far more authentic science than what they or their students have experienced previously.

I think Rebecca and Vojtech's story begins to achieve what I have represented above as the current thinking about science and science education. They are re-examining the contexts they use, the learning and use of knowledge, getting their students doing science, re-examining their own teaching and their purposes in

an effort to help students use science to make sense of their world. And we need to be explicit about this to students so that they can take an active role in making meaning of this science in their world (and not only the teachers' world). Science should explain the natural world and if you take the students' natural world, then the explanations that follow look vastly different from what is often represented in science education texts.

I think these are important things to think about if we are to really engage students in science. No wonder kids are confused about science – science educators are confused about science and its relation to science education.

Acknowledgments

I would like to thank Rebecca Cooper and Vojtech Markus for their wonderful teaching expertise and insights into their classrooms as colleagues in science teacher research.

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Re-thinking science education through re-thinking schooling



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Jim's work is not confined to the Australian Science and Mathematics School. He is currently chair of the South Australian Department of Education's 'Science & Mathematics Futures Innovations Committee', a board member of The Investigator Science & Technology Centre. He is also chair of the Veterans' Children's Education Board for SA and NT.

Abstract

The Australian Science and Mathematics School was designed explicitly to support a renaissance in the teaching of science and to improve the engagement of students in the disciplines of science through highly engaging authentic learning opportunities. The school has adopted an action research approach as a means of re-thinking the elements of schooling and of its science programs. Its working premise is that quality science education is embedded in quality schooling. Science is learned through an innovative interdisciplinary curriculum with a pedagogy aligned to the inquiry methodologies associated with deep engagement in scientific endeavour. The architecturally designed school has transformed the traditional, stereotypical roles of teachers and learners. A strategic partnership with Flinders University has been pivotal in promoting leading edge, emergent sciences in the curriculum and providing professional learning opportunities for staff. The school is now in its fourth year of operation and this paper reflects on key elements that define the school and its science education programs as innovative and transformative.

Introduction

The genesis and development of the Australian Science and Mathematics School (ASMS) was an innovative opportunity, and an opportunity to be innovative.

Almost always, new schools are established and built because of the pragmatic need to service the general education requirements of a new population of students and almost always around a comprehensive neighbourhood schooling model. There was no such driver for the establishment of the ASMS, its origins being driven by the need to explore

new ways of teaching and learning in science. An innovative opportunity was generated that continues to be pivotal in the generation of new ideas and new thinking.

The ASMS was never to be more of the same:

Policymakers and educators in the western world, are gradually realizing that traditional schooling has run its course and that trying to improve it by a policy of 'more of the same', is senseless. Yoram Harpaz (2000)

Students, educators and leaders are all learners at the centre of re-thinking schooling at the ASMS. Their working premise is that quality science education is embedded in quality schooling and they are all striving for what can be better, different, creative and innovative.

Deep thinking and communicating about core beliefs concerning learning and schooling generated six big ideas as 'perspectives for the future' for the ASMS. What would the ASMS do and be? The Australian Science and Mathematics School would:

- Respond to the current and future interests and needs of its students to establish critical and transparent models of excellence in science and mathematics education
- Provide a learning environment of leading edge and enterprise-oriented science, mathematics and technology
- Provide a learning culture for its students that derives from the learning culture of its staff, which in turn derives from their interaction with university and industry scientists and educators
- Prepare young people to be creative, critical, informed and motivated contributors responding to professional, personal and social issues

- Increase participation and success of senior secondary students in science, mathematics and related technologies and transforms students' attitudes to science and mathematics as career paths
- Be an agency for change and enhancement of science and mathematics education for the state of South Australia and then nationally and internationally.

ASMS Cycle of Re-Thinking

The development of the ASMS has been driven by an adaptation of models commonly associated with terms such as 'learning organisations' and 'action research' (Argyris & Schon, 1996; Senge, 1990; Dibella, 2003). The ASMS Cycle of Re-Thinking (Figure 1) is a representation of the interaction of pivotal factors that are explicitly identified as core to the achievement of the outcomes associated with the starting 'big ideas'.

The ASMS views itself as a development and research school that engages in a continuous cycle of planning, acting, studying outcomes of action and reflecting collaboratively in order to develop new knowledge and levels of understanding. This in turn informs planning for subsequent action.

Re-thinking the science curriculum

The ASMS is attempting to better understand how to liberate science teaching from rigid preoccupations about what needs to be learned, in what sequence and when. It has responded by developing an interdisciplinary curriculum and a pedagogical approach for its Year 10 and 11 students that enables student-directed learning which is responsive to students' interests. It is a

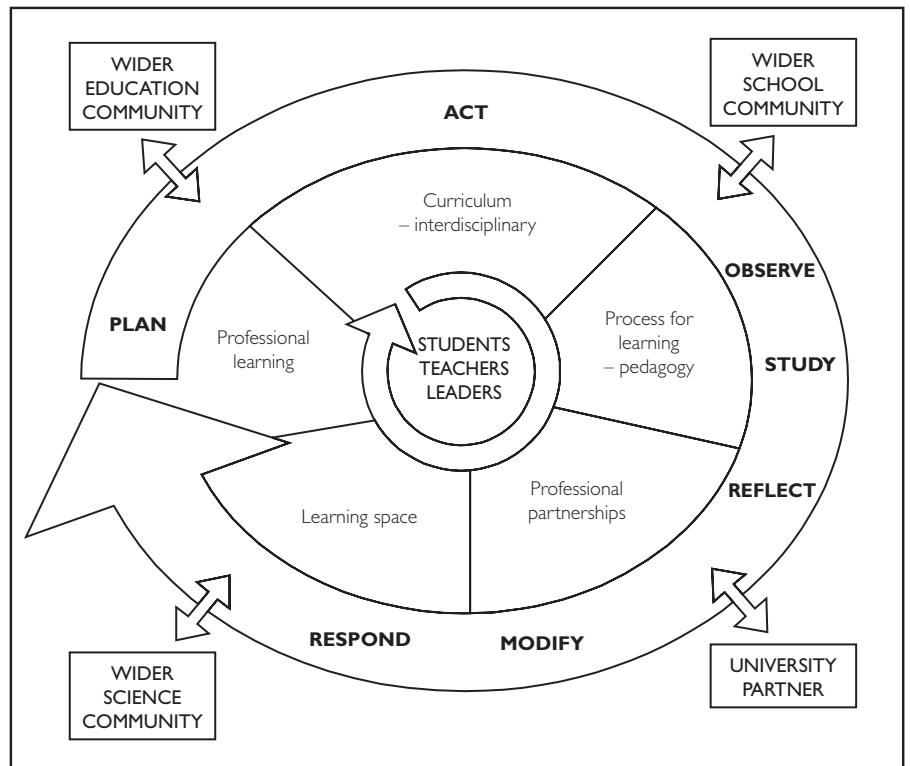


Figure 1 ASMS Cycle of Re-Thinking

curriculum designed to facilitate learning connections across the traditional disciplines and to give confidence that a depth of discipline knowledge and understanding will be gained.

The constructs that provide pathways into higher education are such that Year 12 students remain locked in the state-wide syllabuses describing the traditional disciplines of physics, chemistry and biology.

Learning is structured in Central Studies, around some key themes such as 'Towards Nanotechnology', 'Earth and Cosmos' or 'Sustainable Futures'. These themes liberate science from being seen as a set of narrow technicalities. The interdisciplinary studies are shaped by a curriculum framework (see Figure 2) designed to facilitate deep engagement with essential scientific knowledge, skills and attitudes across the key science disciplines and connect with projects of major significance that may involve

university and workplace studies. Students and staff are weaving scientific understanding and logic into cultural, social, historical, legal and ethical perspectives, generating meaningful and connected understandings about the world for students.

The development of a science education program that engages students with opportunities for learning at the leading edge of enterprise-oriented science has been a significant priority. Predictably, students' future endeavour and their occupations will be aligned with these sciences and technologies. Re-shaping science curriculum for the inclusion of leading-edge science is a significant vehicle for extending the levels of student engagement in learning science. Traditional teaching and learning in schools does not speak to students about the science and technology of satellite navigation, biomimetics, laser tweezers, intelligent polymers, quantum

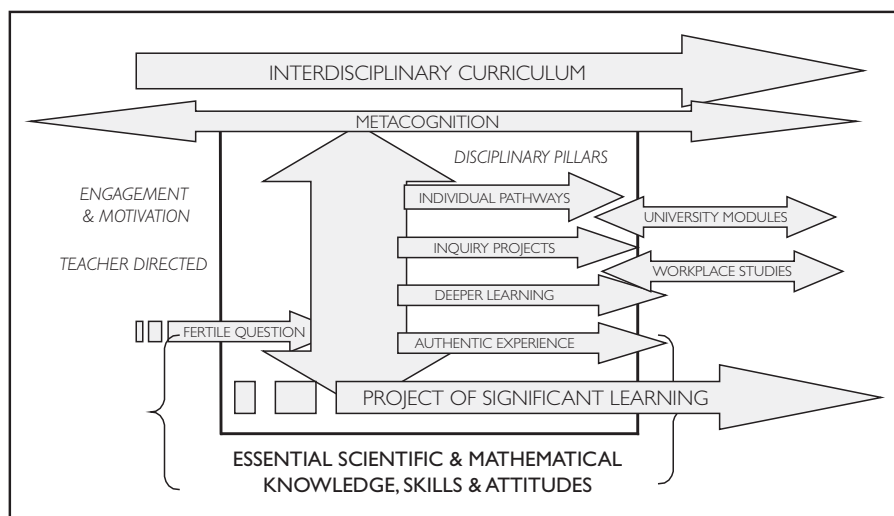


Figure 2 ASMS Central Study Framework

computers, artificial photosynthesis or other emergent technologies that will dramatically change our lives in the near future. A significant focus for curriculum development has been the search for the foundational science that shapes the 'disciplinary pillar' at the centre of each Central Study. Opportunities for learning and deep understanding of the emergent sciences emanate from the disciplinary pillar.

Through the development of 'University Modules', the ASMS has also developed an enrichment and extension curriculum that engages students with snapshots of leading-edge science. University academics tend to take the lead in 'University Modules' with teachers working alongside. The modules allow students to delve deeper into a scientific aspect connected to one of the Central Studies, with some elements finding their way into the core of the Central Studies, supporting further re-generation of curriculum.

The innovative curriculum at the ASMS has been generated from extensive consultation processes and redefines the traditional concept of curriculum in senior secondary education. The curriculum achieves a validity and depth endorsed by practising scientists

and educators. The curriculum is ever evolving as new content and new pedagogical approaches to the teaching of this content emerge. An emergent curriculum, reflective of emergent science, is under development.

Re-thinking learning space

The design of the ASMS building moves away from architectural-pedagogical paradigms that reinforce teacher-centred pedagogical practice and define the traditional power relationship between teacher and student. It is designed for highly collaborative and interactive, student-directed approaches that transfer the power of adolescent social interaction into the learning environment. It allows for students to work independently, interacting in small groups or engaged in direct instruction in groups ranging in size from two to two hundred.

Flexibility and adaptability in the use of space, by both teachers and students, supports a wide variety of teaching and learning activities and styles. Teachers' work spaces are open areas. These merge with 'learning commons' and facilitate ready access

by students throughout the school day. Open, multi-purpose 'studios', where students' primary activities are focused on scientific inquiry, have replaced conventional school laboratories where experimental replication has been the predominant point of engagement for students. Social space merges with physical learning space which, in turn, merges with e-learning space.

The fundamental idea of the ASMS is to be a collaborative learning community where the teacher's predominant role, defined as learning coach, mentor and 'guide on the side', is enhanced by this architecture. The developed concept of a collaborative learning community facilitates the aggregation of critical intellect that, in some ways, emulates that which is typically attributed to scientific research projects.

Re-thinking processes for learning

This architecture facilitates learning that draws on and transfers the power of adolescent social interaction into the learning activities. This fosters high levels of collaboration between students and among teachers and students. The talking, doing, watching and thinking that fosters and generates youthful exuberance and powerful learning in social constructs is applied and adapted to shape rigorous learning in the school.

Through adaptations of Harpaz's 'Community of Thinking' model, teachers at the ASMS are planning learning activities and developing the artefacts to support learning with the following predominant approaches:

- *Talking*: Open-mindedness and the ability to adapt to change is supported by simulations, teamwork, experimentation, ideas generation, problem solving, inquiry projects, discussion, analysis and argument in interactive settings.

- *Doing:* Students are actively engaged in experimentation and investigation assisting them to make connections between their learning and the real-life application of the learning. They are supported in practising and applying their learning and developing models for replication. They are challenged to get things done, to implement solutions and to discover what really works.
- *Watching:* Students are provided with the opportunity, time and space to observe and reflect on experiences. They are engaged in observing, listening, researching and reviewing with an emphasis on understanding ideas and situations from different perspectives. Students are challenged to see and develop different solutions to challenging, 'fertile' questions where objectivity and astute judgement is important.
- *Thinking:* Students are engaged in significant inquiry projects where they are formulating conceptualisations of situations in order to generate theories, models and conclusions that add to their understanding of the situation. Skills of critical analysis and creative thinking are highly valued and supported through the provision of explicit thinking time.

The teaching practice at the ASMS is variously summarised as being collaborative, inquiry-based, and student-centred, constructivist learning. It is applied in a comprehensive, interdisciplinary curriculum framework and is clearly focused on supporting students to think independently and critically and to gain a deep understanding of concepts, in particular around science.

Re-thinking professional partnerships and processes for professional learning

The ASMS is a place where students, teachers, university scientists, parents and community members mutually connect, contextualise and engage in the learning. The provision of a learning culture for its students that derives from the learning culture of its staff has been a pervasive and enduring intent.

The development of a strong partnership with Flinders University has been an integral component supporting the re-thinking. Opportunities for teachers of science to focus on developments in scientific knowledge and methods have come through co-construction of science education programs by teachers and research scientists. Teachers and scientists have worked side by side on the development of curriculum and laboratory activities, on reading and analysing current scientific writings and through participation in science research conferences.

Reflecting on the re-thinking

An innovative, inviting and engaging school culture has been created. It is heard in the voices in the school's buildings; the teacher's voice which is confirming, encouraging, acknowledging and challenging; the student's voice which is excited, confident, inquisitive, sharing and launching into other places. It is generated through exciting curriculum and interdisciplinary teaching where the focus is on connected, student-driven learning and not the confines of traditional subjects. A commonplace activity in the ASMS is telling and listening about learning, and especially learning about learning.

The foundation beliefs on which the ASMS is staking its future are really important for all in the school community. These are being continually worked through and explicitly articulated. A shared sense and awareness is emerging of what it is that drives and supports the behaviours, actions and ethics of the school. You can see people working in sync with each other. There is an awareness of what is happening elsewhere in the school and why. The foundations are in place that allow for a relentless focus on learning, in particular in innovative science. Students are increasingly articulate about their learning, the degree of rigour in the curriculum, their level of engagement with the learning activities, the quality of the relationships in the school community, their learning outcomes and myriad other indicators of importance to their lives. Their benchmarks are the most important of all and attentiveness to these voices will drive future innovative practice.

Reflection is a constant within the ASMS Cycle of Re-Thinking. What our students feel, say and do is of primary interest and importance. Student opinion about their schooling has been collected through the use of the ACER: School Life Questionnaire (see Table 1).

The students' opinions about their schooling experiences provide general support for the directions taken in the re-thinking within the development of the ASMS. The high levels of agreement expressed by students in relation to their feelings about their social integration at the school are consistent with the significant focus on collaborative learning and the sense of a positive community culture that prevails in the school.

The intention to move away from architectural-pedagogical paradigms that reinforce teacher-centred pedagogical practice and define the traditional power relationship between teacher and student is supported by the students'

Table 1 Student Opinion: ACER: School Life Questionnaire (2005 ASMS cohort)

	Percentage Agreement							
	Year 10		Year 11		Year 12		All	
	2004	2005	2004	2005	2004	2005	2004	2005
General satisfaction	71	78	80	69	67	69	73	72
Teacher items	87	85	83	78	85	83	85	82
Relevance items	86	76	84	74	75	76	82	76
Success items	81	74	86	78	68	75	79	76
Status items	69	70	73	72	71	70	71	71
Social integration items	88	88	88	86	91	88	89	87
Negative affect items	18	23	19	21	32	29	23	25

affirmation of their level of satisfaction with teachers and the teaching that they receive. With this context in mind, it is also useful to note the increase in 'negative affect' alongside the decreasing agreement in 'general satisfaction' as students move into their final year of schooling and are faced with state-determined syllabuses and high stakes examinations where students have significantly less opportunity to negotiate and direct their learning.

The learning outcomes of the first cohort of students to complete their final three years of schooling at the ASMS are also reaffirming. These students came to the ASMS from a diversity of backgrounds, from over 40 different feeder schools, from all areas of South Australia, from a range of socioeconomic backgrounds and from a range of cultural backgrounds. Their interest in science, not their ability in science, was used as a criterion for enrolment. Using South Australian

Certificate of Education school exit measures, this cohort achieved well above the means for all students in South Australia. Thirty-two per cent of the ASMS students were in the 90th percentile and 52 per cent achieved results that put them in the top 20 per cent of students in the state.

Such outcomes are welcome data as the ASMS moves forward in its quest to re-think schooling for students in the senior secondary years. However, the leaders and staff of the ASMS along with their University colleagues recognise there are still many factors to re-think including the tracking of graduates from the ASMS to see if careers in science and mathematics are pursued; the challenge of providing interdisciplinary and personalised learning while state-based examinations still assess on a discipline specific basis; and attracting appropriately qualified staff ready to work in innovative ways. The re-thinking continues.

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Science achievement in Australia: Evidence from national and international surveys



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Sue has worked on the Longitudinal Surveys of Australian Youth programme, and has managed the Australian component of Schools around the World, an international project examining assessment in science and mathematics, and Project Good Start, which examined children's numeracy in the transition from preschool to the first year of school.

Abstract

What can we say about science achievement in Australian schools? Does it really need a boost? Is science education in Australia engaging and motivating, or is the curriculum irrelevant and students disinterested? Are there particular issues for Indigenous students? Within the National Testing Program, Australia participates in two major international studies with a partial focus on science: the Trends in International Mathematics and Science Study (TIMSS), conducted with Year 4 and Year 8 students and managed by the International Association for the Evaluation of Educational Achievement (IEA); and the OECD Programme for International Student Assessment (PISA), conducted with 15-year-old students. In addition, the Longitudinal Surveys of Australian Youth (LSAY) program provides us with evidence about the outcomes of education, and the TIMSS Science Video Study provides us with a comparative view of the Australian science classroom and describes its practices. The presentation utilises data from these studies and examines what we know about science teaching in Australia, what students know and understand about science, whether they are interested in science, and whether they continue to study the sciences.

Introduction

The theme of this conference is 'Boosting science learning'. Before we can look at whether science learning needs a boost, however, we should look at the evidence about achievement, about whether students find science engaging and motivating, and whether there are particular issues for particular sub-groups of the population. This paper examines the evidence from Australia's participation in two major international studies that have a partial focus on science: the

Trends in International Mathematics and Science Study (TIMSS), conducted with Year 4 and Year 8 students and managed by the International Association for the Evaluation of Educational Achievement (IEA); and the OECD Programme for International Student Assessment (PISA), conducted with 15-year-old students. Further evidence from the Longitudinal Surveys of Australian Youth (LSAY) program will be examined to ascertain students' participation in sciences at the post-compulsory level, and from the TIMSS Science Video Study to describe the practices in Australian science classrooms. The presentation utilises data from these studies and examines what we know about science teaching in Australia, what students know and understand about science, whether they are interested in science, and whether they continue to study the sciences.

What do we know about science teaching in Australia?

There are two sources of evidence about science teaching in Australia. Firstly, we have data from the teachers of the TIMSS students – not a random sample of teachers but the teachers of a sample of students whose class was chosen randomly. Secondly, we have the TIMSS Video Study, which was a highly intensive examination of Year 8 science teaching in five countries. In Australia, 87 schools participated and the teacher of the science class was filmed for one complete Year 8 science lesson.

The TIMSS survey focused on factors such as teachers' backgrounds, readiness to teach, participation in professional development, and teachers' perceptions about factors limiting instruction. A key element in what students have learned is the amount of time given to teaching science. At Year 4, students

in Australia spent about 5 per cent of their instructional time learning science, which is the third lowest proportion of all countries participating in TIMSS at this level and significantly less than the international average. The proportion of instructional time varied from 16 per cent for the Philippines to 3 and 4 per cent in the Netherlands and Norway. Australian students in Year 8 spent, on average, 13 per cent of their instructional time on learning science, which was similar to the international average and the instructional time spent in 'like' countries such as the USA, England and New Zealand.

Data from the TIMSS video study suggests that Year 8 science lessons focus in some way on high content standards and expectations for learning. Of course the definition of high content standards varies from country to country. In addition, the data suggested that a common content-focused pedagogical approach was used in all of the higher-achieving studies examined.

A number of other teacher characteristics from the TIMSS teacher questionnaires will be discussed along with their relationship with levels of achievement in science. Also examined will be the blueprint 'ideals for science education in Australia' as described in the TIMSS science video study, and their relationship with what was actually observed in the classrooms.

What science do students know and understand?

PISA

The OECD considered science to be so pervasive in modern life that it is important for the future citizens of a country to be scientifically 'literate'. The OECD defined scientific literacy as 'the capacity to use scientific knowledge, to identify questions and

to draw evidence-based conclusions in order to understand and help make decisions about the natural world and the changes made to it through human activity'. PISA was developed to monitor educational outcomes and, because of its cyclical nature, is able to monitor trends in performance over time. PISA allows us to make comparisons of achievement in scientific literacy across OECD (and other) countries. The focus of each cycle of PISA rotates through the three major domains – reading literacy (2000), mathematical literacy (2003) and scientific literacy, which has been the major domain examined in the recent data collection for PISA 2006. In each of the years 2000 and 2003, scientific literacy was examined as a minor domain, and when the data analysis for PISA 2006 is complete we will achieve a complete picture of scientific literacy in the final year of compulsory schooling.

From the PISA assessments to date we are able to group Australian students with countries such as the Netherlands, New Zealand, the Czech Republic, Hong Kong, China and Canada. These countries scored, on average, at a significantly lower level than Finland, Japan and Korea but significantly higher than the OECD average and higher than a group of countries including France, Germany and the USA. The average achievement level of Australian students remained the same since PISA 2000, and, as in PISA 2000, there were no gender differences in scientific literacy in Australia.

The average achievement level of Indigenous Australian students in scientific literacy was significantly lower than that of non-Indigenous students and significantly lower than the international average. These results were very similar to the results in PISA 2000.

TIMSS

The 2002 TIMSS assessment continues Australia's participation in international studies in science, extending back to the First International Science Study in 1970. The present study is the third combined mathematics and science study in which Australia has participated since 1994, and provides the opportunity to build a comprehensive picture of trends in, and patterns of, achievement in science at Year 4 and Year 8. TIMSS uses the curriculum as the major organising concept in considering how educational opportunities are provided to students and how students use these opportunities, and science is assessed in each cycle of the study. There are three content domains defined at Year 4: Life Science, Physical Science and Earth Science, and five domains defined at Year 8: Life Science, Chemistry, Physics, Earth Science and Environmental Science. As well as reporting overall science scores and scores in each of the defined domains, TIMSS also developed four international benchmarks, ranging from an advanced benchmark to a low benchmark.

At Year 4, Australian students scored significantly higher than the international average, statistically similar to that of students in countries such as the Russian Federation, the Netherlands, New Zealand, Belgium and Italy. This group scored at a significantly lower level than the high-performing countries – Singapore, Chinese Taipei, Japan, Hong Kong China, England, the USA and Latvia.

Australia's level of achievement at Year 4 is the same as it was in TIMSS 2002. Of the countries that participated in both TIMSS 1994 and TIMSS 2002, almost half had an average score in 2002 that was significantly higher than Australia's, compared to only one country in 1994.

The achievement of Indigenous students at Year 4 was about three-quarters of a standard deviation lower than that of non-Indigenous students, and was significantly lower than the international average. This indicates a relative worsening of the position of Indigenous students from TIMSS 1994.

At Year 8, Australia's score was again significantly higher than the international average. This score was statistically similar to the scores of students in the Netherlands, the USA, Sweden, Slovenia and New Zealand, but statistically lower than that of students in Singapore, Chinese Taipei, Korea, Hong Kong, Estonia, Japan, England and Hungary. Australian students' scores in science significantly increased from TIMSS 1994, as did those of several other 'like' countries.

The achievement of Indigenous students at Year 8 has significantly improved since TIMSS 1994 – in comparison, the performance of non-Indigenous students remained statistically the same.

Examining the percentage of students who attain the benchmarks in science is also informative. In Year 4 science, 9 per cent of Australian students reached the advanced international benchmark, a significant decline from the 13 per cent who attained this level in TIMSS 1994. Ninety-two per cent of Australian students achieved the 'low' international benchmark, which is similar to the proportion in TIMSS 1994; however, this low benchmark only states that children 'have some elementary knowledge of the earth, life, and physical sciences'. As a developed country, we should think about what an acceptable measure of scientific knowledge should be. The intermediate benchmark is that 'students can apply basic knowledge and understanding to practical situations in the sciences'. If this is a minimum standard, only

three-quarters of our Year 4 students attained that standard.

A very similar picture can be painted for Year 8 students. Nine per cent of students attained the advanced international benchmark, a similar proportion to TIMSS 1994. The low benchmark is described at Year 8 level as 'students recognise some basic facts from the life and physical sciences'. Only 5 per cent of students were unable to attain this benchmark, compared to 11 per cent in 1994. The intermediate benchmark states that 'students can recognise and communicate basic scientific knowledge across a range of topics'. Around one-quarter of Year 8 students did not reach this benchmark; however, this was an improvement from the 31 per cent who failed to reach it in the TIMSS 1994 assessment.

In TIMSS 1994, there were gender differences for Australian students at Year 4 (males performed significantly better than females) but none at Year 8 level. Internationally, all significant gender differences at Year 4 and Year 8 were in favour of males. In TIMSS 2002, however, gender differences internationally were not consistently in favour of males. In a number of countries, there were large gender differences at both year levels in favour of females. In Australia, however, the gender equality seen in TIMSS 1994 had disappeared – males scored around one-fifth of a standard deviation (about 20 score points) higher than females.

At Year 4, few gender differences were evident in the attainment of benchmarks. At Year 8, twice the proportion of male than female students achieved the international benchmark, and slightly fewer males than females failed to achieve the low benchmark. Only 3 per cent of male Indigenous students attained the advanced international benchmark; no female Indigenous student attained

this level. More than 60 per cent of Indigenous female students and 40 per cent of male Indigenous students did not achieve higher than the lowest benchmark.

Are students interested and confident in science?

Evidence about students' attitudes to science is currently gathered from the TIMSS studies. There are questions in PISA but they are set in the context of mathematics for the recent cycle. Students at both year levels were asked to report on their levels of self-confidence in science and whether they enjoy learning science, and Year 8 students were asked the level at which they value science and whether in the future they envisaged a job involving science.

Self-confidence

Australian students generally reported quite high levels of self-confidence, with 66 per cent of Year 4 students and 49 per cent of Year 8 students at the high level of the self-confidence index. In Australia and internationally there is a positive relationship between self-confidence and achievement; however, curiously most of the highest scoring countries had relatively low percentages of students with high levels of self-confidence.

At Year 4 there were no gender differences in self-confidence in science; however, at Year 8 a significantly higher proportion of males reported a high level, and a significantly higher proportion of females, reporting a low level of self-confidence.

Although at least two-thirds of all Indigenous students report having either a medium to high level of self-confidence in learning mathematics, there are still a large proportion

of Indigenous students (both male and female) who indicate low self-confidence in undertaking science study. Of the female Indigenous students, one-third report low self-confidence in learning science. For the male Indigenous students, this figure is closer to one-quarter.

Enjoyment of science

The degree to which students enjoy learning science has some association with science achievement, and it almost certainly has an association with engagement in science leading to continued studies in the area. Most (87%) Year 4 students agreed that they like science to some extent, falling to about two-thirds (67%) of Year 8 students. Australia was one of a small number of countries that showed a significant increase, at both year levels, in the proportion of students who agreed 'a lot' that they enjoyed learning science.

Valuing science

In Australia, the level of students' valuing of science is lower than the international average – only 36 per cent of Year 8 students placed a high value on learning science; however, the correlation between valuing science and achievement (0.26) is higher than the international average. There were significant gender differences evident, with 40 per cent of males and only 33 per cent of females placing a high value on learning science. Only 18 per cent of students were confident that they would like a job involving science, while a further 24 per cent were lukewarm about the idea.

Those Indigenous male students who indicate a high valuing of science performed at a level similar to the non-Indigenous national average. However, those Indigenous female students who report a similar high valuing of science still achieved scores significantly below

that of the international and non-Indigenous national averages.

No relationship was found between self-confidence in learning science and science achievement for either male or female Indigenous students. However, the higher a male Indigenous student valued science, the more likely it was that they achieved at a level that was similar to the non-Indigenous national average for science achievement. Unfortunately, for the female Indigenous students, none of the examined attitude variables (self-confidence, enjoyment and value in learning mathematics or science) appeared to improve female mathematics and science achievement to a level similar to the non-Indigenous national average.

Educational aspirations

Australian students had somewhat lower educational aspirations on average than their international classmates. Internationally, 54 per cent of Year 8 students reported that they expected to complete university, compared to just 40 per cent of Australian students. Those who expected to finish university had substantially higher science achievement levels than those who did not.

Almost one-third of female Indigenous and one-quarter of male Indigenous students wish to complete TAFE; however, the number of Indigenous students who wish to continue with tertiary studies and complete a bachelor's degree is around half of the proportion of non-Indigenous students with similar aspirations.

Do students study science when it's not compulsory?

TIMSS and PISA have provided us with evidence about the achievements, attitudes and self-confidence of

Australian students in a global context. This section of the paper looks at whether this translates into enrolments in science-related areas at the level of schooling when studying science is not compulsory. These data are derived from the *Longitudinal Surveys of Australian Youth* (LSAY), which tracks students from the middle years of secondary school until they are in their mid-twenties, and from its predecessor, the *Youth in Transition Survey* (YIT).

Of the Year 12 students who participated in the 2001 data collection for the 1998 cohort of LSAY, 55 per cent were studying one of the sciences. Almost four in ten students were studying at least one subject in the biological sciences area and about one-quarter were studying at least one subject in the physical sciences area.

Enrolments in chemistry and physics have declined in the period 1993–2001, from about 23 per cent to 18 per cent in chemistry and from 17 per cent to 15 per cent in physics. Enrolments in biology also decreased, from 32 per cent in 1993 to 25 per cent in 2001.

So who is it that studies the sciences at this level? The data suggest two answers to this question, depending on whether it is biological sciences or physical sciences. Females were much more likely than males to be enrolled in biological sciences, males much more likely than females to be enrolled in the physical sciences. There seems to be a tendency for those in the highest achievement levels, and for those from higher socioeconomic backgrounds, to enrol in the physical sciences rather than in the biological sciences. The profile of those enrolled in the physical sciences is high achiever, male, parents from high socioeconomic background, high levels of parental occupation and education, and with a language background other than English. Further analysis found that students who had studied in the physical sciences area

were much more likely to go onto higher education (about 80% did so), while of those who had studied 'other sciences', around one-quarter did not participate in any further education or training, about 40 per cent went into higher education and the remaining third into some form of vocational education and training.

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Creating powerful teacher education opportunities: The need for risk, relevance, resource, recognition, readiness and reflection



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Abstract

Two projects described in this paper illustrate what a successful teacher education model can look like, what its aims were, what happened in terms of teacher professional development, and what pupils accomplished as a result. The paper also describes policies, organisational features, resources, and relationships that informed the projects. In effect, both projects involved a community of teachers, educators and scientists working to develop resource materials involving various technologies for classroom use. Data was collected through teacher surveys, online dialogue, interviews, pupil work, teacher 'show and tell' and limited classroom observation. The data suggests that pedagogic change warrants the presence (in some fraction) of the six elements of relevance, recognition, reflection, resource, risk and readiness. The extent to which these factors were present influenced the pace of pedagogic change. The extent to which teachers made judgements about these facets determined the scope of the pedagogic change.

Introduction

A relevant science education is at the heart of an innovative, knowledge society (National Academy of Engineering, 2005) if it is to produce sufficient numbers of qualified scientists and produce a scientifically aware public (Science Strategy for Scotland, 2001).

In Scotland, The Public Attitudes to Science and Engineering Scottish Comparison Report (Scottish Executive, 2001) showed that 65 per cent of Scots have no formal qualification in any science subject. Not surprisingly, in Scotland, the last few years have seen significant calls to address this situation, and possibly as a consequence, Scotland

has pursued ambitious courses of action. For example, the Curriculum for Excellence (Scottish Executive, 2004) is seeking to promote a 'less crowded and better connected' curriculum that offers more 'choice and enjoyment'. Science for 3–18-year-olds became the first subject nominated for review. In 1999, the HMI reviewed assessment arrangements, because evidence suggested that assessment for primary and the first two years of secondary schooling was fragmented (Hutchinson & Hayward, 2005). The Assessment is for Learning project is trying to develop informed policy by involving teachers, schools, local authorities and teacher educators (Hutchinson & Hayward, 2005). In 2001, the £800 million National Agreement 'A Teaching Profession for the 21st Century' (McCrone) agreement resulted in the following: teacher salary increases; a 'chartered' teacher route to financially reward classroom expertise; proposals for cohesive teacher education programs, including guaranteeing all probationer teachers a post in their first year, and a list of teacher competence statements. The agreement provides contractual understanding for professional development and requires teachers to maintain a professional development record that takes into account their individual needs as well as school, local and national priorities.

In tandem with planned reforms, some modifications were driven by circumstance. For example:

- The lack of availability of teacher managers has probably created 'faculties' in schools.
- There were concerns regarding the gap in cognitive demand between 'Standard Grade' and 'Highers'. Some schools opted for the Higher Still program with Standard Grades being replaced by Access,

Intermediate 1, Intermediate 2, leading to Highers and Advanced Highers.

- Primary school teachers were encouraged to include more and more technology, and to be more accountable for the quality of science provision.

The literature on the use of technology in science classrooms in terms of the potential of dataloggers, CD ROMS, simulations, multimedia authoring, modelling, computer- assisted learning, integrated learning systems and the internet (Newton, 2000; Orion, Dubowski & Dodick, 2000; Rodrigues, 2002; Pallant & Tinker, 2004; Watson, 2001; Rogers, & Newton, 2001; Nachmias, Mioduser, & Shemla, 2000) was growing. However, Cuban (2001) in the USA and Smeets and Mooij (2001) in Europe were signalling that though resource levels in schools had increased, informed use had not. This concern was registered in Scotland (Stark, Simpson, Gray, & Payne, 2000), with Williams, Coles, Wilson, Richardson and Tuson (2000) reporting that mathematics and science teachers displayed more negative attitudes and lower use of information communication technologies. It was argued that even with financial support to purchase equipment or provide professional development for teachers, most teachers continue to use the technology to reinforce existing practice (Cuban 2001; Smeets & Mooij, 2001). Many failures to introduce innovation successfully have been shown to stem from the fact that the introduced innovation was not related to school practices (Fullan & Hargreaves, 1992). It is also possible that limited opportunity for reflecting on practice may result in teachers having limited occasions to communicate what they are doing in their own schools, much less with colleagues in other communities. Consequently, as Olson (2000) suggests these constraints do

not take into account the culture of classroom practice and the pivotal role of the teacher in bringing about change in their classrooms. The influence of science teachers on what and how to teach is often considered to have the most significant impact on student achievement, attitude and motivation. Teachers' personal beliefs affect the degree of pedagogic change, especially when ICT is being advocated (Becker, 2000).

A tale of two projects

Given these viewpoints and the opportunities that were arising as a consequence of various Scottish education reforms in pedagogy, curriculum and assessment, funding was sought for two teacher education projects that shared the same fundamental model of professional development, but involved different school-level cohorts. This paper compares and contrasts the successes, challenges and strategies for the continuing professional development projects. Both projects were designed to encourage teachers to adapt their practice to the changing conditions they face, and to purposely deepen their expertise. One project was aimed at primary school teachers, and the other project was aimed at secondary school science teachers. The use of information communication technologies to promote interest in science and help learners develop a better science understanding was the vehicle used to encourage teachers to develop their understanding of teaching and learning.

Both projects involved a community of teachers, educators and scientists working to develop resource materials involving various technologies to be used in their classes. The primary school project first phase involved 4 Scottish councils, 10 schools (16 teachers), 9 scientists, and 2 secondary

school teachers and took place over 10 months. The primary school project second phase involved 3 Scottish councils, 15 schools (17 teachers), 5 scientists, 2 secondary science teachers meeting over 5 months. Supply cover costs were met by the project, and ICT resources were provided. The community met once a month face-to-face and maintained online contact in between monthly meetings through a virtual learning environment (VLE).

The secondary school project first phase involved four teachers initially. The secondary school second phase involved teachers who were paid an honorarium and randomly divided into three groups, with each group managed by a project officer. They determined when to meet. But all the teachers had access to the VLE.

Data was collected through teacher surveys, online dialogue, interviews, pupil work, teacher 'show and tell' and limited classroom observation and externally commissioned project evaluations

Overall impact

Dr Joanna Le Metais evaluating the secondary school project and Professor Sally Brown evaluating the primary school project identified general areas of growth. These areas included substantive curriculum development, developments in teacher confidence levels and the noticeable impact of classroom strategies on pupils' learning and engagement.

The project data suggests that teachers who reflected on their practice and were ready and willing to take a risk with a facet of their teaching and learning environment, when they have their practice recognised and are provided with adequate resources and relevant support, are likely to produce more sophisticated classroom practice that reflects expertise that has been

consciously developed. In essence the project model involved:

Teachers demonstrating	Facilitator/ Programme providing
Readiness	Resources
Risk	Recognition
Reflection	Relevance

However, the intricate relationship between the six facets determined the extent of pedagogic change. The extent to which teachers made (contingent or deliberate) judgements about these facets determined the scope of the pedagogic change.

Resource in both projects included time, equipment and the support community. Both projects were well resourced in terms of time and equipment, but unequally resourced in terms of community support. This aspect of resource affected the nature of pedagogic change. For example, didactic project officers who continued to 'instruct' and who failed to recognise the teachers' expertise managed the secondary school teachers who produced 'usual' teacher materials and took few risks. These project officers assumed that the teachers' existing skills and accomplishments were of no consequence and that the teachers would benefit from being instructed by the project officers on which strategies to use. In contrast, the secondary school teachers who produced dynamic teacher materials that involved challenging or innovative classroom strategies were managed by project officers who were more open minded and attempted to model risk taking and learning with and from others.

The relationship between recognition and risk was signalled forcefully in the primary school project. Teachers who took the initial risk (tried something with their classes and reported it

during primary project 'show and tell' meetings) came to be recognised as expert teachers within the group. This recognition encouraged them to become more innovative. Some of the more hesitant primary school teachers who eventually took risks and modified classroom practice found their action was recognised and commended by peers, pupils, parents and grandparents. This recognition encouraged them to continue to change their practice.

The notion of readiness applies to teachers and schools. School leadership was crucial in determining the relationship between reflection and readiness. Teachers working in environments where change was not encouraged struggled to introduce new practices. Likewise, teachers who had not reflected on their practice were not ready for change.

The relevance of the project in terms of the reality of classroom practice was significant in determining pedagogic change. But the degree of relevance was influenced by reflection and resource. Stimulating interaction with peers, who recognised the challenges of the classroom, and the nature of engagement with scientists who were able to communicate science well encouraged teachers to review their practice.

Uninterrupted time, good working conditions and a supportive community reflect the basic premise that the work of teachers has a life beyond the individual, and that this will make a difference to the teaching profession.

Many of the primary school teachers, have gone on to have their practice recognised more formally (through HMIE statements, invitations to present at conferences, invitations to manage local council Continuing professional development (CPD) for other teachers and national newspaper coverage, or they have been short-listed for national teacher competitions). Most of the

teachers asked to be kept informed of future opportunities to engage in this type of professional development.

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Student interest in science: The problem, possible solutions, and constraints



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In this paper I want to draw on relevant research to address the theme of this year's conference in three ways:

1. The nature of the problem
2. Possible solutions
3. Constraints on these possible solutions

Part I: The nature of the problem

The quantitative decline in enrolments in the senior secondary sciences and in university, science, particularly higher achieving students, has been well publicised in Australia and, across the OECD and beyond.

I shall therefore focus on research that adds qualitative detail to the issues associated with lack of interest in science among students.

The place of science within the curriculum of schooling

Since 1950, the opportunities not to choose science study in senior schooling have markedly increased.

In a parallel but inverse manner, the unification of the university sector in 1989 has given students many more opportunities, in both the new and older universities, to choose courses other than science, and without the prerequisite constraints the science-related faculties still demand.

Employment opportunities

A recent study at Macquarie University indicates that there are good employment prospects, but that science graduates lack skills that Science and Technology (S&T) positions require in the new Knowledge Society. Declining enrolments in the sciences are associated with the perception that science study is too difficult compared to other subjects, as well as an ignorance of these career prospects.

In 2005, the Deans of Science commissioned a study that found that quite large percentages of teachers had not completed a major three-year sequence of undergraduate studies in the science subject area for which they were responsible. This study did not address the issue of the inadequacies of even a three-year major in science for a teaching career – raised 15 years earlier in the National Review of Science Teacher Education.

Being a science student

Independent studies of students' experience of science in secondary school have been reported by Lindahl in Sweden, Simon and Osborne in England and Lyons in Australia (see Lyons, 2006). These studies present remarkably concordant descriptions of school science as:

- Transmission of knowledge from the teacher or the textbook to the students (our opinions are not involved);
- About content that is irrelevant and boring to our lives; and
- Difficult to learn in comparison with other subjects

The Australian study only involved high achieving students, but most of these concluded *that further science studies should be avoided unless they were needed for some career purpose*. Intrinsic interest, in contrast to other subjects, was low.

The extent of this sense of irrelevance in Japan emerged from a nationwide survey of students in Years 6–9 in 2002. All subjects suffered from a steady decline in interest, but only science and mathematics remained in decline, when the intrinsic worth was considered (Ogura, 2003).

Large scale reviews of students in Australia by Goodrum, Hackling and Rennie (2001) and by TIMSS (ACER/IEA, 2003) found, respectively, that well

over half of secondary students did not agree that the science at school: was relevant to my present or future, or helps me make decisions about my health, and that 62 and 65 % of females and males in Year 4 like science, but by Year 8 only 26 and 33 % did so.

Part 2: Possible solutions

Guaranteed employment at higher than usual salaries would probably attract more students to stay with the enabling sciences in Years 11 and 12, and to undertake science-based university studies, especially if science was promoted like sport by the Australian media.

If Physics and/or Chemistry were made compulsory for all students to Year 12, more students may find them to their liking, and continue with them, although the experience of countries like Japan rather belies this.

These conditions, outside or inside schooling, are so unlikely, that I focus on what can be changed, with sufficient will and commitment, namely, how science is presented in schooling.

What research do we have about students' interests in science and science education?

Inspired teachers

Before discussing this research, I want to acknowledge the existence of inspiring teachers of science and of supportive school environments. Together they can produce positive interest in science their students, whatever the curriculum. However, we would not be meeting on this theme, if the extension of such inspiration across whole systems were a simple matter.

Students' interests

Focal questions

Beginning in the 1980s, Svein Sjøberg, in the **Science and Scientists (SAS)** project explored the reaction of 13-year-olds in a number of countries to different ways of focusing the learning of the same science content. A purposeful and relevant focal question heightened students' interest in science learning. For example, learning about:

Sound < How musical instruments make sounds < How animals communicate with sounds

Focal questions were introduced in the initial form of VCE Chemistry in 1991, but their intended use was thwarted by the examiners' total disregard of them.

Questions and topics

The **Relevance of Science Education (ROSE)** project (Svein Sjøberg, Oslo) grew out of the SAS project. To date, the ROSE project has data from 15–16-year-olds in more than 30 countries (Australia still collecting). Students have responded to long lists of science topics they might like to learn, interspersed with items about their personal and societal aspects of relevance to S&T.

Students in industrialised countries have shown great similarity of interest in ways that contrast with those of students in developing countries. The former are more interested in topics that rarely occur in school science, whereas the latter favour more traditional topics. Since Australian students are more like the former, I will use the report from England (Jenkins & Pell, 2006) to illustrate the findings.

- Most students agree that S&T are important for society.
- A lower level of agreement the science benefits outweigh possible harmful effects.
- Most students do not like science compared with other subjects.

- Most do not agree that school science has made them more critical and skeptical and more appreciative of nature.

The ten most popular topics for boys and girls are listed in Table 4.1 and the ten least popular ones in Table 4.2 of the English Report.

Curricular responses

In his recent book, *Science Education for Everyday Life*, Glen Aikenhead (2005) has provided positive research evidence concerning a number of innovative science curricula that can be described as Humanistic Science Education. Humanistic Science Education has a number of characteristics that contrasted with those of Traditional Science Education, by including the persons of the learners and of science.

Common features in these positively received approaches to science education are:

- Science as a Story involving persons, situations, action
- Real-world situations of S&T that students can engage with
- Focal questions that attract interest
- Contexts as the source and power of concepts in science
- Clearly presented science – related issues of personal and social significance
- Personally engaging, open problems for investigation.

Further evidence of positive student responses to science education with these features comes from the OECD's Programme for International Student Achievement (PISA). In the Science domain of this project, most if not all of these features have been incorporated into its assessment instrument for 15-year-olds in more than 30 countries in 2000 and 2003 for the scientific literacies (clearly defined as

competencies) that this project deemed important for life in the 21st Century (OECD, 2001).

The units in the test instrument consist of a 'real-life Science & Technology situation' about which a set of questions reflecting different competencies are asked. The real-life situations are reports or descriptions (sometimes stories of actual situations) somewhere in today's world that involve science. The real-life situations do not have to reflect the school curriculum for science. They are typical of science's place in 21st century society. In the 2000 testing, Australian students performed relatively well. While the performances overall were not particularly high, they were considerably better than the pessimists had predicted on this very novel test. The very substantial reading involved in the S&T situations had been of particular concern. In the testing of the Reading domain of PISA, girls in every one of the 32 countries outperformed boys, often very significantly. In the Science test, heavily dependent on reading, there were no gender differences among the same students in 26 of the 32 participating countries (repeated in 2003).

These remarkable findings can only be explained, I believe, in terms of the level of interest and engagement that both boys and girls had with these accounts of S&T-based situations. They certainly encourage the changing the school science curriculum to emphasise these features.

New curricula

21st Century Science is a new set of science courses for Years 10 and 11 in England that has included many of these features. It has also recognised that science education needs different courses at the same level if it is to meet the diverse needs and interests of students (Roberts, 1988). Its particular relevance for Australia since that it is a direct consequence of the major

rethinking of the role of science in compulsory schooling in England, the country most influential on science curricula in Australia in the 1990s.

The three subjects making up 21st Century Science began in 2004.

1. Core Science, a mandatory study for all students – a terminal study that can be summarized as Science for Citizenship
2. General Science, an optional study involving biology, chemistry and physics for students planning specialised study of these sciences in Years 12 and 13
3. Applied Science, another optional subject, to arouse students' interest in applications of science in modern society.

The rapid progress in enrolments and the interest of schools in this radical approach to school science warrant Australia giving serious consideration to it - especially the way it deals with students' needs and interests among the purposes for school science in the compulsory years.

Part 3: Constraints to solutions

With such an apparently rich set of positive options for improving the in-school response to the issue of lack of interest in science, what constraints stand in the way of implementing science curricula with these attractive possibilities? I refer to three major sources of constraint – science teachers, academic science, and systemic competing demands.

Science teachers

Informal investigations with science teachers in Australia, have made me aware that, however weak or strong their background in science studies, many of them are seriously deficient in *having any science stories to tell*, in

communicating within and from science, in *knowing science as a way of thinking*, and in *applying science in real-world applications*. None of these aspects of science as a human endeavour had been emphasised in their school or undergraduate science studies.

In theory, these could all be rectified, but they would require very comprehensive and continuing professional development, involving partnerships between organisations with practising scientists and the education system. The 10-year investment behind the new National Science Learning Centre in England is a model for the scale needed.

Academic science

Academic science in Australia has been reluctant to endorse changes in science curricula with Aikenhead's humanistic characteristics. For academic science, the sciences in schooling were preparatory and prerequisite for science-based study at university. Academic science has exercised control to maintain this situation directly, or indirectly through well socialised disciples among the teaching force. Undergraduate studies in the sciences have in turn been primarily introductory to careers in scientific research, leaving graduates for other careers, such as school teaching, deficient in aspects other than foundational conceptual knowledge.

Hitherto, there has been little pressure for academic science to alter its stance, but the current falling enrolments and failure to attract Science's share of higher achieving students means the scene has changed. It is a good time for academic science to give support and attention to the new roles that school science and undergraduate science might play.

Systemic competing demands

At this very time, two very different curriculum scenarios are being played out. Neither has taken seriously into account the crisis in interest that is our theme at this conference. Both, for different reasons, are unlikely to promote humanistic, contextual learning of science – our best understanding of how to engage more students enthusiastically with science. Indeed, it seems likely that in their own way they may cement in place the view of science that, I am arguing, needs to be replaced.

The first scenario can be found in Tasmania, Victoria and Queensland (and in New Zealand). In each case, decisions have been made to rethink the whole curriculum so that it reflects the demands on education for skill learning, that arise from the changing nature of work and from the revolution in information, the Knowledge Society.

To make room for a number of these new learnings, the customary content of a subject like science has been paired down to a smaller set, graced with the title 'Essentials' (although without clear criteria of essentialness). This is not to say that science teachers are excluded from contributing to the teaching/learning of the new priority skills, that in each of these new versions of the curriculum for schooling, appear in terms like Thinking, Communicating, Rich Tasks, Higher Order Reasoning and Problem Solving. These are like foreign language terms to science teachers, whose forte has been transmitting Established Knowledge (with just a dash of Science as Doing).

The second scenario is the National Consistency Project of the Commonwealth Government to which the states have been coerced to join to be eligible for federal funding. In this project, science is one of five areas in which a core of knowledge

is being specified for teaching in a sequence that has checks for learning at Years 3, 5, 7 and 9. This project seems to ignore completely the new skills of first scenario, and has chosen conceptual scientific knowledge as its core content for emphasis. By not prescribing phenomena or contexts to be commonly studied, the Consistency Project misses the fundamental characteristic of scientific concepts, namely, that they only exist because they have phenomenal (contextual) meaning. It also misses what could be a very justifiable and more engaging approach to consistency, namely, that all young Australians should study science-based issues (contexts) that impinge strongly on their lives as they move through the compulsory years, such as obesity, water availability, energy conservation, biological, chemical and nuclear weapons of mass destruction, and safe sex are just four of these key issues in Australia, with genetic engineering, nano-technologies, communication technologies also of significance.

My final concern about these systemic constraints is that should they become the basis for state-wide or national assessment, they will destroy the chance PISA has now shown us about making assessment, at last, authentic to science curricula that are aimed at increasing student interest in science and in the careers that science involves.

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Primary Connections: A new approach to primary science and to teacher professional learning



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Abstract

Primary Connections is a teacher professional learning program supported by curriculum resources that aims to enhance learning outcomes in science and the literacies of science. The program is based on an innovative model that links science with literacy, uses cooperative learning, integrates assessment with teaching and learning, and follows an inquiry process using open investigations. The program was trialled in 56 schools throughout Australia in 2005. Research has demonstrated that the program improves teachers' confidence, self-efficacy and practice, students' learning, and the status of science within schools. The project is an initiative of the Australian Academy of Science, funded by DEST and supported by all states and territories and sectors of schooling.

Introduction

Australia's currently buoyant economy is largely based on exploiting our nation's natural resources of coal, gas, iron ore, gold and other metals. All of these resources are finite and it is timely, at this conference, to focus on boosting science learning as a way of building human capital – the key resource for a knowledge-based economy – so that we can build a future based on ideas and innovation for those times when the natural resources are less abundant. Innovation depends on new thinking, and it is curiosity, creativity and scientific literacy that provide the basis for a knowledge-based economy. Opening minds to the wonders of the natural world, stimulating curiosity and creative thinking, and starting that journey towards scientific literacy requires a strong and effective science program in the primary years of schooling.

High quality teaching of science and literacy in Australian primary schools is a national priority to develop citizens who are scientifically literate and who can contribute to the social, environmental and economic well-being of Australia as well as achieve their own potential (Australian Academy of Science, 2006). Student achievement in science is therefore being monitored through the national assessments of Year 6 students' scientific literacy for which sample testing was undertaken in October 2003 and will be repeated in 2006. Parents also recognise the importance of science rating it as the third most important subject for their primary school children after English and Mathematics (ASTEC, 1997).

Despite science being recognised as a priority area of learning, the teaching of science in primary schools has low status with the second lowest allocation of time in the primary school curriculum averaging 2.7% of teaching time (Angus et al., 2004). Many primary teachers lack confidence and competence for teaching science (Appleton, 1995; Palmer, 2001; Yates & Goodrum, 1990) and consequently score poorly on self-efficacy scales that measure the extent to which primary teachers feel capable of teaching science effectively (Riggs & Enochs, 1990). The limited science discipline studies and science curriculum studies in many Australian initial teacher education programs (Lawrance & Palmer, 2003) gives student teachers little opportunity to build the pedagogical content knowledge (Gess-Newsome, 1999) required to be confident and effective teachers of science. The 2001 national review of the status and quality of science teaching and learning (Goodrum, Hackling & Rennie, 2001) indicated that the teaching of science in primary classrooms is patchy and recommended that primary teachers

Phase	Focus
Engage	Engage students and elicit prior knowledge Diagnostic assessment
Explore	Provide hands-on experience of the phenomenon
Explain	Develop science explanations for experiences and representations of developing understandings Formative assessment
Elaborate	Extend understandings to a new context or make connections to additional concepts through student planned investigations Summative assessment of investigating outcomes
Evaluate	Re-represent understandings, reflect on learning journey and collect evidence about achievement of outcomes Summative assessment of conceptual outcomes

Figure 1 The Primary Connections teaching and learning model (Australian Academy of Science, 2005)

of science be given access to quality professional learning opportunities supported by rich curriculum resources to address this problem. It also argued that collaboration between jurisdictions is essential to produce world-class resources and to reduce wasteful duplication of efforts. *The Primary Connections* program was developed in response to these concerns (Australian Academy of Science, 2006).

Recent national assessments of scientific literacy and international assessments of science achievement present a sobering picture of the health of primary science in Australia. Less than 60 per cent of sampled Year 6 Australian students in 2003 attained the national proficiency standard in six of eight jurisdictions (MCEETYA, 2005). The Trends in International Mathematics and Science Study (TIMSS) shows that the science achievement of Australian Year 4 students has remained stable between assessments made in 1994 and 2002 at a level that was above the international mean; however, countries such as

Singapore, Hong Kong and Latvia have made significant improvements between 1994 and 2002 (Thomson & Fleming, 2004). Seven countries scored significantly higher than Australia on the 2002 assessments (Singapore, Taiwan, Japan, Hong Kong, England, USA and Latvia), and most of these are our trading competitors in terms of knowledge-based exports.

Primary Connections

Primary Connections is an initiative of the Australian Academy of Science, funded by the Commonwealth Department of Science Education and Training, (DEST) and supported by all state and territory education departments, Catholic and independent schools sectors, and by science and literacy teacher professional associations. *Primary Connections* is a teacher professional learning program supported with curriculum resources that aims to enhance learning outcomes in science and the literacies of science.

Teaching and learning model

Primary Connections recognises that there are a number of science-specific as well as general literacies required by children to effectively engage with science phenomena, construct science understandings and develop science processes, and to represent and communicate ideas and information about science (Gee, 2004; Lemke, 1998; Norris & Phillips, 2003; Unsworth, 2001). *Primary Connections* provides opportunities for children to develop the literacies needed to learn science and to represent their developing science understandings and processes. The *Primary Connections* teaching and learning model embeds diagnostic, formative and summative assessment into the teaching and learning process because research shows that students' prior knowledge and teachers' monitoring of students' learning and the provision of formative feedback are powerful factors influencing achievement (Black & Wiliam, 1998; Hattie, 2003). To develop an understanding of the nature of science (Lederman & Lederman, 2004), an understanding of scientific evidence (Gott & Duggan, 1996) and to become scientifically literate, students need to be engaged in an inquiry-oriented and an investigative approach to learning science. The *Primary Connections* teaching and learning model (Figure 1) is therefore scaffolded by an elaborated 5Es inquiry model (Bybee, 1997).

Professional learning model

Primary Connections is a professional learning program comprising a number of complementary elements: professional learning workshops, exemplary curriculum resources, opportunity to practise science teaching supported with resources, reflections

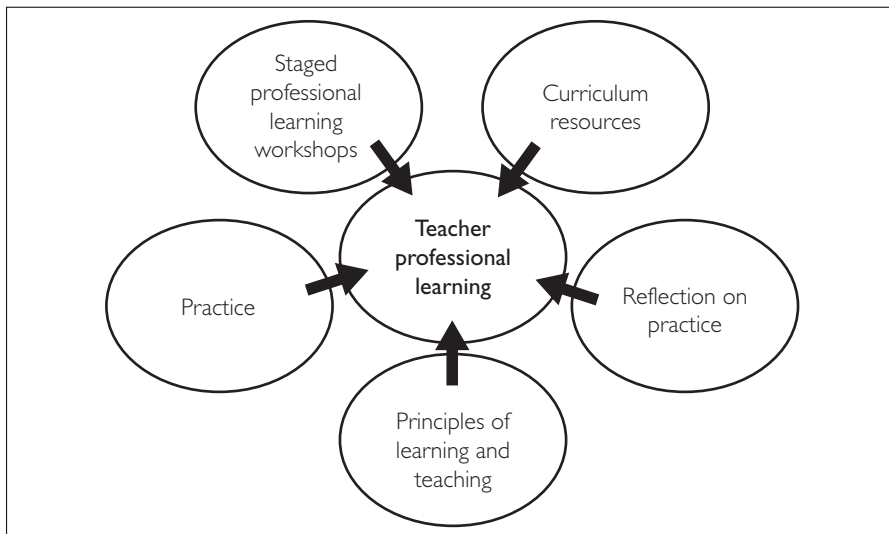


Figure 2 The Primary Connections professional learning model (Hackling & Prain, 2005)

on practice, and is linked to a set of principles of learning and teaching.

This model is based on the Collaborative Australian Secondary Science Project (CASSP) professional learning model that proved successful in effecting teacher change in an earlier Australian project (Goodrum, Hackling & Trotter, 2003; Sheffield, 2004) elaborated with a set of pedagogical principles derived from the Science in Schools project (Tytler, 2002). Primary Connections has developed a suite of comprehensively resourced professional learning modules and has trained a cadre of professional learning facilitators who can deliver Primary Connections professional learning workshops in schools throughout Australia.

In addition to this professional learning program for experienced teachers, a workshop was conducted in July 2005 for university science educators who teach primary science curriculum units in initial teacher education so that new teachers will develop an understanding of the *Primary Connections* approach to science teaching and learning.

Impact of Primary Connections

Primary Connections was trialled in 2005 in 55 schools involving 106 teachers and more than 3000 students. Teachers completed an initial five days of professional learning at a summer

school in January 2005 with three follow-up one-day workshops; the first, half way through Term 1, the second at the end of Term 1 and the third at the end of Term 2. Teachers taught a supplied curriculum unit in Term 1, a unit the teachers developed themselves in Term 2, and a supplied unit in Term 3.

Data were collected by teacher questionnaire, student questionnaire, case studies and by analysis of student work samples. A full research report (Hackling & Prain, 2005) documents all details of the data collection, analysis and research findings; highlights are presented here.

Impact on teachers

Teachers' confidence with nine science and literacy teaching strategies was assessed on a five-point scale. Mean confidence scores increased significantly ($p < .05$) from 3.34/5 at the beginning of the program to 4.04/5 at the end of Term 2. Teachers' self-efficacy beliefs were assessed using a 10-item scale based on Riggs and Enochs'

Table 1 Frequency of total self-efficacy scores on each survey (n=89)

Total self-efficacy score	Initial survey (= 2004)	End of summer school	Mid Term 1, 2005	End Term 1, 2005	End Term 2, 2005
1-10	0	0	0	0	0
11-20	2	0	0	0	0
21-30	20	10	4	3	1
31-40	50	49	52	54	49
41-50	17	30	33	32	39
Mean total self efficacy score for all teachers	35*	38	39	40	41*
S.D.	6.8	5.4	4.5	4.6	4.5

Note: Total self-efficacy score = sum of 10 self-efficacy item scores for each teacher, (/50), with the most positive response given the value of 5 and the least positive the value of 1 on a five-point agreement scale, i.e. scores have been reversed for negative items.

Table 2 Minutes of science taught per week by teachers in 2004, Term 1 2005 and in Term 2 2005

Minutes of science taught per week	Per cent of respondents		
	2004 (n=91)	Term 1 2005 (n=91)	Term 2 2005 (n=85)
60 minutes or more	30.8	72.5	62.4
30 and 60 minutes	40.7	26.4	27.1
Less than 30 minutes	27.5	1.1	10.6

(1990) instrument. Teachers' mean total self-efficacy score (/50) increased significantly ($p < .05$) from 35 to 41, and of educational significance, the number of teachers with low to moderate self-efficacy scores (≤ 30) was reduced from 22 to one by the end of Term 2.

Teachers also reported the frequency with which they used a range of teaching and learning strategies. The strongest increase in strategy use was recorded for developing literacy skills needed for learning science, which suggests that teachers recognised the importance of these skills and had the resources and confidence to teach these skills. There was also a strong increase in the frequency of use of diagnostic assessment as a consequence of it being scaffolded into 'Engage' lessons, and an increased frequency of hands-on activities. At the end of Term 1, teachers indicated their science teaching had improved through increased hands-on practical work, inquiry and investigations, focusing on one topic for a whole term, the 5Es structure, more time on science, increased confidence and the better sequencing and flow between lessons.

When asked at the end of Term 2, 'Has your science teaching improved as a result of participating in the *Primary Connections* program?' 96 out of 97 teachers responded 'Yes'. When asked to explain how their science teaching had improved, the teachers identified

aspects of their knowledge, confidence and practice that had improved as a result of participating in the program. Almost a third of teachers indicated they were now more confident, corroborating other evidence about confidence and increased self-efficacy. A fifth indicated they had a better understanding of the concepts and processes of science, which is indicative of improved pedagogical content knowledge (PCK). Improving teachers' PCK was an important aim of the program.

The amount of science taught increased dramatically as a result of the trial. The amount of science taught was greatest in Term 1 of the trial when teachers were working with supplied units; however, even when working from teacher developed units in Term 2, the percentage of teachers teaching less than 30 minutes per week was reduced from 27 per cent to 11 per cent.

Time on task has always been recognised as the fundamental variable influencing learning as it determines learning opportunity. Clearly, this program has given students in the trial schools far more opportunity to learn science.

Impact on students

Eighty-seven per cent of teachers reported that students had responded positively or very positively to the *Primary Connections* activities and learning approach. Seventy-six per cent of teachers rated the amount of students' science learning with *Primary Connections* as better than previous and 78 per cent indicated that the quality of students' science learning was better than previous.

To provide a measure of learning achievement, the science journals of three classes of students who completed the *Plants in Action* unit at one of the case study schools were analysed. The students represented two intact classes of Year 5 students and the Year 5 students from a combined Year 4/5 class. The work samples generated in the 'Engage' and 'Evaluate' lessons were rated against levels in the National Scientific Literacy Progress Map (MCEETYA, 2005). To provide a more fine-grained analysis, levels of achievement were further subdivided into the sublevels – developing, consolidating and achieved. Explicit criteria for levels and sublevels were defined and dual coding by consensus of two experienced coders ensured a high level of coding reliability.

At the beginning of the unit, the modal level of achievement was 2c and at the end of the unit, it had risen to 3c. Levels were converted to scores to facilitate calculation of means and statistical comparison of 'Engage' and 'Evaluate' mean scores. The mean score had more than doubled over the course of the unit and at the end of the unit 78 per cent of these Year 5 students were working at or beyond Level 3 in their conceptual understandings of plant life cycles. Level 3 is the national proficiency standard for Year 6 students' scientific literacy.

Table 3 Changes in levels of achievement between the initial 'Engage' lesson and the final 'Evaluation' lesson for Year 5 students studying the Plants in Action unit at one case study school.

Achievement level	Number of students (n=72)	
	Engage	Evaluate
1a	11	0
2d	16	3
2c	41	5
2a	3	8
3d	1	15
3c	0	22
3a	0	15
4d	0	4
Mean score	2.54*	5.51*
S.D.	0.855	1.473

Note. Levels of achievement were assigned the following scores: 1a = 1; 2d = 2; 2c = 3; 2a = 4; 3d = 5; 3c = 6; 3a = 7; 4d = 8 where d = developing; c = consolidating; a = achieved.

* Mean scores are significantly different ($p < .05$) using the Wilcoxon signed ranks test.

Impact on schools

Teachers' perceptions of the status of science in their schools were elicited in the teacher questionnaires. Teachers were asked to rank science in importance relative to nine other learning areas. The percentage of teachers indicating science was in the top three subjects doubled from 24 to 50 per cent as a result of the *Primary Connections* trial in their schools. The status of a subject in the school curriculum may also have an influence on the resources and budget allocated to that subject. Previous research (e.g., Keys, 2003) has often indicated that availability of resources and budget are important factors limiting the quality of science teaching in primary schools.

Discussion and conclusions

This paper reports data on the impact of *Primary Connections* on

teachers, students and schools based on a trial in 2005 which involved an intensive professional learning program supported with trial curriculum units. The program improved teachers' confidence, self-efficacy and practice, students' learning, and the status of science within schools. The data suggest that the combination of professional learning and being supported in their teaching with curriculum resources enhances teachers' confidence and self-efficacy through building science pedagogical content knowledge. As a consequence of increased confidence and self-efficacy and using the curriculum resources, the teachers increased the amount of time they taught science and thereby increased students' opportunity for learning science, which resulted in strong science achievement gains.

Feedback from the 55 trial schools is used to revise the trial curriculum units so that they are more effective in

meeting teachers' needs. The revised and published units are now being implemented in schools throughout Australia. *Primary Connections* professional learning is being provided by trained professional learning facilitators using the professional learning modules. There are variations on the professional learning model across jurisdictions and sectors and the efficacy of these different approaches will be the subject of further research.

Acknowledgment

The *Primary Connections* project and associated research is funded by the Australian Government's Department of Education, Science and Training.

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Panel discussion

Putting it to the experts: Boosting science learning – what will it take?



Russell Tytler

Deakin University

Russell Tytler, Professor of Science Education at Deakin University, Melbourne has been involved over many years with Victorian curriculum development and professional development projects. He was principal researcher for the highly successful School Innovation in Science initiative, which developed a framework for describing effective science teaching and learning, and a strategy for supporting school and teacher change. His research interests also include student learning, student reasoning and investigating in science, and public understanding of science.



David Symington

Deakin University

David Symington spent 14 years as a teacher in Victorian schools followed by several decades engaged in the education of teachers and in research in science education. Adjunct Professor Symington later worked for 8 years at the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in several positions, where he learned a good deal about the path from the laboratory bench to the marketplace. Presently, he is engaged with Russell Tytler and others in a number of research and development activities at Deakin University.

Abstract

The final session will bring together issues and ideas emerging from speakers and respondents at the conference sessions, and at participant forums held during the conference, to explore with a high level panel as key hypotheses and possible futures. The panel will consist of key players representing a variety of perspectives on science education. The aim of this closing session will be to sharply identify the key issues facing science education in Australia, and to explore and debate productive ways forward. The aim of this session will be to produce a draft framework that could inform government policy directions.

Panel members



Jim Peacock

Australian Chief Scientist

Jim Peacock was appointed Australian Chief Scientist in March 2006. Dr Peacock is an outstanding scientist with a record of academic excellence and is highly respected by the science, engineering and technology community.

Dr Peacock is an award winning molecular biologist and fervent science advocate. He is recognised internationally as an eminent researcher in the field of plant molecular biology and its applications in agriculture.

In 1994, he was made a Companion of the Order of Australia for outstanding service to science, particularly in the field of molecular biology and to science education. Dr Peacock is a Fellow of the Australian Academy of Science, Fellow of The Royal Society of London, the Australian Academy of Technological Sciences and Engineering, a Foreign Associate of the US National Academy of Sciences and a Foreign Fellow of the Indian National Science Academy.

In 2000 he was a co-recipient of the inaugural Prime Minister's Science Prize, for his co-discovery of the Flowering Switch Gene – a key gene that determines when plants end their vegetative growth phase and begin flowering. This discovery will help boost the productivity of the world's crops by billions of dollars each year and could also help increase the nutritional value of crops eaten by billions of the world's poorest people.

He was also awarded the BHP Bicentennial Prize for the pursuit of excellence in science and technology and the Australian Academy of Science's Burnett Medal for distinguished contributions in the biological sciences.

Dr Peacock has gained valuable experience working in industry having founded the Gene Shears biotechnology company and instituted the GrainGene initiative and the HRZ Wheat Company – linking research with the production of new wheat varieties for Australia. He played a key role in the establishment of cotton as Australia's first highly successful biotech crop.

Dr Peacock is a strong advocate for the integration of science and global business. He drives innovative communication efforts to inform the general public as to the outcomes and value of modern science. He has brought the excitement of science to a broad cross-section of the community and to Australian school students.



Paul Carnemolla

Australian Science Teachers Association

Paul is the current President of the Australian Science Teachers Association (ASTA). He has over 12 years experience in teaching science in schools across 2 sectors which have included the positions of Head Teacher, Science and Director of Studies in large comprehensive schools. He has contributed to the development and implementation of science curriculum changes in NSW including the cross-sectoral Securing their Future project to support the revisions of the HSC science curriculum in 2000 as well as syllabus revisions in Science.

From 2001-2006 Paul has held various positions at the Office of the Board of Studies and has worked primarily as a liaison officer in close and daily contact with schools. In the early part of 2006 he was working for the Catholic Schools Office on a national project in Values Education and has recently returned to schools in the position Director of Studies at St. Catherine's School, Waverley NSW.

Paul had been a member of the Science Teachers Association of NSW (STANSW) and the Australian Science Teachers Association (ASTA) since 1990 and was President of STANSW from 2004-2005. His experience includes convening conferences as well as delivering addresses and workshop presentations for teachers of science. As Convenor of the 2003 STANSW Annual Conference, he and his team broke new ground in hosting a conference held simultaneously in four universities with video conferencing linking each venue.



Léonie Rennie

Curtin University of Technology

Léonie Rennie is Professor of Science and Technology Education at the Science and Mathematics Education Centre and Dean, Graduate Studies at Curtin University of Technology, Perth Western Australia. She has a background in science teaching and curriculum, and is particularly interested in how people learn, and want to learn, in a variety of settings. She is a co-author of the Report "The Status and Quality of Teaching and Learning science in Australian Schools" and has participated in national school-community projects arising from that report. Currently, she is working on two research projects relating to integrated curriculum in science, mathematics and technology, and a state-wide program to enhance scientific literacy in the community. Her scholarly publications include over 150 books and monographs, book chapters and refereed journal articles. She has delivered keynote addresses to audiences in Australia, Brazil, South Africa, Sweden, the US and the Netherlands on her research relating to gender, learning and assessment in science and technology, both in school and out.



Jonathan Osborne

King's College, London

Jonathan Osborne holds the Chair of Science Education at the Department for Educational and Professional Studies, King's College London where he has been since 1985. Prior to that he taught physics in high schools. Professor Osborne is currently the head of department and the President of the US National Association

for Research in Science Teaching (NARST). He has conducted research in the area of primary children's understanding of science, attitudes to science, informal learning, argumentation and teaching the nature of science. He was a co-editor of the influential report *Beyond 2000: Science Education for the Future*, winner of the NARST award for best paper published in JRST in 2003 and 2004, and is a co-PI on the National Science Foundation funded Centre for Informal Learning and Schools. A particular agenda for his research is advancing the case for teaching science for citizenship. To this end, he has conducted a significant body of work exploring the teaching of ideas, evidence and argument in schools.



Rodger W. Bybee

Biological Sciences Curriculum Study (BSCS), Colorado Springs, Colorado, USA

Rodger W. Bybee is executive director of the Biological Sciences Curriculum Study (BSCS), a non-profit organization that develops curriculum materials, provides professional development, and conducts research and evaluation for the science education community.

Prior to joining BSCS, he was executive director of the National Research Council's Center for Science, Mathematics, and Engineering Education (CSMEE), in Washington, D.C. He participated in the development of the National Science Education Standards, and in 1993-1995 he chaired the content working group of that National Research Council project.

Dr. Bybee has written widely, publishing in both education and psychology. He is co-author of a leading textbook titled *Teaching Secondary School Science: Strategies for Developing Scientific Literacy*. His most recent book is *Achieving Scientific Literacy: From Purposes to Practices*, published in 1997. Over the years, he has received awards as a Leader of American Education and an Outstanding Educator in America. In 1998 the National Science Teachers Association (NSTA) presented Dr. Bybee with the NSTA's Distinguished Service to Science Education Award.



Joy Thompson

*Tertiary science student and
2005 Science Olympiad*

Joy Thompson was awarded a National Undergraduate Scholarship by the Australian National University, Canberra, and is now a first year Bachelor of Philosophy (Science) student there. Originally from Bellingen, NSW, she was home-schooled until Year 6 before attending high school in Sydney, first at an elite private school, where she was dux of Middle School, and then at James Ruse Agricultural High School, where she was dux in 2005. In the NSW HSC, she received Premier's Awards in 2004 and 2005, as well as topping the state in Cosmology, English Advanced and Comparative Literature. She attended the 2003 Professor Harry Messel International Science School and in 2005 was a member of the Australian team at the International Biology Olympiad, where she won a silver medal. After completing her undergraduate degree, Joy plans to continue her studies of biology, including a PhD and ultimately a research career that combines neuroscience, immunology and genetics. When she is not in the lab, Joy studies the classics, relaxes with friends and writes poetry.



Michael Frazis

*Secondary student and
2006 Science Olympiad*

Michael is a Year 12 student and Head Prefect at Sydney Grammar School. A graduate of ASI's Australian Science Olympiad program, he recently attended the 2006 International Chemistry Olympiad in Pusan, South Korea where he achieved a Silver Medal. Michael is interested in Biochemistry and once finished school he would like to study engineering/commerce or science/commerce. When not studying, Michael's curricular activities include rowing, rugby, piano and cadets.



Dianne Stuart

Minerals Council of Australia

Dianne Stuart is an educator with a wide-ranging background in secondary teaching and educational administration.

She is currently the Director Education with the Minerals Council of Australia - the minerals industry's peak representational body.

In this role she has developed and managed the minerals industry's National Education Program – a high profile partnership between the Australian minerals industry and the school education system.

The minerals industry's school education initiatives at both the national and State level have sought to balance the aspirations and needs of teachers and students with the imperatives of a major industry.

Rapidly changing imperatives of both industry and the education sector maintain a challenging dynamic for Dianne's work – most recently within the context of widespread skills shortages and far-reaching Vocational Training and Education reforms.

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Poster presentations

1 **Ruth Targett & Kate Anderson**

Moriah College, NSW

Action Research – Collaboration between Honours Years 9-10 Science Students and Postgraduate Science Students from UNSW

High school students have designed and carried out a project related to a postgraduate Science mentor. Students were able to access university laboratories and equipment and were linked to their mentors through WebCT. This has led to a rise in interest and the number of students undertaking senior science subjects in Year 11 and 12 within the school.

2 **Sally Parker & Kate Anderson**

Moriah College, NSW

A New Differentiated Science Matrix

The poster will focus on the use of the new Science Matrix designed specifically to engage students in Science. This new learning matrix uses hands on investigation; presentation of research through a choice of a variety of creative product types; considers philosophical Science issues; promotes the development of Science as a continual process; and personalises the Science experience in order to make it more accessible. The Science Matrix is part of the teacher's notes that accompany COSMOS magazine which also includes powerful learning tools such as guided brainstorming activities, the use of graphic organisers, questioning toolkits and question builders.

3 **Graham Foster**

Epsom Girls Grammar, New Zealand

Thinking Skills in Science

We have observed that most questioning in science is using lower levels of thought and cognition. By linking questions to Anderson's Taxonomy and through the construction of a model to develop explanation, we have found a significant shift in the cognitive responses to questions and we have developed higher level questions to target more able science students.

4 **Rosemary Hafner**

Science Teachers' of NSW

Issues facing practising science classroom teachers

The Association is undertaking a survey of its members to identify those issues that practising science classroom teachers identify as the main challenges faced in relation to delivering high quality, effective teaching and achieving positive learning outcomes for students. The poster will provide summary information of the interim findings of the survey.

5 **Louisa Ivey**

Earth Science, WA

'ESWA is promoting and supporting the teaching of Earth Science in Secondary Schools across Western Australia'

Earth Science Western Australia's Mission is to raise the profile of geoscience in the State's secondary schools to a level matching the strategic needs of WA, increase awareness of the wide range of career opportunities it provides, and increase the number of students entering tertiary geoscience studies.

ESWA is a consortium representing the University of Western Australia, Curtin University, the Geological Survey of WA, WA Museum, and CSIRO. ESWA has financial and Board support from the resource industry, professional organisations, the Chamber of Minerals and Energy of Western Australia and the Science Teachers Association of Western Australia). ESWA has engaged an Executive Officer, Earth Science Secondary Education, to facilitate and coordinate support for Earth and Environmental Science Course of Study to be implemented in Secondary Schools across WA in 2007.

Earth and Environmental Science is an exciting new course with broad scope for engaging learning experiences including concepts from chemistry, physics, biology and geology. ESWA is developing an extensive range of rich learning resources to ensure relevant, Western Australian contextualised learning for students of Earth and Environmental Science. Many current sustainability issues for WA will be examined including the Metropolitan water supply shortage, impact of agriculture on river systems and soil quality, renewable energy generation, the discovery and extraction of earth resources with minimal impact. ESWA

is coordinating seminars for teachers presented by industry and research scientists to enrich teacher's knowledge and skills in geoscience.

6 **Dr Eileen Kennedy**

UNSW Foundation Year, NSW

Detecting understanding by using models

How do we find out if our students understand what we teach them? How do we probe their understanding? How do we engage them in informal conversations? A useful simple strategy that has been employed at UNSW Foundation Year is the use of models. Many of our students come from cultures in which student views are not regularly canvassed. This approach has enlivened and enhanced their social and intellectual lives. Photographs of these activities and transcripts of conversations during teaching and learning sessions will illustrate this poster.

7 **John Lloyd**

St Paul's Catholic College, NSW

Teaching for a sustainable Future – Model Solar Car Challenge

Photographic display of students designing, building and racing cars over the last five years with brief descriptions of the purpose and outcomes of this activity including student reflections on the learning involved.

8 **Dr Jan Lokan**

Formerly ACER, now retired

Windows on the world of science teaching: More results from the TIMSS Science Video Study

As part of the Third International Mathematics and Science Study (TIMSS – now Trends in Mathematics and Science Studies) in 1995 and 1999, video studies of national random samples of class lessons were carried out in several countries as a way of describing national pictures of science and mathematics teaching practices at Year 8. Australia was selected to take part in the 1999 video study and did so with the help of substantial funding from the US National Science Foundation.¹

The science achievement results of Australian students in TIMSS and other comparative studies will be featured in Dr Sue Thomson's paper *Science achievement in Australia: Evidence from National and International Surveys* and brief reference to some of the results about teaching practices will be made. The Poster Display will extend the presentation and discussion of results concerning Year 8 science teaching contexts and practices in the five video study countries and will also include an analysis of the Australian results in relation to statements of aims for science education in Australia

¹ACER and the Australian Commonwealth, State and Territory governments also contributed significant funds for the project.

9 **Dr Leah Moore**

University of Canberra, ACT

Preservice Teachers Speak: What it takes to become an effective science teacher

This research compares the results of two studies, one conducted with Australian preservice science teachers and one with their Canadian counterparts. It analyses their responses to questions about 'What it takes to become an effective science teacher at various stages in their candidature'.

10 Paula Taylor

Department of Education & Training, VIC

Ongoing Contextualised Action Research in Schools

The School Innovation in Teaching (SIT) – Science, Mathematics and Technology is a program that enables Victorian teachers to incorporate action research into their teaching practice. The research involves both teachers and students and seeks to inform improvement in teacher pedagogical practice, students' attitudes to science and students' science learning outcomes. The poster highlights the elements of the SIT action research process and the historical origins of the program. The program grew out of the School Innovation in Science Research Project, a three-year research project conducted by Deakin University from 2000 to 2002. Managed by the Victorian Department of Education & Training and funded through the *Growing Victoria Together* initiative, the project was the pivotal component of the Science Innovation in Schools Strategy (SISS). The success of the program is evidenced in the more than 400 Victorian schools where it has been implemented and by its translation into the Principles of Learning and Teaching.

11 Christine Preston

University of Sydney, NSW

Stick it where it fits!

Stick it where it fits! If we want to boost science learning we have to ensure children are given opportunities to engage in age appropriate topics and activities.

An analysis of primary and junior secondary science text books used in NSW reveals that the types of hands on experiments suggested do not always match the age of the children and as such are inappropriate. The result is that secondary school children are bored rather than stimulated by science experiences. Some of the activities promoted for use at early secondary level would be better used in primary school and replaced with higher order activities designed to develop students' deeper understanding of science. Further a lack of communication between primary and secondary teachers means that children's prior knowledge and experiences are not being built upon to enhance their scientific understanding or interests. Secondary teachers blame inconsistent approaches to science in primary schools for ignoring prior learning of students and starting from scratch.

12 Ann Osman

Victorian Curriculum & Assessment Authority, VIC

Revitalising Science Curriculum Bottom Up – Top Down

How to make science contemporary and make the transition from P to 10 into senior secondary science seamless. This poster will show how the traditional disciplines have blended to produce newer areas of bio technology, nanotechnology and neuroscience.

13 **Dr Lyn Carter
& Prof Philip
Clarkson**

Australian Catholic University, VIC

**Science Education and
Mathematics Education in the
Era of Globalisation: Findings
from Early Research**

It is becoming clear that contemporary education including science and mathematics education, needs to be considered in tandem with globalisation as the dominant logic reconfiguring the social landscape in which education is embedded. Education and globalisation become mutually implicative, with globalisation the macro-level sets of forces shaping the conditions of education, while education increasingly promotes globalisation. This proposition holds for both the formal types of education at primary, secondary and tertiary levels, and those increasing informal education and learning opportunities. This poster cites evidence from several papers already published within JRST by Carter (forthcoming; 2005) to argue that globalisation is embedded within science education, even though it is under-acknowledged and under-theorised in their respective research agenda. It also reports on successive studies investigating the impacts of globalisation in mathematics education (Clarkson, 2005; 2004) which hold implications for science education.

14 **Dr Colleen Spence
& Sue Wilson**

*Merici College & Australian Catholic
University, Signadou Campus, ACT*

**Findings of a CRIMS project to
increase student interest and
confidence in Maths and Science**

The outcomes of the ASISTM funded CRIMS Project (Context Rich Integrated Maths & Science) will be presented in this poster. The CRIMS Project is currently operating in four secondary colleges in Canberra. The goals of the project are to increase student interest and confidence in maths and science and to promote the use of context-based and open-ended investigations through teacher PD, networking and resource sharing. The poster will summarise the experiences of the project to date with regard to how change occurs in schools and how even small positive changes in pedagogy can have a positive effect on student outcomes. Teacher resources that have been developed will also be available.

15 **Dr Ann Cleary**

Merici College, ACT

**Trial of a fully integrated Maths
and Science course in year 7**

Merici College, a Catholic girls' school for Years 7 to 12, is trialling a fully integrated Maths and Science course in Year 7 as part of the CRIMS project (Context Rich Integrated Maths and Science). Four out of eight Year 7 classes are involved in the project. In the first semester of the trial, students are exploring the Working Scientifically and Space and beyond. We have found that the immersion of students in engaging Science topics reduces negative feelings in their approach to Mathematics and that they are more prepared to take risks in doing mathematical calculations. Direct links have been made between Space and Measurement, Scale, Decimals and Directed numbers. The trial is being evaluated by externally moderated focus groups of students and teachers, student surveys and student skills tests that are common for all Year 7 classes. Results to date will be presented and a sample of teacher resources will be available.

16 **Dr Constance K Barsky**

*Learning by Redesign,
The Ohio State University, Ohio, USA*

A Successful Model of Intensive Professional Development in Science and Mathematics Education

In the mid-1990s, over 2000 science and mathematics teachers in Ohio completed intensive six-week summer Discovery Institutes in Physical Science, Life Science or Mathematics by Inquiry. This professional development was part of a statewide initiative in education reform. A survey of these teachers showed that their attitudes toward inquiry-based instruction, their capacity to adopt inquiry-based teaching strategies, and their classroom use of inquiry-based instructional practices experienced strong, positive and significant growth during their participation. A longitudinal study demonstrated that the impact of the professional development was sustained over several years. In a separate study, assessment data on nearly 7000 students showed that students of Discovery teachers consistently outperformed students from a comparable control group on public release test items from the National Assessment of Educational Progress. Furthermore, both girls and African American students of Discovery teachers demonstrated higher levels of achievement in both science and mathematics compared to their peers.

17 **Dr Premandh M Kurup & Prof Mark W Hackling**

*LaTrobe University and
Edith Cowan University, WA*

Impact of high school science in students' beliefs about, understandings of, and intentions to act to reduce greenhouse gas emissions and the greenhouse effect

Greenhouse gases emissions contribute to the greenhouse effect and climate change. Citizens need to be scientifically literate about the greenhouse gases effect in order to participate in decision-making and to take appropriate actions in their own lives for a sustainable, green and clear environment. Collectively these decisions and actions have similar impact and significance as those taken by industry to reduce carbon emission by geo-sequestration. This study will investigate the relationship between what is learned in science and students' beliefs about, understandings of, and intentions to act to reduce greenhouse gases emissions and the greenhouse effect. This poster will present findings of the study so far.

18 **Cheryl Peers**

Australian Academy of Science, ACT

Primary Connections: Linking science with literacy

This is a national project initiated and managed by the Australian Academy of Science to develop a science program comprising a sophisticated professional learning program supported with rich curriculum resources. The Australian Government has funded Stage 2 (2004 – 2005) and Stage 3 (2006 – 2008) of the project (\$4.8M).

Purpose

To improve learning outcomes in science and literacy by developing curriculum resources and a professional learning program that will improve teachers' confidence and competence for teaching science and literacy through developing their science pedagogical content knowledge.

Research Component

The project is monitored and informed by ongoing evaluation through a thorough research component conducted by Professors Mark Hackling and Vaughan Prain from Edith Cowan and La Trobe Universities respectively.

The Stage 2 trial in 2005 involved 56 trial schools and 106 trial teachers Australia-wide.

Stage 3 will expand the research component to monitor trial teachers, whole school implementation and the efficacy of professional learning facilitators trained to support uptake.

19 **Dr Wilhelmina Van Rooy**

*School of Education,
Macquarie University, NSW*

Understanding biology teaching practice: Perspective of an experienced practitioner

Case study approach of an experienced biology teacher working with a group of senior NSW HSC students on a unit of work dealing with disease. The research explores how the teacher 'shapes/moulds' her knowledge about teaching and that of biology to account for practice. Syntactic knowledge about biology and substantive knowledge are presented.

20 **Mr Peter Weddell**

*National Awards for Quality Schooling,
ACT*

National Awards for Quality Schooling

These awards celebrate the achievements of individual teachers, school principals and support staff. This is a pictorial display of 2006 Award winners and their achievements which cover the full range of the curriculum and also focuses on science teaching and learning achievements.



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Conference program

Sunday 13 August

6.00 – 7.30 **Welcome Reception** Centenary Ballroom, Hyatt Hotel Canberra

Monday 14 August

9.00 **Conference Welcome** Hon Julie Bishop, Minister for Education Science and Training

9.15 **Conference Opening** Professor Geoff Masters, Chief Executive Officer, ACER

9.30 **Keynote Address 1** Federation Ballroom 1 & 2
'Towards a science education for all: The role of ideas, evidence and argument'
Professor Jonathan Osborne, King's College, London
Chair Dr John Ainley, ACER

10.30 **Morning Tea**

11.00 **Concurrent Sessions 1**

Session A: Federation Ballroom 1

'What science do students want to learn? What do students know about science?'
Associate Professor Barry McCrae, ACER
Chair Dr Lawrence Ingvarson, ACER

Session B: Canberra Room
'Inquiry in science classrooms – rhetoric or reality?'

Professor Denis Goodrum, University of Canberra, ACT
Chair Kerry-Anne Hoad, ACER

Session C: Centenary Ballroom

'Addressing the looming crisis in the supply of suitably qualified science teachers'
Dr Kerri-Lee Harris, University of Melbourne, VIC
Chair Pamela Macklin, ACER

Session D: Federation Ballroom 2

Forum:
'Boosting science learning – what will it take?'
Professor Russell Tytler and Adjunct Professor David Symington, Deakin University, VIC
Chair Marion Meiers, ACER

12.15 **Lunch and Poster Displays**

1.15 **Concurrent Sessions 2**

Session E: Federation Ballroom 1

'How can professional standards improve the quality of teaching and learning science?'
Dr Lawrence Ingvarson and Ms Anne Semple, ACER
Chair Pamela Macklin, ACER

Session F: Canberra Room
'No wonder kids are confused: the relevance of science education to science'

Dr Deborah Corrigan, Monash University, VIC
Chair Dr Ken Rowe, ACER

Session G: Centenary Ballroom

'Rethinking science education through rethinking schooling'
Associate Professor Jim Davies, Australian Science and Mathematics School, SA
Chair Marion Meiers, ACER

Session H: Federation Ballroom 2

'Forum (repeated): Boosting science learning – what will it take?'
Professor Russell Tytler and Adjunct Professor David Symington, Deakin University, VIC
Chair Kerry-Anne Hoad, ACER

2.30 **Afternoon Tea**

3.00 **Keynote Address 2** Federation Ballroom 1 & 2
'The community's contribution to science learning: Making it count'
Professor Léonie Rennie, Curtin University of Technology, WA
Chair Dr John Ainley, ACER

4.15 **Close of Discussion**

7.00 **Conference Dinner** Federation Ballroom 1 & 2, Hyatt Hotel Canberra



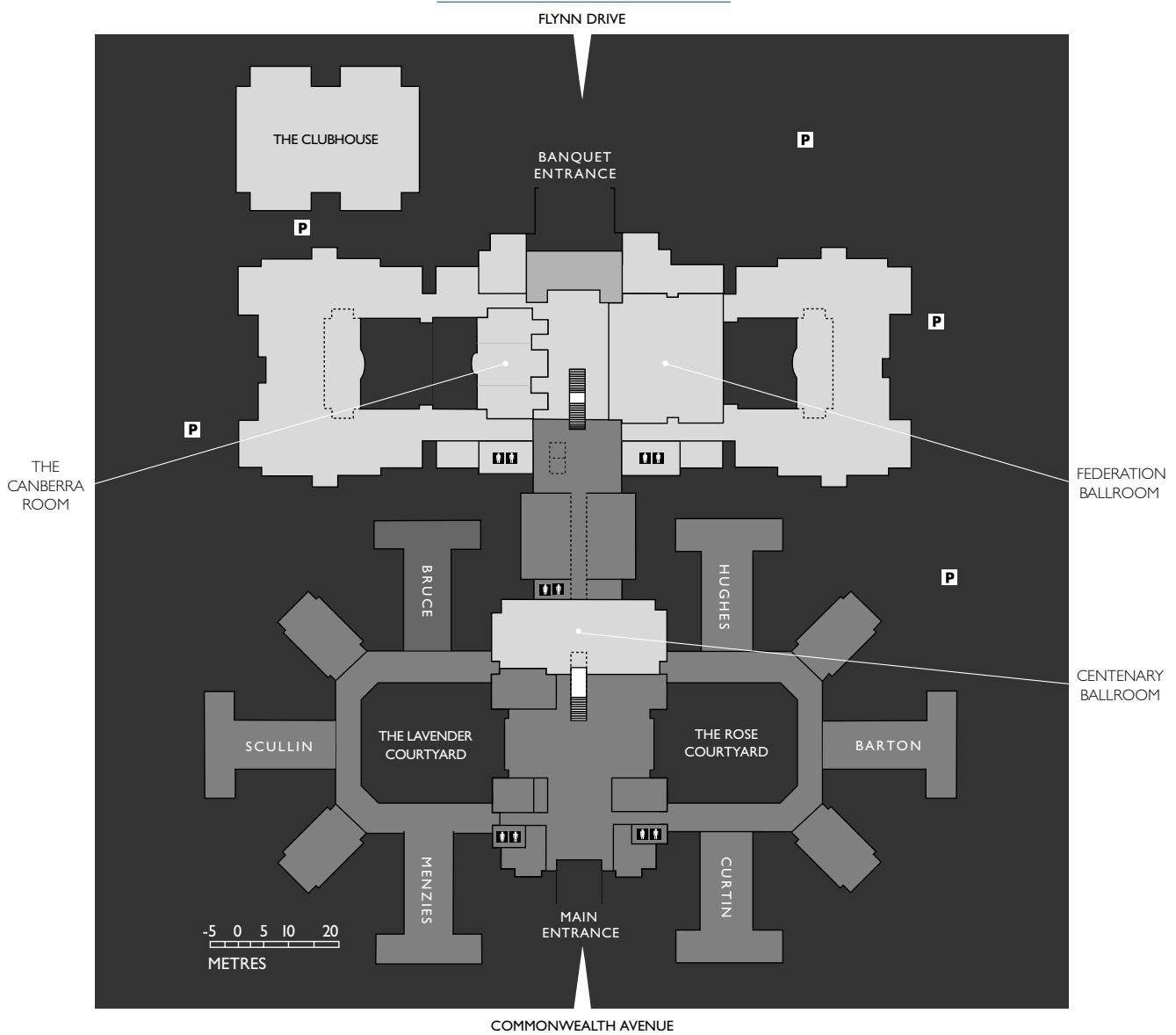
Tuesday 15 August

- 9.15 **Keynote Address 3** Federation Ballroom 1 & 2
'Boosting science learning through the design of curriculum materials'
Dr Rodger Bybee, Executive Director Biological Sciences Curriculum Study, Colorado USA
Chair Dr John Ainley, ACER
- 10.30 **Morning Tea**
- 11.00 **Concurrent Sessions 3**
- | | | | |
|---|---|---|---|
| Session I: Federation Ballroom 1
'Science achievement in Australia: Evidence from National and International Surveys'
Dr Sue Thomson, ACER
<i>Chair</i> Dr Ken Rowe, ACER | Session J: Canberra Room
'Creating Powerful Teacher Education Opportunities: The need for risk, relevance, resource, recognition, readiness and reflection'
Dr Susan Rodrigues
University of Dundee, Scotland
<i>Chair</i> Anne Semple, ACER | Session K: Centenary Ballroom
'Research and boosting science learning: Diagnosis and potential solutions'
Adjunct Professor Peter Fensham, Queensland University of Technology
<i>Chair</i> Marion Meiers, ACER | Session L: Federation Ballroom 2
'Primary Connections: A new approach to primary science and to teacher professional learning'
Professor Mark Hackling
Edith Cowan University, WA
<i>Chair</i> Kerry-Anne Hoad, ACER |
|---|---|---|---|
- 12.15 **Lunch and Poster Displays**
- 1.15 **Panel Discussion** ***Putting it to the experts: 'Boosting science learning – what will it take?'***
Panel Dr Jim Peacock, Australian Chief Scientist; Paul Carnemolla, President ASTA; Prof Leonie Rennie, Curtin University; Prof Jonathan Osborne, King's College London; Dr Rodger Bybee, BSCS USA; Joy Thompson, tertiary science student and 2005 Science Olympiad; Michael Franzis, secondary student and 2006 Science Olympiad; Dianne Stuart, Minerals Council of Australia
Chair Professor Russell Tytler and Adjunct Professor David Symington, Deakin University, VIC
- 2.30 **Closing Address** Professor Geoff Masters, Chief Executive Officer, ACER
- 3.00 **Close of Conference**



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Hyatt floorplan



Level 1

Function Venues

- Centenary Ballroom
- Federation Ballroom
- The Canberra Room



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Conference delegates

<i>Dinner table no.</i>	<i>Delegate name</i>	<i>Delegate organisation</i>
8	Dr Christopher Acland	Trinity Grammar School, NSW
	Mr David Agostinetto	St George College, SA
2	Dr John Ainley	ACER, VIC
6	Mr James Aitken	The Learning Federation, VIC
9	Dr Carol Aldous	Flinders University, SA
22	Ms Marie Allen	Campbelltown PAHS, NSW
7	Ms Kate Anderson	Moriah College, NSW
	Mrs Kathleen Anderson	Telopea Park School, ACT
3	Ms Penny Anderson	Depart of Education, TAS
	Dr Patricia Angus	Bruce CIT, ACT
8	Mrs Lillian Arici	Brisbane Girls Grammar School, QLD
16	Ms Jenny Arnold	The University of Melbourne, VIC
11	Ms Dagmar Arthur	Dept. Educ. & Training, NSW
	Ms Denise Bailey	
20	Ms Sharyn Bana	Christ Church Grammar School, WA
23	Mrs Rowena Barnett	Presbyterian Ladies College, NSW
14	Mrs Andrea Barr	St Patrick's College, NSW
8	Mrs Belinda Barrie	Brisbane Boys' College, QLD
1	Dr Constance Barsky	The Ohio State University, USA
	Mr John Barton	St Joseph's Primary School, NSW
11	Mrs Gabrielle Bastow	Catholic Education Office, WA
	Mr Donald Bates	Dubbo School of Distance Educ., NSW
10	Ms Jane Battrick	Dept of Education & Training, VIC
19	Mr Tony Begley	St Peter's College, SA
23	Mr Ian Bentley	La Trobe University, VIC
7	Dr Atit Bhargava	Scotch College, VIC
17	Miss Joanna Bonner	Scotch Oakburn College, TAS
11	Ms Pam Borger	Dept. of Educ. & Training, VIC
16	Mrs Jennifer Borowski	St Paul's School, QLD
	Mr Mike Brennan	Newington College, NSW
	Dr Beth Brook	Wynnum North State High School, QLD
15	Ms Erin Brooke	Knox Grammar School, NSW
10	Mrs Jan Brooks	DECS SA
20	Ms Linde Brush	Kingswood College, VIC
	Ms Ally Bull	NZCER, NZ
	Mr Andrew Burn	Miller Technology High School, NSW
	Mrs Moira Burns	Temora High School, NSW
9	Mr Richard Burns	CSIRO Education, ACT
1	Dr Rodger Bybee	BSCS, USA
17	Mrs Kathy Cairns	Caroline Chisholm College, NSW
	Ms Rosemary Cameron	A.B. Paterson College, QLD
	Mr Brian Campbell	Thomas Carr College, VIC
	Mr Clyde Campbell	Eatons Hill State School, QLD
5	Mr Paul Carnemolla	Aust Science Teachers Assoc., ACT
	Mr Ian Carroll	Dept. of Education & Training, WA
6	Dr Lyn Carter	Australian Catholic University, VIC
	Ms Lisa Causton	Catholic Education Office, WA
	Ms Eng Chee	Dept. of Education & Training, VIC

<i>Dinner table no.</i>	<i>Delegate name</i>	<i>Delegate organisation</i>
	Mrs Jan Cheetham	St Clare's College, ACT
23	Mrs Jaya Chowdhury	Presbyterian Ladies College, NSW
20	Mr Carl Ciccarelli	Santa Maria College, WA
8	Mrs Deborah Clancy	St Catherine's School, NSW
	Dr Ann Cleary	Merici College, ACT
18	Mr John Cluett	Albany Junior High School, NZ
	Mr Vince Connor	Catholic Education Office, NSW
19	Mr Laurence Cook	Christian Outreach College, Brisbane, QLD
17	Mrs Michelle Cook	Caroline Chisholm College, NSW
	Mr Ty Cooper	All Saints Catholic Boys College, NSW
	Mr Brian Copland	Oxley College Ltd, NSW
14	Ms Kara Coughlan	The MacRobertson Girls High School, VIC
7	Ms Terri Comish	ACER Press, NSW
2	Dr Debbie Corrigan	Monash University, VIC
	Ms Meg Cowey	Dept. of Educ. & Training, WA
8	Mr William Cowlshaw	Anglican Church Grammar School, QLD
	Ms Jenny Cox	Charles Sturt University, NSW
	Ms Judith Cox	Wilderness School, SA
	Dr Sarah Craig	Immanuel College, SA
21	Mrs Maria Criaris	Our Lady of the Sacred Heart College, SA
	Mr Grahame Crowfield	Arden Anglican School, NSW
18	Mr Bendan Crowley	Marymount College, QLD
	Ms Anne Curtain	Dept of Education, Science & Training, ACT
	Mrs Toni Daly	Dubbo School of Distance Educ., NSW
22	Mrs Sharon Davey	Gleeson College, SA
16	Mr Mark David-Tooze	All Saints Anglican School, QLD
5	Assoc. Prof. Jim Davies	Flinders University, SA
	Mr Matt Davies	Dept of Education, Science & Training, ACT
10	Mr Neville Davies	Dept of Education & Training, VIC
12	Ms Anna Davis	Catholic Education Office, Sydney, NSW
13	Ms Maria Delima	Loreto College, SA
	Ms Susan Dennett	Dept. of Education & Training, VIC
15	Ms Rebecca Dennis	Holy Spirit College, NSW
	Mr Fred Deshon	University of Western Australia, WA
12	Ms Denise Devitt	Depart of Education, TAS
4	Ms Swati Dey	Dept. Educ. & Training, ACT
3	Mr Philip Diprose	Dept of Education, Science & Training, ACT
21	Mrs Fiona Jane Dove	Wycliffe Christian School, NSW
20	Ms Pascale Drever	Ravenswood School for Girls, NSW
8	Miss Woolnough Driver	Brisbane Girls Grammar School, QLD
14	Mrs Sarah Dudley	Sacred Heart College, TAS
17	Ms Judith Dutton	Crestwood High School, NSW
	Mrs Jane Easterbrook	Mt St Benedict College, NSW
13	Ms Kathryn Edmondson	Loreto Kirribilli, NSW
13	Mr Danny Edwards	Loreto College, SA
8	Mrs Teresa Evans	Brisbane Grammar School, QLD
	Ms Julie Evans	Cabramatta High School, NSW
13	Ms Anna Farina	Siena College, VIC

<i>Dinner table no.</i>	<i>Delegate name</i>	<i>Delegate organisation</i>
1	Adj. Prof. Peter Fensham	Queensland University of Technology, QLD
3	Mr David Finlay	La Trobe University, VIC
	Mrs Trish Fisher	Bronte Public School, NSW
22	Mr Timothy Flaus	Bowral High School, NSW
9	Ms Annette Foley	University of Ballarat, VIC
	Mr Stephen Ford	Lake Ginninderra College, ACT
16	Mr Graham Foster	Epsom Girls Grammar, NZ
7	Mr James Friend	Shore Sydney CEGS, NSW
19	Mr Peter Furey	Brighton Grammar School, VIC
	Ms Penny George	Melba High School, ACT
	Mr Alex Georgiadis	Saint Stephen's College, QLD
	Ms Marisa Glabus	Rooty Hill High School, NSW
2	Prof. Denis Goodrum	University of Canberra, ACT
14	Mr David Gove	Kambala, NSW
18	Mr Robert Graham	St Ignatius College - Riverview, NSW
18	Ms Sue Grandison	Pembroke School, SA
	Ms Regina Grant	NSW Office of Board of Studies, NSW
2	Prof Mark Hackling	Edith Cowan University, WA
	Mrs Susan Hackney	Cerdon College, NSW
	Ms Julie Haeusler	Dept. of Education & Training, NSW
5	Ms Rosemary Hafner	Science Teachers' Association of NSW
	Mrs Melissa Halpin	Dubbo School of Distance Educ., NSW
15	Mr Mark Hamilton	Wesley College, VIC
6	Prof. Susan Hamilton	University of Queensland, QLD
20	Ms Jillian Harrington	McCarthy Catholic College, NSW
20	Mrs Julie Harris	Christ Church Grammar School, WA
1	Dr Kerri-Lee Harris	The Univ of Melb, VIC
18	Mr Manuel Hatzi	Pembroke School, SA
	Mrs Wendy Hawking	Yarra Valley Grammar School, VIC
9	Mr Iain Hay	University of Canberra, ACT
	Mr Troy Hayduk	Radford College, ACT
	Mr Michael Hayes	MLC School, NSW
4	Mrs Christina Healy	Catholic Education Office Sydney, NSW
9	Ms Marian Heard	CSIRO Education, ACT
21	Ms Helen Heugh	St Leo's Catholic College, NSW
5	Mr Niels Hider	Aust Science Teachers Assoc., ACT
3	Ms Kerry-Anne Hoad	ACER, VIC
15	Mr James Hoadley	Wesley College, VIC
19	Dr Allin Hodson	Urrbrae Agricultural High School, SA
12	Mrs Giannina Hoffman	SSABSA, SA
	Mrs Alison Horn	Donvale Christian College, VIC
	Mrs Elaine Homas	Bethany College, NSW
13	Mr Paul Houseman	Loreto Kirribilli, NSW
21	Mrs Dianne Hunter	St Clare's College, NSW
15	Mr Wayne Hunter	Knox Grammar School, NSW
19	Mr Mark Innes	Urrbrae Agricultural High School, SA
1	Dr Lawrence Ingvarson	ACER, VIC
21	Mr Conrad Ivanov	St Clare's College, NSW

<i>Dinner table no.</i>	<i>Delegate name</i>	<i>Delegate organisation</i>
12	Ms Louisa Ivey	Earth Science Western Australia, WA
	Ms Diane Jackson	SCEGGS Darlinghurst, NSW
19	Mr Stuart Jamieson	Melbourne Grammar School, VIC
	Ms Berenice Jidorko	Holy Family Primary School, ACT
	Ms Vivianne Johnson	Dept of Education, Science & Training, ACT
	Mr John Johnstone	Sydney Olympic Park Authority, NSW
	Mr Trevor Jones	Marsden State High School, QLD
19	Mr Sam Jordan	Prince Alfred College, SA
19	Mr Chris Kaczan	Urrbrae Agricultural High School, SA
13	Ms Evangelia Katsikoyannis	Killester College, VIC
15	Mr Michael Kay	Sydney Boys High School, NSW
6	Dr Eileen Kennedy	University of NSW, NSW
11	Mr Gary Kerr	Depart of Educ and Training, NSW
13	Mr Michael Key	Loreto Kirribilli, NSW
3	Prof. Denise Kilpatrick	La Trobe University, VIC
9	Mr Ross Kingsland	CSIRO Education, ACT
22	Mr Stephen Kirk	Albion Park HS, NSW
	Ms Carmel Kriz	Catholic Schools Office, NSW
11	Ms Ina Kuehlich	Dept. of Educ. & Training, VIC
	Dr Premmedh Kurup	La Trobe University, VIC
	Mr Scott Lambert	Dept of Education, Science & Training, ACT
	Mr Alan Lee	Radford College, ACT
15	Mr Mark Lee	Knox Grammar School, NSW
12	Mr Gerard Lewis	Catholic Education Office, VIC
12	Mr Simon Lindsay	Catholic Education Office, VIC
18	Mr John Lloyd	St Pauls Catholic College, NSW
	Ms Lara Lloyd	Dept of Education, Science & Training, ACT
2	Dr Jan Lokan	(Formerly ACER, now retired)
16	Mr Paul Looyen	MacArthur Anglican School, NSW
9	Ms Mary Loveless	University of Waikato, NZ
4	Ms Pam Macklin	ACER, VIC
	Dr Stephanie Mander	CIT, ACT
9	Dr Jerry Maroulis	University of Southern Qld, QLD
	Dr Ron Martin	ACER, VIC
1	Prof. Geoff Masters	ACER, VIC
21	Ms Judith McCrea	St Leo's Catholic College, NSW
2	Assoc. Prof. Barry McCrae	ACER, VIC
	Mrs Donna McDonald	St Francis Xavier College, ACT
13	Ms Mary McDonnell	Killester College, VIC
10	Miss Shona McEnaney	Dept of Education & Training, VIC
	Mr Marty McGoldrick	Marist North Shore, NSW
12	Mr Phil McIntosh	Catholic Educ Office, Wollongong, NSW
6	Dr David McKay	University of the Sunshine Coast, QLD
4	Mrs Marilyn McKee	Dept. Educ. & Training, WA
10	Mrs Kerri McLeod	Dept of Education & Training, VIC
18	Mr Keith McMullen	William Carey Christian School, NSW
4	Mr Tim McMullen	CEO Sydney, NSW
5	Ms Marion Meiers	ACER, VIC

<i>Dinner table no.</i>	<i>Delegate name</i>	<i>Delegate organisation</i>
1	Dr Trish Mercer	Dept of Education, Science & Training, ACT
15	Mr Chris Metcalfe	Melbourne Girls Grammar School, VIC
	Mr David Miller	Toowoomba Grammar School, QLD
14	Mr Gregory Mills	Sacred Heart College, TAS
	Mr Paul Mills	Dept of Education, Science & Training, ACT
	Dr Leah Moore	University of Canberra, ACT
	Ms Maureen Moore	St Joseph's Catholic College, NSW
15	Mr Ken Muhling	Cowra High School, NSW
21	Mrs Anne Murphy	St Clare's College, NSW
18	Mr Chris Murphy	Marymount College, QLD
17	Mr Timothy Murray	St Andrews College, NSW
	Ms Deborah Murtagh	Mt St Michael's College, QLD
21	Mrs Tina Neate	Our Lady of the Sacred Heart College, SA
	Mr Brendan Newell	Cannon Hill Anglican College, QLD
19	Dr John Nicholson	Melbourne Grammar School, VIC
11	Mrs Louise Nielsen	Dept of Education & Training, WA
	Dr Sally Nobbs	Wilderness School, SA
14	Mr Patrick Nolan	Aquinas College, WA
4	Ms Rosalie Nott	Catholic Education Commission, NSW
21	Mrs Rosemary Nunnerley	St Clare's College, NSW
10	Mr Brendan O'Brien	Dept of Education & Training, VIC
	Mrs Jane O'Brien	Canberra Girls' Grammar School, ACT
6	Dr Robert O'Brien	ACER, VIC
8	Mr Matthew O'Brien	Brisbane Boys' College, QLD
16	Mrs Sue O'Connell	Catherine McAuley, NSW
17	Ms Caroline O'Hare	St Andrews College, NSW
	Ms Eryn O'Mahony	St Columba's College, VIC
1	Prof. Jonathan Osborne	King's College London, UK
4	Ms Ann Osman	VCAA, VIC
16	Mrs Kate Padman	Methodist Ladies College, WA
20	Mrs Colleen Palmer	Browns Plains SHS, QLD
6	Dr Debra Panizzon	University of New England, NSW
7	Ms Sally Parker	Moriah College, NSW
	Mr Warren Parkinson	Brisbane School of Distance Educ, QLD
	Mr Rob Paynter	Barker College, NSW
	Mr Craig Pearce	ANSTO, NSW
	Ms Cheryl Peers	Australian Academy of Science, ACT
12	Mr Perry Peter	SSABSA, SA
22	Ms Kirsty Phillips	Hawker College, ACT
	Ms Robyn Pillans	Annesley College, SA
22	Ms Lisa Pluis	Hawker College, ACT
19	Mr Donald Plumb	Christian Outreach College, Brisbane, QLD
16	Mr Michael Podgorny	John Septimus Roe Angl Comm School, WA
1	Prof. Paige Porter	The University of WA
23	Ms Stephanie Porter	Loreto College, VIC
	Ms Christine Preston	University of Sydney, NSW
	Mr Steve Punch	John Edmondson High School, NSW
	Mrs Chris Purdie	

<i>Dinner table no.</i>	<i>Delegate name</i>	<i>Delegate organisation</i>
	Mr Neil Quinn	St Mary Star of Sea College, NSW
	Mrs Mary Rafter	Queensland Studies Authority, QLD
	Mr Peter Razos	Trinity Grammar School, VIC
20	Mrs Judith Read	Ravenswood School for Girls, NSW
13	Mrs Diane Reed	Loreto Kirribilli, NSW
	Ms Joan Reimann	Immanuel College, SA
1	Prof. Leonie Rennie	Curtin University of Technology, WA
	Ms Louise Reynolds	ACER, VIC
	Mr Mark Rix	Catholic Educ Office, Sydney, NSW
5	Mr Michael Roach	Hamilton Secondary College, VIC
16	Mr Daniel Robins	Lindisfame Anglican School, NSW
2	Dr Susan Rodrigues	Univ of Dundee, Scotland, UK
20	Dr Holly Rose	Christ Church Grammar School, WA
	Ms Robyn Rosengrave	Queensland Studies Authority, QLD
	Ms Louise Rostron	Australian Academy of Science, ACT
14	Mrs Wendy Rowan	St Patrick's College, NSW
3	Dr Ken Rowe	ACER, VIC
	Dr Brad Rundle	Trinity Grammar School, VIC
	Mrs Melanie Rundle	Carey Baptist Grammar School, VIC
10	Mr Peter Russo	DECS, SA
	Ms Rachel Ryan	Biotechnology Australia, ACT
20	Miss Laura Sacchetta	McCarthy Catholic College, NSW
7	Mr Peter Saffin	Pearson Education Australia, VIC
5	Mrs Aline Saliba	Granville Boys High School, NSW
	Mrs Judy Sara	Aust. Science & Maths School, SA
7	Mr Ralph Saubern	ACER, VIC
11	Mr Glen Sawle	NSW Dept. of Educ, NSW
10	Mr Bruce Schmidt	Dept of Education & Training, Grampians Region, VIC
7	Mr Tim Scouller	Shore SCEGS, NSW
8	Mr Craig Seawright	St Catherine's School, NSW
21	Mrs Emma Seccombe	Bishop Tyrrell Anglican College, NSW
	Ms Assimina Semertjis	St Columba's College, VIC
5	Ms Anne Semple	ACER, VIC
4	Dr Pauline Sharma	Catholic Education Office, VIC
	Mrs Leonie Shaw	Dept. Education & the Arts, QLD
17	Mrs Margaret Shepherd	Freeman Catholic College, NSW
5	Mrs Nola Shoring	Australian Academy of Science, ACT
14	Mr Ian Simpson	Aquinas College, WA
	Mr Noel Simpson	Dept of Education, Science & Training, ACT
	Mr Ernst Smeets	MLC School, NSW
	Mr Ian Smith	Dubbo School of Distance Educ., NSW
6	Mr Vaughan Smith	Caulfield Grammar School, VIC
	Mrs Deborah Snaith	Dept Education, NSW
	Mr John Sodeau	Liverpool Girls' High School, NSW
	Dr Colleen Spence	Merici College, ACT
	Mr Nicholas Stansbie	Ballarat and Clarendon College, VIC
9	Ms Vicki Stavropoulos	CSIRO Education, ACT
	Dr Robert Stevens	Dept of Education & Training, NSW

<i>Dinner table no.</i>	<i>Delegate name</i>	<i>Delegate organisation</i>
10	Ms Karen Strang	Dept of Education & Training, VIC
3	Ms Dianne Stuart	Minerals Council of Aust., ACT
17	Mrs Joanne Surman	St Mary's College, SA
22	Ms Julie Swain	Campbelltown PAHS, NSW
	Ms Maria Tavarnesi	MCEETYA, VIC
2	Adj. Prof. David Symington	Deakin University, VIC
18	Mr Andrew Szabo	St Ignatius College - Riverview, NSW
7	Ms Ruth Targett	Moriah College, NSW
	Ms Debra Talbot	Design Ed Consulting, NSW
17	Mrs Debbie Taylor	The Peninsula School, VIC
11	Ms Paula Taylor	Dept of Education & Training, VIC
5	Dr Colin Taylor	Australian Science Innovations, ACT
6	Ms Margaret Taylor	ACER, VIC
22	Mr Peter Teakle	St Ignatius' College, SA
22	Mr Nicholas Thill	St Aloysius College, NSW
	Mrs Elizabeth Thrum	Mt St Benedict College, NSW
	Mr Daniel Tibbits	Lake Ginninderra College, ACT
	Mrs Drina Timm	Barker College, NSW
	Mr Robert Tomaschewski	Education Queensland, QLD
2	Dr Sue Thomson	ACER, VIC
	Ms Helen Trevethan	Dunedin College of Education, NZ
2	Prof. Russell Tytler	Deakin University, VIC
11	Mr Kim Van Den Berghe	Dept of Education & Training, VIC
12	Dr Wilhelmina Van Rooy	Macquarie University, NSW
	Ms Suzanne van Strien	Radford College, ACT
4	Ms Terri Vander Spoel	Education Queensland, QLD
11	Ms Susanne Vaughan	Depart of Education and Training, WA
	Dr Bruce Waldrip	University of Southern Queensland, QLD
18	Mrs Bronwyn Walters	Tara Anglican School, NSW
10	Mr Mark Ward	DECS, SA
16	Mrs Kirsten Wardrop	St Laurence's College, QLD
13	Mr Christopher Warren	Kincoppal - Rose Bay School of the Sacred Heart, NSW
3	Mr Peter Weddell	National Awards for Quality Schooling, ACT
15	Mr Andrew Weeding	Knox Grammar School, NSW
17	Miss Debbie White	Caroline Chisholm College, NSW
	Ms Wendy Whitham	Aust Govt Depart of Educ, Science and Train., ACT
	Mrs Diana Whymark	Lyneham High School, ACT
	Ms Melissa Williams	St Mary's Cathedral College, NSW
14	Ms Sharon Williams	The MacRobertson Girls High School, VIC
	Mrs Anne Wilson	Moreton Bay College, QLD
14	Mr Gordon Wilson	Camberwell Grammar School, VIC
	Mr Kim Wilson	St Francis Xavier College, ACT
	Mrs Lynette Wilson	Canberra Institute of Technology, ACT
	Ms Sue Wilson	Australian Catholic University, ACT
	Mrs Robyn Woinarski	St Clare's College, ACT
9	Dr Jim Woolnough	University of Canberra, ACT
	Mr David Wyatt	Saint Stephen's College, QLD
4	Dr Brian Young	Dept. Educ. & Training, WA
7	Mr Alexander Young	Flickntick Pty Ltd, TAS