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FOCUSING ON THE SCIENCE TEACHER

SETTING

There is a considerable body of evidence that indicates the importance of the teacher in determining student learning and attitudinal outcomes. This evidence is based for instance on analysis of system wide student results with teacher characteristics as an independent variable (Barber & Mourshed, 2007; Darling-Hammond, 2007), or on studies of student attitudes and aspirations, involving questionnaires of classroom environment characteristics (Fraser, 1986), or interviews with students (Darby, 2005; Lyons, 2006a). While this finding might be intuitively obvious, and long assumed as the underpinning of teacher education, it is nonetheless important to substantiate, and furthermore to fill out in some detail. Thus, an important research agenda flowing from this is to explore just what are the characteristic behaviours of teachers of science that contribute to effective student learning, and positive attitudes and aspirations.

This research into the nature of effective science teaching, amounting to a description of the effective science teacher, is of fundamental importance in determining our emphases in training teachers of science, and in planning for ongoing professional learning of teachers. It is also critically important for making judgments about the current state of teaching of science, and submitting orthodoxies to critical scrutiny. Thus, for example, the influential report into the Status and quality of science teaching in Australia (Goodrum, Hackling & Rennie, 2001) focused strongly on current practices of teachers of science, measured against contemporary and explicit ideas about inquiry teaching and the goal of scientific literacy. The findings of that report rang alarm bells, describing a subject maintaining a commitment to transmissive pedagogies and failing to engage students in meaningful learning. The report has been influential in setting the agenda for a number of policy initiatives in Australia.

There are a number of points to be made about a research agenda focusing on the nature of effective teaching in science:

- First, implicit in any notion of ‘effective’ or ‘exemplary’ or ‘quality’ teaching of science, is the question of purposes of science education. These purposes are culturally bound, and shift over time as the broader purposes of schooling are questioned and debated. They are also multi-dimensional, with different purposes (such as cultural, economic, or personal development: Symington & Tytler, 2004) demanding particular teaching approaches.
- Second, questions of the relative value of dimensions of science capability such as investigative skills, science content knowledge, and dispositions,

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or of short term knowledge vs. longer term learning orientations, have serious implications for how we might frame effective teaching. Views on the relative importance of these capabilities also shift over time. This time dimension, concerning the implications for teaching of the constantly changing views of the purposes and practices of school science, will be an important focus for this chapter.

- Third, views about what constitutes effective teaching sits in an interesting relation to the status quo. Researchers may choose to measure effectiveness against student outcomes on current system wide assessment measures, or they may choose measures that effectively critique current assessment norms, for instance by focusing on higher order thinking or student engagement. The question of what is 'effective' is inevitably grounded in value considerations, and in the politics of teacher and system change (Tytler, 2003). Different participants in the education system may have different views on what is appropriate.
- Fourth, research concerning the nature of effective teaching in science has considerable implications for teacher education and professional learning, and for policy directions concerning science education more broadly. Such research informs contemporary questions about the nature and purposes of school science.

This chapter explores research into the teaching of science in Australasia since 1980. The particular focus of the chapter is on research that provides insights and evidence based conclusions about what constitutes effective practice in school science, and to a lesser extent about the current practice of teachers of science. It does not attempt to review research that deals with content specific teaching sequences, but focuses on broader characteristics of effective science teaching. The chapter intersects to some degree with the chapters in this volume on student conceptions research, on classroom environments, and on pedagogical content knowledge. Indeed, everything discussed in this book has implications for the teacher of science.

In the chapter we review research that takes different approaches to exploring the characteristics of effective teaching in science. These approaches are:

- Studies of student learning and its pedagogical implications
- Studies of acknowledged effective teachers
- Studies of teachers and classrooms more generally, increasingly through video studies
- Teacher practitioner research
- Research to support the defining of standards

THE PEDAGOGICAL IMPLICATIONS OF RESEARCH ON STUDENT LEARNING

A major approach to the identification of effective science classroom practice is to base it on research into student learning, and theoretical perspectives that emerge from this. The research into student conceptions, and the associated constructivist underpinnings developed to make sense of the findings, has provided such an approach. From the beginning, Australian and New Zealand researchers have been in the forefront of developments in student conceptions research. Here, we are concerned with the implications that were drawn for the teaching of science.

The major insights into student learning delivered by this research is that students come to science classes with prior conceptions that are often qualitatively different and opposed to scientific ways of looking at the world. Unrecognised, these naïve or alternative conceptions interfere with science learning. In general terms, this places demands on the teacher to find ways of accessing and engaging with students' conceptions, which immediately shifts the emphasis in teaching away from clear and efficient delivery, to that of gaining insight into student thinking and negotiating meaning (Gunstone, 1991). These implications were drawn in the early work, and became increasingly explicit as curriculum and teaching models were developed under the constructivist / conceptual change theoretical umbrella (Tytler, 2002a; Hubber & Tytler, 2004). Conceptual change approaches to teaching take their cue from the realisation that learning key science ideas involves the transformation of often well developed informal conceptions, rather than the implantation of packaged science insights. The approaches are varied, but all involve bringing students' prior conceptions into the open, and challenging these using structured activities and classroom discussion within the framework of science ideas. The implications of this research into children's learning, and subsequent research into teaching approaches based on conceptual change ideas, led to a broadening of conception of the role of the teacher.

For instance, in their seminal theoretical work on generative learning, Osborne and Wittrock (1985, p. 75) argued that a teacher needs to

- provide opportunities for pupils to consider, contemplate and expand their views of the world; …
- encourage, challenge and/or reflect back to pupils the views they expound;
- engender the view that success or failure is dependent on students' own actions; and
- ensure that effort is met with success.

These emphases on challenge, metacognitive reflection, and responsibility for learning were subsequently echoed strongly in the Project for the Enhancement of Effective Learning (PEEL).

The interactive teaching approach (Biddulph & Osborne, 1984) was based on the notion of using students' questions as the basis of activity sequences, and involved teachers becoming 'more sensitive to children's ideas and questions' and developing 'the skill of interacting with the children to challenge, modify and extend their ideas' (p. 6). These fresh insights into student learning and implied pedagogies were used to argue that teaching involves a range of distinct roles. Biddulph and Osborne describe four major roles for the teacher in the interactive approach, those of *facilitator of learning* (providing or guiding children and resources), *resource person* (providing information), *naïve fellow investigator* (expressing ignorance of an explanation) and *challenger of ideas* (that are not consistent with evidence). Osborne and Freyberg (1985) described the teaching roles of motivator, diagnostician, guide, innovator, experimenter and researcher. Bell (1993a, 1993b) described the varied roles required of teachers developed out of investigating the experience of teachers in the Learning in Science Project (LISP). They were (p. 97):

- Teaching as researching – finding out what students are thinking
- Teaching as responding – interacting with students' thinking (listening, questioning, challenging, encouraging reflective thinking, motivating)
- Teaching as assessing students' thinking (diagnosing, comparing before and after views, encouraging self assessment)
- Teaching as managing learning (planning, structuring, grouping, facilitating discussion and helping individuals)
- Teacher as learner (learning alongside students)

A number of studies in Australia and New Zealand utilised constructivist/conceptual change principles to develop teacher professional development approaches that strongly implied particular pedagogies arising from the constructivist research. In New Zealand this was the focus of the LISP (teacher development) project (Bell, Kirkwood & Pearson, 1990; Bell, 1993a; Bell & Gilbert, 1994, 1996), which placed a strong emphasis on reflection on practice, and sharing of ideas and beliefs. A similar approach was taken in a related initiative at the university of Canberra, the Primary and Early Childhood Science and Technology Education Project (PECSTEP: Kirkwood & Symington, 1995). In both projects, a set of workshops was accompanied by classroom action research where teachers trialled ideas and reported back. For both projects the outcomes included teacher reporting of more positive learning environments, and increased skill in the use of strategies "which created the opportunity for the teacher to interact with the students' thinking" (Hipkins et al., 2002, p. 92). These included cooperative group work, a range of strategies designed to probe student ideas, a variety of approaches to students sharing ideas, concept mapping, and open ended activities encouraging students to explore their own questions (Pearson & Bell, 1993).

The focus of the classroom sequences and strategies explored in these pedagogical and teacher development projects was the complexity of interaction between students' and teachers' ideas implied by the research into student learning. The LISP project on assessment extended this exploration of the student-teacher interaction to the formative assessment of student thinking as a central part of the pedagogical response to students' ideas. This research (Bell & Cowie, 1999, 2001) places assessment, or 'formative interaction' (Cowie, 2000) at the heart of effective teaching and learning practices.

The LISP research led to a clarification of the implications for teaching of new perspectives on student learning in science, and particularly to a more nuanced conception of the multiple roles of the teacher in supporting student learning. In both Australia and New Zealand, the need to support teachers in this more complex environment led to a number of interrelated strands of research: first, into the development and evaluation of particular teaching moves, second, into the skills and more general strategies needed by teachers to engage with and challenge students' conceptions, third, into the particularities of teaching sequences appropriate to different content, and fourth, into the epistemological challenges implied by these ideas.

An example of the first approach is the development of teaching activities or moves such as the Predict-Observe-Explain (POE) strategy for probing and challenging student conceptions, or the use of concept mapping (White & Gunstone, 1992; Gunstone, 1995). A corpus of writing built up in the mid 1990s around teachers' work in implementing constructivist teaching sequences, often written by teachers in collaboration with academics, focusing on the exemplification of conceptual change approaches, and the difficulties encountered by teachers in negotiating the pedagogical and epistemological territory implied by these new ideas. Significant edited volumes at this time (e.g. Fensham, Gunstone & White, 1994; Hand & Prain, 1995) contained a mix of academic articles exploring theoretical principles and general pedagogical strategies, and articles by teachers exploring content-specific teaching and learning sequences. White (1994) argued the need to develop a 'theory of content' which would clarify the implications for teaching of the structures of different types of science knowledge. This focus on pedagogies appropriate to particular science content has driven much of the research into conceptual change teaching sequences (Treagust & Gunstone, this volume), and underpins the construct of, and research into, pedagogical content knowledge (Berry, this volume). This work also saw the beginnings of other significant strands of research into teaching and learning, such as language use and the literacies of science (Prain, 1995; Prain & Hand, 1996; Prain & Waldrip, this volume), and metaphors and analogies (Harrison & Treagust, 1993; Harrison & Treagust, 2000; Aubusson, Harrison & Fogwill, this volume).

Implications for teachers

A key issue of this research into teaching practices and curriculum sequences arising from this growing insight into student learning and the need to engage with student thinking, is the substantial shift in belief and practice of the teacher away from a role of knowledge provider to the more varied and demanding roles described above. The difficulty of this shift for teachers is the focus of many of the research reports described in this chapter.

Apart from the challenges involved in developing skills in questioning and probing strategies, leading discussion, supporting group work, and challenging conceptions, the difficulty for teachers is that developing their practice towards that advocated by the research into student learning requires epistemological shifts. Carr et al. (1994) argued that effective student learning requires of teachers that they develop a more human-centred view of the nature of knowledge construction in science, and of learning in science. Tobin (1993), studying teachers changing their practice towards constructivist principles, argued that the shift must involve a profound change from an objectivist to a constructivist epistemology. Taylor (1993), exploring with a teacher the shifting of practice towards more student centred, constructivist practices, argued that mainstream constructivist epistemologies have the effect of covertly sustaining centralist teaching practices, with the teacher still the locus of knowledge. He proposed the development of a more socially critical constructivist pedagogy that focuses strongly on students' subjectivities.

Work of this kind is strongly aligned with research from a gender perspective, and cultural perspectives more generally, on the teaching of science. Kirkwood and Symington (1995) explore the epistemological and practical implications of gender perspectives in teaching science, describing dichotomies in traditional and inclusive perspectives relating to science knowledge, teaching, and learning. They worked with female primary school teachers to develop a more inclusive perspective on science, emphasising the importance of people and relationships for learning and knowing.

This body of research thus inevitably led to greater attention to social perspectives on learning, and the role of language in learning. Bell, Cowie and Jones (this book), and Hipkins et al., (2002) describe how, over more than a decade of research in the LISP projects, the perspective on student learning changed from personal constructivism, through social constructivism, to socio-cultural perspectives. Correspondingly, these shifts were accompanied by changing perspectives on effective teaching practices.

PEEL

White and Gunstone (1989) called for promoting metalearning, or metacognition, as an approach to the problem of changing students' science conceptions. They argued that if students could be encouraged to reflect on their beliefs and the adequacy of these to provide fruitful explanations, and to exercise greater responsibility for and control over their own learning, they would become more effective learners. Flowing from these presumptions of the learner as a rational agent was a focus on student learning behaviours, metacognition and higher order thinking pioneered by the Project for Enhancing Effective Learning (PEEL) at Monash. PEEL led to a set of pedagogical principles that became the basis of a program of research.

PEEL was founded in 1985 for the purpose of improving the quality of learning in everyday science classrooms. The project was initiated by science teachers at Laverton High School in Victoria, Australia, and tertiary academics from Monash University and the University of Melbourne, who felt compelled to respond to observations of students being disinterested, disengaged and displaying poor approaches to learning. From its beginning, PEEL employed a method of collaborative action research involving teacher-researchers as participants in improving teaching and learning in their own classrooms:

> Participants observe, collect data, share and reflect upon outcomes, act to change procedures, and document experiences. It is a personal, intimate method of research. It confronts and challenges closely-held attitudes,

> perceptions, conceptions and abilities relating to the nature of learning, the profession of teaching, one's own worth and success, and personal satisfaction and fulfilment. The process of change is often tiring, sometimes upsetting, sometimes rewarding, and always challenging. (Baird & Northfield, 1992, p.ii)

PEEL involves teachers meeting regularly in their own time to share and analyse experiences, ideas and new practices. Various structures provide forums for teachers to share their ideas and learn from teachers in other schools, such as books, a journal called *PEEL SEEDS* (since 1989), a CD-Rom, regular meetings, an annual PEEL conference, short-courses and in-service programs, and multiple editions of a compendium of teaching procedures developed or extended by teachers (see, for example, Baird & Mitchell, 1986; Baird & Northfield, 1992; Mitchell, 2006; PEEL Publishers, 2005). The PEEL website (PEEL Publications, 2008) acts as a gateway to many of these resources and forums.

The success of PEEL is exemplified by its sustained presence in schools. While the program was intended to run for two years, the process of collaboration has maintained the momentum of teacher involvement. PEEL now operates as a network of autonomous groups of teachers, involving teachers from many secondary schools in Australia who are dedicated to researching classroom approaches that stimulate and support student learning. In addition, PEEL has received considerable attention internationally. Training for primary and secondary teachers extends beyond Australia such that PEEL networks now operate in Finland, Sweden (Baird & Higglund, 1994), Canada and China. Further, PEEL has developed strong links with the Teacher Effectiveness Enhancement Programme (TEEP) in the UK, where the PEEL procedures are integrated into their training programmes (Teacher Effectiveness Enhancement Programme, n.d.).

The underlying aim of PEEL is to support students to feel more willing and able to manage and control their own learning (Baird & Mitchell, 1986). The identification of complementary behaviours that encapsulate good learning behaviours and poor learning tendencies provide the basis for purposefully and strategically selecting teaching tactics that promote quality learning. The 12 Principles of Teaching for Quality Learning (see Figure 1), codified in 1997, are based on critical features of teaching that PEEL teachers consistently reported as leading to successful learning. These are (PEEL Publications, 2008):

- Share intellectual control with students
- Look for occasions when students can work out part (or all) of the content or instructions.
- Provide opportunities for choice and independent decision-making.
- Provide diverse range of ways of experiencing success
- Promote talk which is exploratory, tentative and hypothetical.
- Encourage students to learning from other students' questions and comments.
- Build a classroom environment that supports risk-taking

- Use a wide variety of intellectually challenging teaching procedures
- Use teaching procedures that are designed to promote specific aspects of quality learning
- Develop students' awareness of the big picture: how the various activities fit together and link to the big ideas.
- Regularly raise students' awareness of the nature of different aspects of quality learning.
- Promote assessment as part of the learning process.

Mitchell's doctoral thesis (1993) provided in-depth and longitudinal data on students' response to teachers' adoption of PEEL approaches. He found that, despite initial resistance to the types of changes in teaching procedures used by PEEL teachers, most students preferred more active engagement with materials, their peers and their teachers. Evidence from classroom dialogue, student journals and performance on assignments and tests showed that students generally asked more demanding questions, were more aware of their work habits, and were more regularly involved in high levels of intellectual activity (Loughran, 2003).

The other important contribution of PEEL has been its commitment to teacher research. The impact of the program is most felt at the classroom interface by the teachers and students involved in the program. The major goal for these teachers "is to teach more effectively in their own classroom settings" (Loughran, 2003, p.183). Participation in the rigours of academic writing and dissemination of their research findings is both secondary and challenging for a variety of reasons. "For teachers, a wider communication of their findings is difficult to achieve and there are few incentives to publish their work as there is little status or career advancement for publishing" (p.183). Loughran makes the point that there are few outlets for teachers to disseminate their research findings, but he uses PEEL as an example of the benefit to teachers, and the academy, when such collaboration can be achieved: "Teachers' accounts of their work have increased our understanding of classroom teaching and learning in ways that could only have been achieved through a forum of sharing their perspectives on practice" (p.183).

Erickson et al. (2005), writing on PEEL, argued that while the evaluation of such collaborative projects can tend to rely on the professional judgements of the participants, such judgements are deemed worthy evidence on the basis that "teachers are the most critical agents in the process of constructing and nurturing particular types of learning environments in their own classrooms and so their perceptions of their relative success in this regard are important" (p.794). Also important are the changes in stress levels, enjoyment and satisfaction of teachers that have resulted from their involvement in a project such as PEEL. Not only teachers, but students stand to benefit from a more satisfying classroom environment. According to White (1992), the program has sustained credibility and acceptance by teachers because the methods, purposes and incentives emerged from within a school setting and responded to teachers' own concerns, rather than being imposed from an external body.

Consistent with the conceptual focus of PEEL, the direction of research at Monash University has moved towards describing and clarifying pedagogical content knowledge (Berry, this volume) which focuses on the knowledge that teachers draw on in their teaching (see, for example, Loughran, Berry, & Mulhall, 2006; Mulhall, Berry, & Loughran, 2003). The action research methodology employed by PEEL has been adopted by others interested in teacher change research (Loughran, 2004, 2007).

RESEARCHING EXEMPLARY TEACHERS

Another approach to researching the characteristics of effective practice is to directly study good practice in real classrooms. A range of studies in Australia (Tobin & Gallagher, 1987a, 1987b, Goodrum, Hackling & Rennie, 2001) and elsewhere over the last few decades have described the sorry state of teaching of science in secondary schools. Attention has focused on the emphasis on factual information driven by textbook use and tests, lack of small group activity (Gallagher & Tobin 1987), negotiation of low level cognitive demand (Sanford 1987), and the concentration of conceptual activity in a minority of 'target' students (Tobin & Gallagher 1987a). The situation, in terms of dominant teaching practices, is somewhat different in primary schools. Critique of the teaching of primary science has centred on the lack of confidence of primary teachers in their science subject matter knowledge, and the effects of this on their willingness to teach science (Goodrum, Cousins & Kinnear, 1992) and their competence to teach science effectively. Appleton's (2002) research for instance showed how teachers of primary science tend to focus on the 'activity that works' rather than a coherent conceptual program.

A series of studies in the US responded to this perception of impoverished science teaching by engaging in studies of recognised exemplary science programs, to ascertain their key characteristics. A major and well published Western Australian project focused on case studies of classroom practices employed by 'exemplary' teachers, rather than programs (Tobin & Fraser, 1987). The project was explicitly framed within constructivist principles, which were claimed to lead to greater value being placed on higher order cognitive learning (Tobin & Fraser, 1989, 1990). The project involved case studies being constructed by five research teams, of 13 science teachers nominated by key educators in Western Australia. The key criterion.for selection of these exemplary teachers was thus recognition by peers.

The project reported considerable diversity amongst the methods these teachers used, but nevertheless produced four broad assertions concerning exemplary science teachers (Tobin & Fraser 1988, 1990), that they:

1. used management strategies that facilitated sustained student engagement
    - sensitive and sure monitoring of all students' behaviour and engagement
    - smooth flow between different aspects of the lesson
    - students worked together cooperatively

  - teachers had goals of autonomy and independence
2. used strategies designed to increase student understanding of science
  - use of a range of verbal strategies to monitor and support student understanding, such as analogies, use of concrete examples
  - questioning in whole class or group situations, which focused on facilitating understandings
  - encouragement of active engagement of all students
  - emphasis on understanding rather than rote learning
  - focus on understanding of science methods, problem solving methods, an attitude of scientific inquiry
  - sufficient content knowledge to productively engage with student conceptions
3. utilised strategies that encouraged students to participate in learning activities
  - focus on high level cognitive work but provision of 'safety nets' to encourage engagement of all
  - sensitivity to all students' learning needs, appropriate questioning and supportive responses
  - setting up supportive small group atmosphere
4. maintained a favourable classroom learning environment.

This last assertion has been the subject of a significant body of Australian research into classroom learning environments (see Fraser et al., this book) that explores students' perceptions of such things as their involvement, degree of teacher support, the extent of task orientation, order, and the clarity of rules.

Treagust (1991) in a study allied to this broader project describes how differences in the personalities and teaching philosophies of two exemplary biology teachers were manifested as differences in styles of structuring the lessons, of managing student interactions, and in their expectations. Both teachers encouraged students to take responsibility for their own learning, and maintained a focus on conceptual knowledge. Treagust developed five assertions that describe what both teachers displayed in common, characterising the exemplary nature of their practice. Both teachers:

- exhibited classroom management and organization styles that resulted in smooth transitions between one class structure and another (part of this was organization, but also circulation round the room and dealing individually with students);
- encouraged learning from students of different ability levels (giving extension work, asking all students to respond, rephrasing questions, soliciting further comment after an inadequate answer, providing out of class support);
- manipulated the social environment to encourage students to engage in academic work (giving praise, referring to student work, seeding

questions to students who had previously struggled but now had succeeded, allowing diversions but moving back to the main points);

- set academic work that had a high level of cognitive demand (asking students to elaborate on answers, rephrasing questions, structured support, focusing clearly on student understanding); and
- used the laboratory in an inquiry mode and as an integral part of the course (asking students to come prepared for practical work, asking students to explain what they were doing and why, asking for links between the activities and ideas in the text).

The general image created in these case stories is of attentiveness of teachers to students' different science learning needs, the creation of an inquiring environment which focuses on significant understandings, and the fostering of a cooperative atmosphere that encourages student autonomy. Different teachers in the project had very different styles in terms of their teacher or student–centredness, their strictness or friendliness, and also the way they structured different phases of the lessons. It is clear that in these specifics, and accepting the identification of these teachers as exemplary, there is no one model of quality science teaching, but rather broad principles.

A study by Tobin, Kahle and Fraser (1990) of two successful secondary science teachers led to a complex view of the barriers to higher level cognitive learning in science, including underestimation of the cognitive aptitude of students. The two teachers had very different styles, which were analysed in terms of metaphors for specific roles in teaching. The study was somewhat disheartening in its judgments of the teachers' practice.

Studies of exemplary classrooms and teachers — some issues

The research into recognized exemplary teachers and programs can potentially help identify elements of science classroom practice that teachers in general might aspire to, and that can be used to guide school change and teacher professional development. However, there are a number of issues that attach to this approach. First, how do we select for effective or exemplary practice? Who chooses and on what basis? Inevitably the selection will involve the operation of value judgments, and there is a danger in this approach that the act of selecting will tend to emphasise existing norms. Teachers may be selected on the basis of conforming to currently accepted images of excellence. If they are chosen on the basis of student results, this will reinforce the operation of current assessment practices as the determinants of best practice. Happs (1986, 1987) observed two teachers identified as exemplary, and claims that when operating outside their field of expertise they could very effectively reinforce student misconceptions. He makes the point that teachers may build up reputations for their class control and logistical organisation, but this is not the same thing as judging the development and retention of real science understandings in their students. Tobin & Garnett (1988) found instances of nominated exemplary primary science teachers with significant classroom control problems. Tobin, Espinet, Byrd & Adams (1988) found that an 'exemplary' teacher they studied, who regularly won prizes and was lauded by his peers, in practice fell far short of the principles of good learning found in the literature.

Second, studies of this kind, because they seek to exemplify what is currently the case, tend not to raise questions about the multiple purposes of science education, the nature of science learning and knowledge, or the different types of student outcomes that may be appropriate to focus on.

Ethnographic studies of classrooms

Darby's (2005) study of a Year 7 class and their teacher used ethnographic methods to build a picture of students' preferences in relation to science teaching. Students perceived engaging pedagogy as having both instructional and relational dimensions. Instructional pedagogy relates to the teachers' tendency to use the students' ideas in her conceptual teaching, particularly when introducing new concepts and when clarifying previously encountered understandings. Relational pedagogy referred to teachers' interpersonal interactions with them, and was characterised by students' expectation that a teacher:

- is passionate and enthusiastic about the subject and teaching it;
- creates a comfortable learning environment where the teacher is friendly, and students did not feel threatened to share their ideas publicly; and
- provides help in developing students' conceptual understanding by being encouraging, attentive to students' learning needs, and understandable.

Darby asserts that good teachers, particularly in the middle years, are aware that how they relate with students on a personal level affects opportunities for learning just as much as their methods of instruction.

THE SCHOOL INNOVATION IN SCIENCE RESEARCH PROJECT

The School Innovation in Science (SIS) research project was a school and teacher change initiative with a strong focus on pedagogy (Tytler, 2007a). A major aspect of the approach was the development of a framework to describe effective science teaching and learning: the *SIS Components*.

A large part of the background to SIS was the concern with the lack of engagement of students with science across the middle years 5 to 9 of schooling, and the project knowingly adopted some of the recommendations and strategies of the Victorian Middle Years Research and Development project. The drop off in interest in schooling more generally across the middle years has been linked with the personal and social challenges associated with adolescence. The MYRAD project generated out of these concerns a model of school organisation and change that emphasised the creation of opportunities for sustained and in-depth learning, and social structures within the classroom and school that can provide support during the adolescent years. Much of the focus of the project was on school level structures, and the SIS emphasis on science professional learning teams was consistent with this. In terms of effective classrooms, the project has emphasised teacher efficacy and student responsibility and autonomy. It recommended, as the basis of a middle years pedagogy, that teachers need to (Hill, Jane, Mackay & Russell 2000):

- Emphasise active, student centred learning and the development of autonomous learners;
- Emphasis higher-order thinking and in-depth learning;
- Establish high expectations of all;
- Make thoughtful and purposeful use of the new information technologies;
- Put in place safety nets and provide support and special assistance for low achieving and 'at risk' students; and
- Create school and classroom cultures which reward effort rather than ability and cooperation rather than competition.

These approaches to teaching and learning were echoed in many initiatives and reviews focusing on pedagogy, for instance the 'productive pedagogies' project in Queensland or the DEST report "Beyond the Middle" (Luke et al., 2003). The "productive pedagogies" project of the Queensland government (http://education.qld.gov.au/corporate/newbasics/html/pedagogies/differ/dif.html) emphasised 20 pedagogical principles aligned with findings from middle years research, clustered under *intellectual quality*, *connectedness*, *supportive classroom environment*, and *recognition of difference*.

The SIS Components were developed out of interviews with effective teachers of science across three states. The teachers were recommended by education department personnel, academics and practicing teachers active in the science teachers' associations, and hence represented peer judgments about the nature of quality professional practice. Tytler (2003) describes the essentially political nature of framing what was to be emphasised in developing the Components out of the interview data, taking into account contemporary trends in the literature and understandings of the purposes of school science. Tytler, Waldrip and Griffiths (2004) discuss the theoretical perspectives represented by the components, and describe a method by which the draft Components were validated against the practice of a further set of identified effective primary teachers, compared to the practice of a large number of teachers who were in the project. This judgment was made using a 'component mapping' technique in which teachers locate their practice against the components during an interview with a trained coordinator. The SIS Components are neither simply prescriptions for teacher actions nor are they focused on student activity. The SIS Components state that in classrooms that effectively support student learning and engagement in science:

1. Students are encouraged to actively engage with ideas and evidence
2. Students are challenged to develop meaningful understandings
3. Science is linked with students' lives and interests
4. Students' individual learning needs and preferences are catered for
5. Assessment is embedded within the science learning strategy
6. The nature of science is represented in its different aspects
7. The classroom is linked with the broader community.
8. Learning technologies are exploited for their learning potentialities

Each of these SIS Components was further detailed through sub Components, and a considerable body of supporting material was generated to unpack these and link them with major strands in the science education literature.

During the SIS project, the team based professional learning processes, through which classroom practices were focused on and innovation was supported, were evaluated (Tytler, 2005, 2007). Over the three years of the project teacher practice was shown by the component mapping process to shift substantially across the different components, for both primary and secondary teachers. Large scale tests of student attitudes and achievement showed significant correlations between scores on these, and teacher conformity to the SIS Components, although in the latter case the evidence was somewhat inconsistent (Tytler, in press).

Following SIS, a number of major projects were supported in Victoria to extend the School Innovation model to middle years and then P-12 pedagogy more generally, using focus groups to refine the framework. Further projects were supported by interviews with effective teachers of mathematics, and technology. These developments resulted in a more refined treatment of relational aspects of classroom teaching and learning, and in the cases of mathematics and technology, greater emphasis on problem solving, on student identity, and on creativity and imagination. This research has sharpened understandings of the distinctiveness of teaching in different disciplines. The link between the SIS Components and middle years teaching principles is apparent, and they align with the PEEL principles also, which were developed out of experience in real classrooms. PEEL researchers were involved in SIS, and the work of PEEL fed into a number of aspects of the SIS project. Where SIS extends beyond PEEL is in its greater recognition of the wider framing of the purposes of school science, to acknowledge humanistic aspects of science practice, the importance of students' lives and interests in providing meaningful contexts for learning, the nature of science, and the way the curriculum needs to incorporate contemporary community concerns and practices. These concerns are strongly aligned with calls for a focus on scientific literacy as the driving purpose of school science (Goodrum, Hackling & Rennie, 2001), and with the Australian statement for learning in science which includes *Science as a body of knowledge*, *Science as a way of knowing*, and *Science as a Human Endeavour* as its three organisers. This contemporary reworking of the fundamental purposes of science education must be reflected in contemporary conceptions of science teacher practices and beliefs.

Professional Standards for the teaching of science

The SIS Components have a large degree of overlap with the National Professional Standards for highly accomplished teachers of science (Australian Science Teachers Association, 2002). These were based on analysis of the research literature, and a program of consultation with key players (Ingvarson, 1992, Ingvarson & Ferguson, 2000). The standards focus on the teachers' commitment to their own and others' professional growth, and their knowledge about science and science curricula, teaching and learning in science, and of students and learning. In terms of classroom practice, the standards include the designing of coherent learning programs appropriate for student needs and interests, the creation of learning environments that are intellectually challenging and emotionally supportive, engaging students in inquiry that coordinates ideas and evidence, extending students' understanding of major science ideas, developing students' confidence and ability to use science in decision making, and using a variety of strategies for assessing students' learning and providing feedback. The standards are intended to allow science teachers to demonstrate their accomplishment through the construction of a professional portfolio.

CLASSROOM VIDEO STUDIES

The use of video to capture, analyse and gather commentary on classroom related occurrences is gathering momentum internationally and in Australia. An example of an early study was the Science Classroom Management Project (Butler, Beasley, Buckley & Endean, 1980), where video was used to examine classroom interactions between the students and the teacher. Stimulated recall techniques were used to provide teacher and student commentary on interaction patterns in the classroom, and results were fed back to teachers at regular intervals for comment and critique. The analysis focused on nonverbal visual records of teacher and student behaviour; in particular, Pleasure, Arousal and Dominance, and their impact on student task involvement. The results demonstrated the affective component of classroom communication, and that such emotional states can be conveyed nonverbally (Wilson & Butler, 1982).

Of particular importance and breadth of scope is the more recent Trends in Mathematics and Science Study (TIMSS) video study, which investigated and described teaching practices in Year 8 mathematics and science across seven countries, five of which participated in the science study: Australia, Czech Republic, Japan, the Netherlands and the United States. An analysis of the science lessons from an Australian perspective are reported in Lokan, Hollingsworth and Hackling (2006). The premise behind this TIMSS study is that research on teaching as it is practiced can lead to better understanding of factors that might enhance opportunities for students learning (Lokan et al., 2006). The Australian sample involved teachers from across the country. One randomly selected teacher from 87 schools was filmed for one complete Year 8 science lesson. The study also had a professional development intent in that snapshots of practice are now available for teacher training purposes.

The data provided strong endorsement for the quality of science teaching in Australia. When compared with lessons from other high achieving countries, the Australian science lessons reflected some aspects of contemporary ideals for exemplary teaching (referring to, for example, Goodrum, Hackling, & Rennie, 2001; Tytler, 2002b), particularly in the teachers' attempts to relate content to students' lives and interests, and the links between evidence and science ideas through inquiry-based pedagogies. The cross national comparison showed that Australia, after Japan, devoted more time to "making connections" rather than "acquiring facts" when developing scientific content. Inquiry-based activity was the most common approach used by teachers to make these connections:

Australian lessons appeared to have a strong focus on developing ideas through an inquiry, inductive process and supporting canonical ideas with examples of real life issues while also providing multiple types of activities that had the potential to engage student' interests. (Lokan et al., 2006, p.xix)

While Lokan et al. asserted that these strengths in the Australian scenario forms the basis for enhancing scientific literacy, they also concluded that a dominance of teacher-led practical work provided limited opportunities for students to generate their own research questions and investigations, and that only half of the activity-based lessons included opportunities for public discussion of results and conclusions. Given the centrality of inquiry learning, an implication of the findings is that teachers need to enhance their skills of managing inquiry lessons, particularly in the areas of promoting more student-directed investigations and in their management of quality whole class discussions to ensure that the scientific concepts underlying the investigations can be developed from the inquiry process (Lokan et al., 2006).

More recently, the Australasian Science Education Research Association has supported the development of a proposal for an Australia – New Zealand video project researching good practice as the basis for professional development materials.

AESTHETICS AND SCIENCE TEACHER PEDAGOGIES

Evaluation and description of effective teaching has predominantly focused on actions and teacher knowledge that are observable and measurable at the classroom interface. Such descriptions provide greater insight, however, when they take into account the personal dimensions of teaching, such as the role that teachers' passions, interests and commitments play in shaping the nature of their interactions with their students and the science content. While passion has been shown to be a desirable quality of effective teachers (Education Training Committee, 2006), scant research explicitly delves into the relationships between teacher passion and teaching effectiveness. Such research has the potential to investigate the nexus between classroom practice, and teachers' beliefs, values and commitments in relation to the nature of teaching and learning, science and school science. Research by Darby (2008) broaches this relationship with a framework called "aesthetic understanding" derived from a Deweyan perspective on aesthetic experience. To have an aesthetic understanding of what it means to teach a subject is an indication of where a teacher's passions lie with respect to teaching the subject and the discipline, to what extent a teacher has a coherent and intuitive sense of what is required to teach the subject and bring it to life for students, and how the teacher is transformed by what they know as they develop an identity in relation to the subject.

Such an holistic perspective on the teacher provides a way forward in exploring synergies between research into teacher identity and self-efficacy in the science context, teachers' commitments to the subject and the discipline, and the knowledge required to teach the subject. For example, Hipkins (2006) recognises that how teachers position themselves ontologically with respect to science is invariably shaped by their personal response to the subject. In her investigation of science teachers' approaches to the teaching of the nature of science, she found that teachers tended to replace more formal accounts of the way science knowledge is generated with more impassioned accounts based on the practices and objects of their own scientific inquiries. She found that teachers' narratives revealed both passion for their personal learning and an ethical concern for their students' learning to care for both the natural world and science as a means of its investigation. As a strand of research developing overseas, further research into the aesthetic dimensions of teaching and learning is warranted in the Australian context, particularly in terms of how our understanding of these aspects of teaching influence, shape and become determinants of teacher effectiveness.

It is often assumed that the acquisition of disciplinary knowledge confers on teachers an appreciation and enthusiasm for the subject that can be transmitted to students. This combination of subject matter knowledge and passion are qualities of effective teachers (Darby, 2005), but are potentially lacking for teachers with limited teaching experience or for teachers teaching out-of-field (Darby, 2008; Ingvarson, Beavis, Bishop, Peck, & Elsworth, 2004). Other research shows that, while a teacher's practice is dependent on the experiences that the teacher has had with the subject or discipline, these experiences are not necessarily related to exposure at university level. For example, other factors, such as career trajectory (Siskin, 1994) and professional development (Tytler et al., 1999) have been found to be cogent in determining how teachers approach teaching and learning. Tytler et al. (1999) reported that the purpose of professional development for teachers relatively inexperienced in a content area is "to induct them into the culture surrounding the content, or into new ways of looking at it" (p.210). For science, this meant an appreciation of productive activity sequences as opposed to the acquisition of disembodied content knowledge. Appleton (2005) found similarly that professional development for primary science teachers should focus not only on improving their knowledge of content, constructivist teaching approaches, PCK and the nature of science, but also on giving teachers a positive and successful experience of doing and teaching science. This aesthetic construct adds to the insights generated by Bell and Gilbert (1994, 1996) and Kirkwood and Symington (1995) concerning the importance of the affective and social dimensions in teacher professional learning.

FUTURE CHALLENGES

The studies described above represent a growing understanding of teachers' practice in support of student learning in science, and a largely compatible set of descriptors of supportive pedagogies. These have supported, in some cases, substantial professional learning initiatives. There are a number of challenges, however, that a future research program on the teacher of science needs to accommodate. These relate to (a) the challenges of the current and looming shortage of trained teachers of science, (b) the challenges to the purposes and practices of school science raised by downward trends in student engagement and wider conceptions of schooling and the agency of students, and (c) the need to more effectively represent the insights of this research in supporting teachers.

Teacher supply and retention

There has been a focus in recent years on the problems associated with the unmet demand of qualified science and mathematics teachers, and the increasing incidence of teaching out-of-field (Department of Education Science and Training, 2003; Education Training Committee, 2006). For example, a survey involving 8.2% of teachers of junior science in Australia (Harris, Jensz, & Baldwin, 2005) showed that 16% of respondents lacked a minor in any university science discipline, while 8% had not studied any tertiary science. A recent study of beginning teachers in Australia showed that 40.1 % of teachers nationally and 57% in Victoria had taught subjects outside their qualifications (Rodd, 2007). These figures are apparently rising.

The reality is that many schools experience difficulty recruiting qualified teaching staff, and this is exacerbated by the aging staff profile, uncertainty amongst younger teachers about career paths, and poor teacher retention partly as a result of job dissatisfaction (Harris & Jensz, 2006; Harris et al., 2005). Rural and regional areas have been reported to have higher unmet demand for mathematics and science teachers than in metropolitan areas, and with this, a greater incidence of underqualified teaching (Lyons, Cooksey, Panizzon, Parnell, & Pegg, 2006). The proposed solution to this problem is two fold: to draw more students into post compulsory and tertiary science and mathematics, and to make careers in maths and science teaching a more attractive option (Department of Education Science and Training, 2003; Education Training Committee, 2006; Harris et al., 2005; Rodrigues et al., in press). Ingersoll (1998) suggests these measures alone would not suffice. Also needed are improved conditions for teachers to curb poor teacher retention rates. Thomas (2000) recognises that both of these actions are important long term solutions, but that in the short term, skilling up of existing teachers should be offered as funded retraining schemes that remove the burden of time and cost from the teacher, suggesting study leave to develop appropriate mathematical knowledge and skills.

Thus, there is and will be an increasing need to understand the issues of retention of teachers of science, and how best to support 'out of field' teachers of science. Science teacher research is needed, that addresses these issues.

Challenges to the nature and purposes of school science

A substantial body of evidence suggests that substantial changes are needed in science teaching if we are to capture the interest and commitment of students. Studies overseas and in Australia have shown that traditional science teaching is failing to engage students, and that the issue relates more centrally to the pedagogies used in science teaching, more so than the content (Goodrum, Hackling & Rennie, 2001; Lyons, 2006a, 2006b). Part of this circumstance relates to the wider issue of the democratisation of the classroom and the changing conception of the agency of the student.

The call for science literacy to be the major purpose of science education (Goodrum, Hackling & Rennie, 2001) challenges traditional assumptions about the role, and expertise of science teachers. This purpose, focusing on the preparation of students for adult lives engaged with science based ideas and technologies, implies greater attention being given to the nature of science, the coordination of ideas and evidence, and response to science in personal and social settings. These changes place demands on teachers of science to develop skills in discussion of issues and debate, in teaching science in contexts where the evidence is uncertain, and in supporting students in open-ended exploration. The Australian national statements of learning (MCEETYA, 2006) include as major organisers ‘science as a way to know’ and ‘science as a human endeavour’, and again these imply a focus on more investigative, problem solving approaches, and representations of human aspects of science practices. An explicit focus on the literacies of science also has implications for teacher knowledge and practice, as do calls for the inclusion of broader capabilities such as creativity, teamwork and communication that are increasingly represented in contemporary science curricula such as the Victorian Essential Learning Standards (VELS: http://vels.vcaa.vic.edu.au)

The call for a re-imagining of science education (Tytler, 2007b) includes a need to incorporate contemporary, and local community practice. This has implications for the teacher of science in that it entails negotiating knowledge that is less certain and practices that are more interdisciplinary than is the case with established, canonical science. Teaching based around local science practices arguably involves more open and potentially challenging pedagogies, and a different view of knowledge than is the case with traditional canonical content (Tytler, Symington, Smith & Rodrigues, 2008; Tytler, Symington, Kirkwood & Malcolm, in press).

These changing views of the purpose and practices of school science thus challenge any ‘steady state’ version of what it is to be a good science teacher. They imply a widening of views of the nature of science, and of the pedagogical knowledge and skills needed to teach science. They are of course practices that already exist in some measure in Australasian schools, since there are many accomplished teachers of science, engaged in innovative programs. If we as a research community are to support science education moving in these directions, we need to be engaged in research into the nature of these practices, and into ways of supporting teachers to adopt them.

Translating the research for teachers

Teaching is a complex enterprise, and capturing its nature such that it can be useful for driving teacher education and professional learning, is a difficult task. The pedagogical principles developed in these studies are compatible, but described at varying levels of specificity. The SIS project, described above, used one-on-one interviews and detailed supporting documentation to establish shared understandings of the SIS Components. Words can be misleading, and teachers and researchers may interpret pedagogical statements quite differently. There is a need to theorise the process of engaging teachers in a shared pedagogical language, as part of a research agenda aimed at supporting change. This will involve developing such a language, and ways of exemplifying it. The video capture of classrooms, such as used in TIMSS, offers a potential way forward. With coded video, teaching approaches and curriculum planning can become apparent such that teachers can see new possibilities directly, and the possibility of miscommunication is minimised.

Arising out of this review is an agenda for research into science teaching that is critical for the future of science in our schools. This agenda includes (a) the attraction, retention and professional support of science teachers in a situation of critical shortage, (b) the development and promotion of pedagogies relevant to new directions for science education, and (c) the development of research findings in a form that can support teachers in transforming their practice.

REFERENCES

Baird, J. R., & Higglund, S.-O. (1994). *Teacher collaborative action research: A Swedish adaptation of an Australian project.* Paper presented at the Annual Conference of the Australian Teacher Education Association, Brisbane, July 3-6.

Baird, J.R. & Mitchell, I.J. (Eds). (1986). *Improving the quality of teaching and learning: An Australian case study – The PEEL project.* Melbourne: Monash University.

Baird, J. R., & Northfield, J. R. (1992). *Learning from the PEEL experience*. Melbourne, Vic.: The Monash University Printing Services.

Baird, J.R. & White,R.T.(1982). Improving self-control of learning. *Instructional Science, 11*, 227-247.

Barber, M., & Mourshed, M. (2007). *How the world's best school systems come out on top*. Report commissioned by the Directorate of Education, OECD. Retrieved May 2008 from www.mckinsey.com/clientservice/socialsector/resources/pdf/Worlds_School_Systems_Final.pdf

Bell, B. (1993a).(Ed.) *I know about LISP, but how do I put it into practice? Final report of the Learning in Science Project (teacher development).* Hamilton, University of Waikato.

Bell, B. (1993b). *Children's Science, Constructivism and Learning in Science.* Geelong, Australia: Deakin University Press.

Bell, B. and Cowie, B. (1999). Researching teachers doing formative assessment. In J. Loughran (Ed.) *Researching Teaching*. London: Falmer Press.

Bell, B. and Cowie, B. (2001). *Formative assessment in science education*. Dordrecht: Kluwer.

Bell, B. and Gilbert, J. (1994). Teacher development as professional, personal and social development. *Teaching and Teacher Education*, 10(5): 483-497.

Bell, B. and Gilbert, J. (1996) *Teacher development: a model from science education*. London: Falmer Press.

Bell, B., Kirkwood, V. and Pearson, J. (1990). Learning in Science Project (teacher development): The framework. *Research in Science Education*, *20*(1), 31-40.

Biddulph, F. (1990). *Pupil questioning as a teaching/learning strategy in primary science education. SAME papers 1990* (pp. 60-73). Hamilton, NZ: Centre for Science and Mathematics Education Research, University of Waikato.

Biddulph, F. & Osborne, R. (eds) (1984). *Making sense of our world: An interactive teaching approach.* Hamilton, NZ: Science Education Research Unit, University of Waikato.

Butler, J.E., Beasley, W.F., Buckley, D. & Endean, L. (1980). Pupil task involvement in secondary science classrooms. *Research in Science Education, 10*, 93-106.

Carr, M., Barker, M., Bell, B., Biddulph, F., Jones, A., Kirkwood, V., Pearson, J., & Symington, D. (1994). The constructivist paradigm and some implications for science content and pedagogy. In P. Fensham, R. Gunstone& R. White (Eds), *The content of science: A constructivist approach to its teaching and learning* (pp. 147-160). London: The Falmer Press.

Darby, L. (2005). Science students' perceptions of engaging pedagogy. *Research in Science Education, 35*, 425-445.

Darby, L. (2008). Negotiating mathematics and science school subject boundaries: The role of aesthetic understanding. In M. V. Thomase (Ed.), *Science in Focus* (pp. 225-251). Hauppauge, NY: Nova Science Publishers.

Darling-Hammond, L. (2007). The flat earth and education: How America's commitment to equity will determine our future. *Educational Researcher, 36*(6), 318-334.

Department of Education Science and Training. (2003). *Australia's teachers: Australia's future. Advancing innovation, science, technology and mathematics. Agenda for action*. Canberra: Commonwealth of Australia.

Education Training Committee. (2006). *Inquiry into the promotion of mathematics and science education*. Melbourne: Parliament of Victoria.

Erickson, G., Minnes Brandes, G., Mitchell, I., & Mitchell, J. (2005). Collaborative teacher learning: Findings from two professional development projects. *Teaching and Teacher Education, 21*, 787-798.

Fensham, P., Gunstone, R., & White, R. (1994). Science content and constructivist views of learning and teaching. In P. Fensham, R. Gunstone, & R. White (Eds.), *The content of science: A constructivist approach to its teaching and learning* (pp. 1-8) . London, UK: Falmer.

Fraser, B. (1986). *Classroom environment*. London: Croom Helm.

Fraser, B., & Tobin, K. (1993). Exemplary science and mathematics teachers. In B. Fraser (Ed.), *Research implications for science and mathematics teachers* (,Vol. 1 pp. 1-6). Perth: Curtin Key Centre for School Science and Mathematics.

Freyberg, P., & Osborne, R. (1985). Assumptions about teaching and learning. In R. Osborne & P. Freyberg (Eds.), *Learning in science: The implications of children's science* (pp. 82-90). Auckland, New Zealand: Heinemann.

Gallagher, J. & Tobin, K. (1987). Teacher management and student engagement in high school science. *Science Education, 71*, 535-555.

Goodrum, D, Hackling, M. & Rennie, L. (2001). *Research Report: The status and quality of teaching and learning of science in Australian schools.* Canberra; Department of Education, Training and Youth Affairs. http://www.detya.gov.au/schools/publications/index.htm.

Goodrum, D. Cousins, J. & Kinnear, A. (1992). The reluctant primary school teacher. *Research in Science Education, 22*, 163-169.

Gunstone, R. (1995). Constructivist learning and the teaching of science. In B. Hand & V. Prain (Eds), *Teaching and learning in science: The constructivist classroom* (pp. 3-20). Marrickville, NSW: Harcourt Brace.

Hand, B. & Prain. V. (Eds). (1995). *Teaching and learning science: The constructivist classroom.* Sydney: Harcourt Brace.

Happs, J. (1987). Good teaching of invalid information: Exemplary junior secondary science teachers outside their field of expertise. In K. Tobin & B. Fraser (Eds), *Exemplary practice in science and mathematics teaching.* Perth: Curtin University of Technology.

Harris, K.-L., & Jensz, F. (2006). *The preparation of mathematics teachers in Australia. Meeting the demand for suitably qualified mathematics teachers in secondary schools*. Melbourne: Centre of the Study of Higher Education, The University of Melbourne.

Harris, K.-L., Jensz, F., & Baldwin, G. (2005). *Who's teaching science? Meeting the demand for qualified science teachers in Australian secondary schools*. Melbourne: Centre for the Study of Higher Education, The University of Melbourne.

Harrison, A., & Treagust, D. (1993). Teaching with analogies: A case study of Grade 10 optics. *Journal for Research in Science Teaching, 30*(10), 1291-1307.

Harrison, A., & Treagust, D. F. (2000). Learning about atoms, molecules, and chemical bonds: A case study of multiple-model use in Grade 11 chemistry. *Science Education, 84*(3), 352-381.

Hill, P., Jane, G., Mackay, T. & Russell, J. (2000). *Victorian Middle Years Research and Development Project (MYRAD)*. Paper delivered at the second Middle Years of Schooling conference, Melbourne, August.

Hipkins, R. (2006). *Ontological possibilities for rethinking teaching of the nature of science*. Unpublished doctoral thesis, Deakin University, Burwood, Australia.

Hipkins, R., Bolstad, R., Baker, R., Jones, A., Barker, M. , Bell, B., Coll, R., Cooper, B., Forret, M., Harlow, A., Taylor, I., France, B., & Haigh, M. (2002). *Curriculum, Learning and Effective Pedagogy: A Literature Review in Science Education.* Report to the Ministry of Education, New Zealand. University of Waikato and New Zealand Council for Educational Research with Auckland College of Education

Hubber, P. & Tytler, R. (2004). Conceptual change models of teaching and learning. In G. Venville & V. Dawson (Eds), *The art of science teaching* (pp. 34-53). Perth: Allen and Unwin.

Ingersoll, R. M. (1998). The problem of out-of-field teaching. *Phi Delta Kappan, 79*(10), 773-776.

Ingvarson, L., (1992). Professional standards for the teaching of science: An exploratory study. *Research in Science Education, 22*(1), 204-213.

Ingvarson, L., Beavis, A., Bishop, A. J., Peck, R., & Elsworth, G. (2004). *Investigation of effective mathematics teaching and learning in Australian secondary schools*. Melbourne: Australian Council for Educational Research.

Ingvarson, L. & Ferguson, P. (2000). *Developing standards for the professional certification of science teachers.* Paper presented at the Annual conference of the Australasian Science Education Research Association, Fremantle.

Kirkwood, V., & Symington, D. (1995). Gendered teaching in science classrooms. In B. Hand & V. Prain. (Eds), *Teaching and learning science: The constructivist classroom* (pp. 21-43). Sydney: Harcourt Brace.

Lokan, J., Hollingsworth, H., & Hackling, M. (2006). *Teaching Science in Australia: Results from the TIMSS 1999 Video Study*. Camberwell, Vic.: Australian Council for Educational Review.

Loughran, J. (2003). Exploring the nature of teacher research. In A. Clarke & G. L. Erickson (Eds.), *Teacher inquiry: Living the research in everyday practice* (pp. 182-189). London: Routledge.

Loughran, J. (2004). Learning through self-study. In J. Loughran, M. L. Hamilton, V. K. LaBosky & T. L. Russell (Eds.), *The international handbook of self-study of teaching and teacher education practices* (pp. 151-192). Dordrecht: Kluwer Academic Publishers.

Loughran, J. (2007). Teachers as leaders: Building a knowledge base of practice through researching practice. In T. Townsend & R. Bates (Eds.), *Handbook on leadership in teaching* (pp. 585-596). Dordretch: Springer.

Loughran, J., Berry, A., & Mulhall, P. (2006). *Understanding and developing science teachers' pedagogical content knowledge*. Rotterdam: Sense Publishers.

Luke, A., Elkins, J., Weir, K., Land, R., Carrington, V., Dole, S., Prendergast, D., et al. (2003). *Beyond the Middle: A report about literacy and numeracy development of target group students in the middle years of schooling* (Vol. 1). Canberra, ACT: Commonwealth Department of Education Science and Training. Retrieved January, 2007, from http://www.dest.gov.au/sectors/school_education/publications_resources/literacy_numeracy/beyond_the_middle_years.htm

Lyons, T. (2006a). Different countries, same science classes: Students’ experiences of school science in their own words. *International Journal of Science Education, 28*(6), 591–613.

Lyons, T. (2006b). The puzzle of falling enrolments in physics and chemistry courses: Putting some pieces together. *Research in Science Education, 36*(3), 285–311.

Lyons, T., Cooksey, R., Panizzon, D., Parnell, A., & Pegg, J. (2006). *Science, ICT and Mathematics Education in Rural and Regional Australia. The SiMERR National Survey*. Canberra: Department of Education, Science and Training.

Ministerial Council on Education, Employment, Training and Youth Affairs (MCEETYA). (2006). *The Australian statements of learning for science.* Melbourne: Curriculum Corporation. Retrieved January, 2007, from http://www.mceetya.edu.au/verve/_resources/Science_SOL06.pdf)

Mitchell, I. (1993). *Teaching for quality learning.* Unpublished doctoral thesis, Monash University, Clayton, Australia.

Mitchell, I. (2000). *PEEL in Practice: 650 Ideas for quality teaching.* Melbourne: Monash University CD.

Mitchell, I. (Ed.). (2006). *Teaching for effective learning: The complete book of PEEL teaching procedures* (2nd ed.). Clayton, Vic.: PEEL Publishing.

Mulhall, P., Berry, A., & Loughran, J. (2003). Frameworks for representing science teachers' pedagogical content knowledge. *Asia Pacific Journal of Teacher Education and Learning, 4*(2), 1-25.

Osborne, R. & Freyberg, P. (1985). *Learning in science: The implications of children's science*. Auckland, Heinemann.

Osborne, R. and Wittrock, M. (1985). The Generative Learning Model and its Implications for Science Education. *Studies in Science Education, 12*, 59-87.

Pearson, J., and Bell, B. (1993). *The teacher development that occurred. A report of the Learning in Science Project (teacher development).* Hamilton, University of Waikato.

PEEL Publications. (2008). *PEEL Project for Enhancing Effective Learning*. Retrieved 30 January, 2008, from http://peelweb.org

PEEL Publishers. (2005). *PEEL in practice [electronic resource]: 1200 ideas for quality teaching*. Clayton, Vic.: PEEL Publishers.

Prain, V. & Hand, B. (1996). Writing for learning in secondary science: Rethinking practices. *Teaching and Teacher Education, 12*(6), 609-626.

Rodd, D. (2007, January 30). Teachers' doubt casts cloud over classrooms. *The Age,* p. 3.

Rodrigues, S., Tytler, R., Darby, L., Hubber, P., Symington, D., & Edwards, J. (2007). The usefulness of a science degree: The 'lost voices' of science trained professionals. *International Journal of Science Education, 29*(11), 1411-1433.

Siskin, L. S. (1994). *Realms of knowledge: Academic departments in secondary schools.* London: The Falmer Press.

Symington, D. and Tytler, R. (2004). Community leaders' views of the purposes of science in the compulsory years of schooling. *International Journal of Science Education, 26* (11), 1403-1418.

Taylor, P. (2003). Collaborating to reconstruct teaching: The influence of researcher beliefs. In K. Tobin (Ed.), *The practice of constructivism in science education* (pp. 267-297). Hillsdale, New Jersey: Lawrence Erlbaum Associates.

Teacher Effectiveness Enhancement Programme. (n.d.). *Teacher Effectiveness Enhancement Programme*. Retrieved 1 February, 2008, from http://www.teep.info

Thomas, J. (2000, October). *Mathematical science in Australia: Looking for a future*. Retrieved January, 2007, from http://www.FASTS.org

Tobin, K. (1993). Constructivist perspectives on teacher learning. In K. Tobin (Ed.), *The practice of constructivism in science education* (pp. 215-226). Hillsdale, New Jersey: Lawrence Erlbaum Associates.

Tobin, K., & Fraser, B. (Eds.) (1987). *Exemplary practice in science and mathematics education*. Perth, Western Australia: Curtin University of Technology.

Tobin, K. & Fraser, B.J. (1989). Barriers to higher-level cognitive learning in high school science. *Science Education, 73*, 659-682.

Tobin, K. & Fraser, B.J. (1990). What does it mean to be an exemplary teacher? *Journal of Research in Science Teaching, 27*(1), 3-25.

Tobin, K. & Gallagher, J. (1987a). Target students in the science classroom. *Journal of Research in Science Teaching, 24*, 61-75.

Tobin, K., & Gallagher, J. (1987b). What happens in high school science classrooms? *Journal of Curriculum Studies, 19,* 549-560.

Tobin, K. & Garnett, P. (1988). Exemplary practice in science classrooms. *Science Education, 72,* 197-208.

Tobin, K., Espinet, M., Byrd, S., & Adams, D. (1988). Alternative perspectives of effective science teaching, *Science Education, 72,* 433-451.

Tobin, K., Kahle, J.B., & Fraser, B. (1990). *Windows into science classrooms: Problems associated with higher level cognitive functioning.* London: The Falmer Press.

Treagust, D.F. (1991). A case study of two exemplary biology teachers. *Journal of Research in Science Teaching, 28*(4), 329-342.

Tytler, R. (2002). Teaching for understanding in science: Constructivist / conceptual change teaching approaches. *Australian Science Teachers Journal, 48*(4), 30-35.

Tytler, R. (2003). A window for a purpose: Developing a framework for describing effective science teaching and learning. *Research in Science Education, 30*(3), 273-298.

Tytler, R. (2005). School innovation in science: Change, culture, complexity. In K. Boersma, M. Goedhart, O. de Jong & H. Eijkelhof (Eds.), *Research and the quality of science education* (pp. 89-105). Dordrecht, The Netherlands: Springer.

Tytler, R. (2007a). School Innovation in Science: A model for supporting school and teacher development. *Research in Science Education. 37*(2), 189–216.

Tytler, R. (2007b). *Re-imagining science education: Engaging students in science for Australia's future.* Camberwell: Australian Council for Educational Research.

Tytler, R. (in press). School Innovation in Science: Improving science teaching and learning in Australian schools. *International Journal of Science Education.*

Tytler, R., Smith, R., Grover, P. & Brown, S. (1999). A comparison of professional development models for teachers of primary mathematics and science. *Asia Pacific Journal of Teacher Education,* 27(3), 193-214

Tytler, R., Symington, D., Kirkwood, V., & Malcolm, C. (In press). Engaging students in authentic science through school – community links : learning from the rural experience. *Teaching Science.*

Tytler, R., Symington, D., Smith, C., & Rodrigues, S. (2008). *An Innovation Framework based on best practice exemplars from the Australian School Innovation in Science, Technology and Mathematics (ASISTM) Project.* Canberra: Commonwealth of Australia. Retrieved June, 2007, from http://www.dest.gov.au/sectors/school_education/programmes_funding/programme_categories/key_priorities/asistm/default.htm#ASISTM_Exemplary_Practice_Report

Tytler, R. Waldrip, B, & Griffiths, M. (2002). Talking to effective teachers of primary science. *Investigating, 18*(4), 11-15.

Tytler, R., Waldrip, B. & Griffiths, M. (2004). Windows into practice: Constructing effective science teaching and learning in a school change initiative. *International Journal of Science Education, 26*(2), 171-194.

White, R. T. (1992). The dissemination of PEEL. In J. R. Baird & J. R. Northfield (Eds.), *Learning from the PEEL experience* (pp. 270-273). Melbourne: Monash University Printing Services.

White, R.T. (1994). Dimensions of content. In P. Fensham, R. Gunstone and R. White (Eds), *The content of science: A constructivist approach to its teaching and learning* (pp. 255-262). London: The Falmer Press.

White, R.T., & Gunstone, R.F. (1989). Metalearning and conceptual change. *International Journal of Science Education, 11*(Special Issue), 577-586.

White, R.T. & Gunstone, R.F. (1992). *Probing understanding.* London: Falmer

Wilson, J.M. & Butler, J.E. (1982). Nonverbal behaviour of classroom teachers and its influence on pupil task-involvement. *Research in Science Education, 12*, 55-63.

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