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Curriculum, Learning and Effective Pedagogy:
A Literature Review in Science Education

Report to the Ministry of Education

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Curriculum, Learning and Effective Pedagogy: A Literature Review in Science Education

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Chapter One: Introduction

This review was commissioned by the Ministry of Education to report on significant international and New Zealand research on effective pedagogy and the links between student learning, curricula, pedagogy and assessment in science education across the compulsory sector. The review seeks to answer the following question:

> How does the national and international literature on science education inform our understanding about effective teaching practice/pedagogy on student achievement in science education for the diversity of students in New Zealand?

Chapter Two outlines the methodology and framework adopted in this review. It describes the review team and the collaborative process through which the review was developed and outlines the review's objectives, intended purpose and audience. Details about the literature searches and the analysis and writing process are described and the overall framework for the review is illustrated. The final section of Chapter Two presents a short analysis of the learning outcomes that are specified by *Science in the New Zealand Curriculum.*

The remainder of the review is structured into four parts. The structure and content of these parts are described below.

PART I: BACKGROUND

(Chapters Three and Four)

Chapter Three, **"New Zealand Student Achievement in Science - Evidence from National and International Studies"** describes two nation-wide assessment projects which provide extensive data on New Zealand students' achievement in science during the review period 1991-2001: the National Education Monitoring Project (NEMP) and the Third International Mathematics and Science Studies (TIMSS). Chapter Three describes the assessment approaches used in both TIMSS and NEMP and then gives a detailed report on New Zealand students' TIMSS and NEMP achievement results in overall terms, and in relation to factors including: gender and ethnicity groupings; students' attitudes to science; home resources; home language; and other factors related to schooling and teaching. The detailed analyses of TIMSS and NEMP given in Chapter Three indicate some of the major issues apparent in New Zealand students' science achievement, and indicate areas which need investigation in order to develop more effective and equitable pedagogies to raise achievement and reduce disparity in New Zealand science education for all New Zealand students.

In Chapter Four, Bell provides an historical backdrop for research and curriculum developments in New Zealand science education during the review period. In this chapter, **"The Learning in Science Projects and Associated Thesis Research"**, Bell describes five research projects at the University of Waikato conducted between 1979 and 1996. These projects were funded by the Department of Education and later the Ministry of Education. One of their major goals was to research, develop and evaluate effective pedagogies to improve learning in science in New Zealand classrooms. Chapter Four describes each of the Learning in Science (LISP) projects including the major research findings, and the uptake and impact (or lack of impact) of these findings on subsequent New Zealand science curriculum and classroom pedagogy.

These two chapters provide a background for the literature reviewed in chapters Five to Nine. A diagrammatic overview at the end of Part I serves as a point of reference for the remaining review chapters. The overview is intended to assist readers who are unfamiliar with recent science education literature to identify the significance of trends and developments in research, curriculum development, and policy; and some of the relationships between research, policy, practice and student outcomes in New Zealand science education.

PART II: EVIDENCE FROM CLASSROOM RESEARCH IN SCIENCE EDUCATION

(Chapters Five, Six and Seven)

Chapter Five, **"Pedagogy to Support the Achievement of 'Content' Learning Outcomes"** introduces recent international and New Zealand classroom research that has sought to evaluate the conceptual learning outcomes that are actually achieved by students when various pedagogies are used. Many classroom studies reported during the review period 1991-2001 provide evidence for teaching approaches that can lead to enhanced student science learning, engagement and achievement. Chapter Five reviews international and New Zealand research relating to: pedagogical approaches intended to enhance students' metacognitive and higher-order thinking skills; pedagogical approaches based on the role of models, modelling, metaphor and analogies in science; and the role of group work discussions in the science classroom. Chapter Five also explores three internationally significant longitudinal research projects that have sought to combine aspects of these various pedagogies into learning programmes.

Chapter Six, **"Learning to 'do' science"** investigates pedagogies to support students' engagement and learning through practical work and science investigations. Three different pedagogical approaches are described and compared. These are "recipe" practical work, "open" investigations and "fair testing" approaches. In this chapter some of the evidence from the classroom based research points to non-achievement of intended outcomes, in particular when either "recipe" practical work or "fair testing" is the predominant pedagogy employed. However the chapter also discusses ways in which the possible or intended outcomes of practical work could be better achieved with some modification to existing practice.

Chapter Seven, **"Literacy and Science Learning",** reviews classroom-based research where the focus has been on improving the communication of science ideas. Data reported in Chapter Three raise issues concerning the relationship between "reading literacy" and achievement in science. Similarly LISP findings reported in Chapter Four raise issues concerning the role of language in the communication of science ideas. The issues raised are relevant to all students at some points in their learning, but pose particular challenges for students who are not learning science in the language that they speak in other settings, or who have poorly developed reading literacy skills for their age. Classroom-based research that informs the issues raised is outlined, and the features of pedagogy that have been demonstrated to improve communication during science learning are identified.

PART III: THE INTEGRATION OF SCIENCE PEDAGOGY WITH RICH STUDENT EXPERIENCES

(Chapters Eight and Nine)

Chapter Three indicates that New Zealand students exhibit a wide spread in science achievement, and this spread has been linked to factors including ethnicity, home language, socio-economic status, and home and family resources. There are many possible reasons for the achievement gap that some pupils experience in science classrooms. Factors of significance appear to include: students not learning in their first language; barriers to full engagement where the culture of school is different from the culture of the student's social and family groups; and a lack of rich background experiences on which new learning builds. Chapter Eight, **"New Approaches To Science Education In The New Zealand Cultural Context"**, addresses new dimensions of the challenge to help all students engage and achieve in science in New Zealand's increasingly multicultural classrooms. The use of narrative pedagogy introduces a future-focused element to the discussion, although some evidence of effectiveness from classroom-based studies is reported. Chapter Eight notes significant gaps in the research base concerning the success of bicultural and/or multicultural approaches to learning science in New Zealand classrooms and suggests some areas for policy debate.

Research findings reviewed in Chapters Four to Eight indicate the importance of teaching science in real contexts in order to engage students' interest, to increase relevancy of science to students' lives, and to help students develop better understandings in science and about science. Chapter Nine, **"Curriculum Integration And Experiences Beyond The Classroom To Enhance Science Learning"**, further investigates the idea of science learning in real contexts, reviewing research in the areas of: curriculum integration; environmental education and science education; and out-of-school experiences. While specific Ministry of Education policy statements exist in each of these areas, we have found relatively little New Zealand classroom (or "beyond-the-classroom") research that investigates the implementation and effect of these policies on New Zealand students' science learning in practice. This chapter reviews available New Zealand research and international research in these areas to provide indications about the kinds of policies and practices that may enable the incorporation of integrated and/or out-of-class experiences to promote effective and engaging science learning for a wide range of students.

PART IV: SUMMARY AND POLICY IMPLICATIONS

(Chapter Ten)

Finally, Chapter Ten **"Summary, Synthesis and Implications"** synthesises the outcomes of all the review chapters and provides a number of recommendations for future policy directions in New Zealand science education.

Chapter Two: Methodology and Framework

2.0 Introduction

Chapter One presented a review question for which there are few simple answers. To provide well-founded, evidentially based and informative answers to this question requires an analytical approach which is complex and comprehensive but also as clear and accessible to readers as possible. This chapter describes the methodology and analytical framework adopted in this review. Section 2.1 describes the review team and the collaborative process through which the review was produced. Section 2.2 outlines the review's objectives and intended purpose. Section 2.3 illustrates and describes the review's analytical framework, and section 2.4 provides details about the literature searches and the reviewing and writing process.

The review question in Chapter One is based on the premise that evidence of "effective pedagogy" and "student achievement" in science education (and evidence of the relationship between the two) is identifiable and accessible to analysis. This premise should be accepted with the caution that defining what is meant by the terms "effective pedagogy" and "student achievement" is no simple task. The two final sections of this chapter address this issue. Section 2.5 deals with the question of what constitutes evidence of "effective pedagogy" and hence the criteria that were used to analyse the research reported in this review. Section 2.6 deals with the question of what constitutes "student achievement" or "positive outcomes for students"[1] in science. Student achievement may be defined differently depending on what are seen as desirable learning outcomes for students. There is, and has long been, debate about the appropriate outcomes for science education. Chapter Two concludes by outlining a range of potential student outcomes that have been advocated in science education and explaining how the research evidence presented in later chapters relates to this range of outcomes.

2.1 The Review team

This review was produced collaboratively by the Centre for Science and Technology Education Research at the University of Waikato (CSTER), and the New Zealand Council for Education Research in Wellington (NZCER) with input from Auckland College of Education (ACE). CSTER and NZCER/ACE had each submitted proposals to the Ministry in response to a request for proposals issued on 4 May 2001. The project collaboration occurred at the request of the Ministry of Education, which felt that maximum benefit could be gained from the two teams working together. In early June 2001 both teams were advised by the Ministry that the contract was to be shared between them.

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[1] This term is also used in the review (see the objectives listed in section 2.2)

On June 15 2001, the project directors and writers from both teams met with members of the Ministry to negotiate the sharing of the review. A mutually agreeable scheme was devised wherein the two teams would combine their efforts and operate as a single team with two working strands (Appendix A). Although the unplanned collaboration added an extra degree of complexity to the project, we were fortunate to be able to establish a strong and productive working relationship which drew on the strengths of both teams. The review project was run as a single contract with two writers overseen by both directors. It was agreed that there would be close collaboration and ongoing communication between the directors and the two writers by regular phone calls, email, and physical meetings throughout the entire review process.

2.2 Review purpose and objectives

2.2.1 Purpose of the review

This review was commissioned in support of the Ministry's stated mission to "raise achievement and reduce disparity", and to provide a synthesis of evidence about the effectiveness of curriculum in practice. The Ministry's review specifications indicated that the selection of science as a context was primarily due to the early mandating date of *Science in the New Zealand Curriculum*; the early availability of *Putäiao*, the Maori medium science curriculum document; and the availability of cyclical assessments of science achievement from the National Education Monitoring Project (NEMP) and the Third International Mathematics and Science Study (TIMSS), which provided recent data on the science achievement outcomes of New Zealand students.

The following review objectives were given by the Ministry:

- To use a literature review as a tool to interrogate, critique, and inform educational practice in New Zealand through a reflexive consideration of the international and New Zealand research.

- To contribute to a comprehensive knowledge base for educational policy on what works in science education through synthesising landmark and recent research evidence about effective science education.

- To synthesise what the research reveals about what is needed to ensure effective educational practice for diverse students (in particular for Maori, Pakeha and Pacific boys and girls, and students from families of different socio-economic backgrounds).

- To identify research evidence about effective pedagogies and the policies, approaches, and conditions that enable such pedagogies to be effective in practice.

- To provide a synthesis of evidence about effective practice that is explicitly linked to positive outcomes for students (including knowledge, skills, attitudes, and values).

- To synthesise evidence about effective curriculum integration that supports science learning outcomes.

- To provide a broad perspective, not only of what is known about effective policy and practice, but also areas where development and research are needed.

- To provide a high-quality review report that is useful for informing policy and practice and respected by New Zealand educators.

2.3 Review framework

2.3.1 The nature of the review

Although it was initially commissioned as a "literature review", this review is not a literature review in the conventional sense. It is not another summary of the published research literature. By necessity this review had to be of a different character to that of a conventional review of research literature in order to fulfil all of the review objectives listed in the section above - particularly the need for empirical evidence of pedagogy linked to positive science educational outcomes for students.

Three interconnected factors played powerful roles in directing the ultimate nature and structure of this review. The first factor was our goal of producing a review that would be informative and useful to both policy makers and the education community (if not reaching the latter in its first iteration, then through later dissemination of its key findings). Because the review is situated in the context of *science* education, its validity must also be recognised by New Zealand's science education research community. We sought throughout the review's development and writing to maintain a balance between accessibility and academic integrity and to ensure that the crucial issues in New Zealand science education were presented with sufficient clarity to inform policy makers, readers from general education backgrounds, and readers from science education backgrounds.

The second factor that influenced the final shape of the review was an ongoing process of negotiation and dialogue with the Ministry of Education and the review's advisory group. This dialogue accompanied the review's development from its initial stages to the completion of the final report and is described in more detail in section 2.4. Related to this, the third factor was the broad scope and latent complexity of the review's objectives. Discussions with the Ministry of Education indicated that this review was envisaged as being of a different character to previously commissioned literature reviews, for example, the series of Strategic Review Initiatives prepared in 2000. We were directed to focus particularly on the results of TIMSS and NEMP and to interpret these findings using the review team's expertise and knowledge in the field of science education research. We were also asked to search for examples of New Zealand research that the Ministry believed would have been overlooked within the boundaries of a conventional academic literature review. On this guidance, the current review is based on the integration and synthesis of information derived from five forms of evidence:

- New Zealand national trend data on student achievement in science (TIMSS, NEMP, and PISA).
- New Zealand classroom research findings.
- Large-scale research reviews and meta-analyses from the international science education research literature.
- Case studies and classroom research from the international science education literature.
- New Zealand and international science education literature with a "future focus".

The diagram illustrated in figure 2.1 (next page) indicates the relationship between these five forms of evidence and how these were brought together in a framework for analysis to inform policy and practice in New Zealand science education. The following is a description of how the diagram is to be read.

Centre of the framework: the New Zealand context

The centre of the framework represents the current state of New Zealand science education as measured by two kinds of research evidence:

- Data on New Zealand student achievement in science as measured by TIMMS and NEMP (box at middle left).
- Findings from New Zealand classroom research in science education (box at middle right).

Arrows indicate our view of the relationship between these two kinds of research evidence. The TIMMS and NEMP findings provide evidence of some of the achievement issues faced by New Zealand students. Research findings from New Zealand classrooms provide contextual information about the kinds of teaching and learning interactions occurring in New Zealand classrooms and evidence of their effects on students. Together, these two sources help to sketch a picture of current science teaching and learning practices in New Zealand classrooms and the effect of these practices on students' learning in science, and how these may relate to student performance in national assessment regimes such as TIMSS and NEMP.

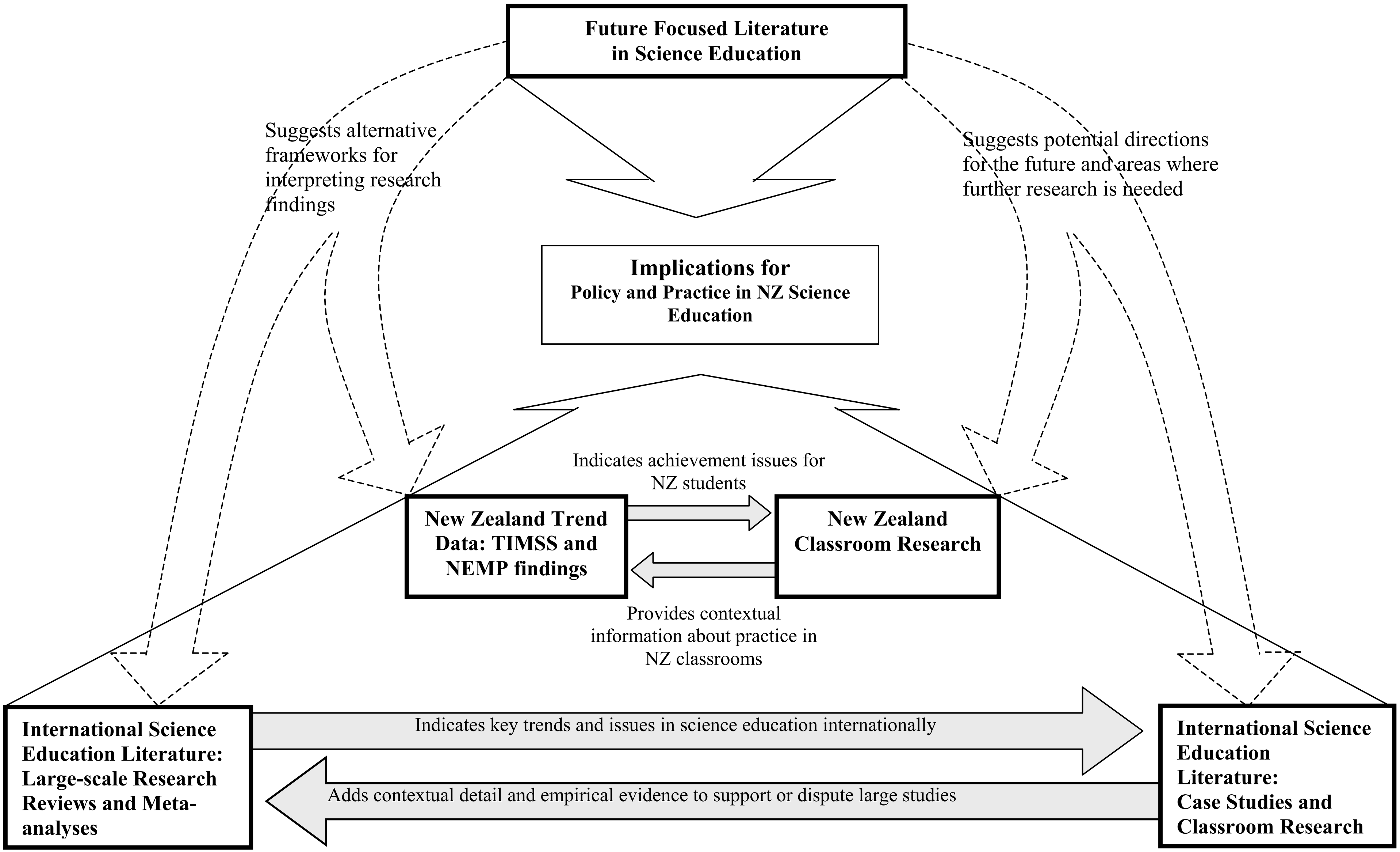

Figure 2.1 Framework for the literature review: Integrating evidence to inform pedagogy and policy in NZ science education.

Lower periphery of the framework: the international context

The New Zealand achievement data and classroom research findings present an important, but not complete perspective from which to evaluate the current state of New Zealand science education. The goal of raising students' achievement in science and the search for ways to improve the effectiveness and inclusiveness of educational policy and practice in science education are concerns for many nations, not least all those who participate in TIMMS (Atkin and Black, 1997). In some cases international research literature can provide evidence about policies and practices that appear to be effective in meeting these aims and which may be applicable to the New Zealand context. In other cases, the findings of international research provide a reference point against which to appraise those features of policy and practice which are particular to the New Zealand context. For these reasons the New Zealand situation represented at the centre of figure 2.1 is in turn framed by international research literature in science education. As with the New Zealand data, the international research literature can be classified into two main categories. The box at the bottom left represents large studies, research reviews, and meta-analyses. This type of research indicates some of the key trends and issues that impact on science education practice and student achievement in other countries. The box at the bottom right represents case studies and specific pieces of classroom research, which add contextual detail and empirical evidence to support and/or dispute the findings of large studies and meta-analyses, and provide descriptions of the effectiveness of specific practices in specific classrooms. As the arrows show, the relationship between these two types of study in the international literature is analogous to the relationship between the New Zealand trend data and New Zealand classroom research.

The upper periphery of the framework: future directions in science education

As the large upward-facing arrow that encompasses the whole bottom half of figure 2.1 indicates, a critical analysis of recent New Zealand and international research evidence can point towards implications for policy and practice in New Zealand science education. However, one of the review objectives is "to provide a broad perspective, not only of what is known about effective policy and practice, but also areas where development and research may be needed" (see section 2.2). There is a substantial body of recent science education literature which, by its nature, is not always complemented by extensive empirical classroom evidence. This literature is concerned with (for example): the nature of science and the nature of science education; international and national debates about the purposes of science education; multicultural critiques of science education (including Maori critiques); the role of science education within a "knowledge society"; and questions about what constitutes desirable outcomes of an education in science. These kinds of issues are not wholly separate from empirical classroom evidence; on the contrary, the empirical evidence often forms the basis for such literature through the identification of problems related to current practice. In return, these primarily theoretical arguments suggest alternative frameworks for interpreting current evidence and equally suggest potential policy directions and areas for which further research is required.

We are aware that this literature is typically written for an academic audience and is not necessarily easily accessible to those outside the field of science education research. We have sought to create a balance between academic integrity and accessibility in these matters by using a strategy of “foregrounding” and “backgrounding." The dashed lines on the diagram illustrate how literature with a future focus in science education has been backgrounded. In this way, the literature serves to inform, rather than overshadow, the classroom research evidence and achievement data which is foregrounded in the lower half of the framework. Where possible in the review, the major themes in literature with a strong future focus have been linked to findings from New Zealand research. Where New Zealand classroom research evidence in these areas is currently scarce, we have indicated this to suggest possible areas for future research and policy attention.

2.4 The literature search process

Within the boundaries of the framework described in section 2.3, a great deal of material had to be located, evaluated, analysed, and integrated in a relatively short period of time. The literature search process can be conceptually separated into three main phases:

- The first phase consisted of the development of a preliminary search strategy followed by a broad sweep of recent national and international science education literature.
- The second phase consisted of a refinement of the review’s scope and additional searches for New Zealand research.
- The third phase consisted of synthesis and integration of draft review findings, further addition of New Zealand research, and relating of findings to New Zealand policy contexts.

Feedback from the Ministry and the review advisory group was received and incorporated periodically throughout the review’s eight-month development. This feedback was critical in shaping the direction and final form of the review.

2.4.1 First phase: preliminary search strategy and a broad sweep of the literature

A preliminary strategy based on the tender specifications was developed to assist in the search process, to enable sharing of search tasks between the members of the review team, and to provide a basis within which the review structure would begin to emerge. The initial strategy was developed during a planning meeting with the entire review team in Hamilton on July 6, 2001. This was subsequently adjusted and refined through ongoing discussions between the team members in response to the early identification of relevant themes and literature categories. The initial search process was iterative and there was significant overlap between each of the key tasks. These were:

Team identification of key research

Based on the preliminary framework, members of the review team provided lists of key references known to them to be of relevance to the search.

Electronic and physical journal searches

Electronic searches were made on library databases ERIC, Catchword, Proquest, Index New Zealand, using keywords associated with our preliminary framework. Lists of all records retrieved from these searches were printed out and examined by members of the team. Where possible, full abstracts for references deemed to be relevant to the review were obtained. Following the search protocol used by Carr, McGee, Jones, McKinley, Bell, Barr, and Simpson (2000) in a previous Ministry of Education literature review, physical searches were made of over 20 key journals (Appendix B) to pick up relevant articles which could have been missed by using electronic searches alone.

Internet searches

Where overseas universities were known or thought to have federal or local government funding for science education research programmes, their websites were searched for any downloadable research reports. We also used the Internet to retrieve articles from journals published online.

Review of recent international literature reviews in science education

Recent large-scale international literature reviews of research on effective science education were examined including: Goodrum, Hackling, and Rennie's (2000) review of Australian school science teaching and learning; Rennie, Fraser and Treagust's (1999) review of Australian research in science education; Harlen's (1999) review of science teaching and learning in Scotland; and the two-volume *International Handbook of Science Education* (Fraser and Tobin, 1998). These reviews provided an overview of current international research, and indicated references and areas of literature which were relevant to our review framework. A dozen major edited collections of research in science education published within the last decade were distributed among members of the team for review.

Advice of national and international colleagues

The review team made contact with colleagues from the Australian science education community to inform them of the purpose and objectives of the review and to request their assistance in identifying key papers, research, or researchers working in areas which fell within the scope of the review. A positive response was received from all members. Both writers and one of the project directors met with these colleagues at the Australasian Science Education Research Association conference in Sydney in mid-July. Several of our Australian colleagues sent or emailed papers in response to our requests, and provided further assistance locating papers during the review process.

2.4.2 End of first phase: review of initial outcomes and refinement of review structure

The initial searches yielded more than 800 journal abstracts, a dozen international reviews or government research reports, and approximately 200 book chapters of both international and New Zealand research which were of relevance to the review objectives. In mid-August 2001 the two writers met for two-and-a-half days to physically review and classify the outcomes of the initial searches. This led to the development of a provisional structure for the review, as distinct categories of chapter and sub-chapter headings emerged from the cumulative reading and discussion of the abstracts. The provisional structure was presented for discussion at the first advisory group meeting in

August 2001. During the meeting, feedback from the Ministry suggested some concerns about the initial structure that we had drawn up for the review. Specifically, it was suggested that the review required:

- a more specific focus on NZ socio-cultural context; and
- a more critical focus on pedagogies for which there is evidence of achievement outcomes.

On the advice of our advisory group, the overarching research question stated at the beginning of Chapter One was drafted to help us further develop the review to meet the Ministry's requirements.

2.4.3 Second phase: refinement of scope and search for additional NZ material

After our first advisory group meeting, we re-evaluated the initial review structure and search results and revised our plans to include a more explicit search for New Zealand research literature to incorporate into the review. Concurrently, we continued to focus on the large amount of international literature which we had amassed in order to fulfil our objective to interrogate, critique, and inform science educational practice in *New Zealand* through a reflexive consideration of the international and New Zealand research. The second phase of literature searching focused more explicitly on identifying recent New Zealand classroom research that may not have been picked up during the first searching phase. Strategies used were:

Searches of published research and conference proceedings

To locate recent pieces of New Zealand research, physical searches were made of conference proceedings from the New Zealand Association of Research in Education (2000), the Australasian Science Education Research Association (1999 to 2001), and a national research seminar on science education in primary schools held at Wellington College of Education (September 1999). The NZCER research library was also checked for relevant research. The Curriculum Division manager at Learning Media was informed of the purpose of the review and several publications and research reports were released for inclusion.

Canvassing of New Zealand science education researchers

In mid-September, Waikato University hosted the second National Science Education Symposium, a gathering of researchers from the New Zealand Science Education community. On this occasion we repeated our request for assistance to identify New Zealand research, including unpublished theses, which would be appropriate for inclusion in the review (Appendix C). Once again positive responses were received and several colleagues sent us New Zealand studies and theses. Other researchers in addition to those attending the symposium were contacted personally or by email.

Thesis searches

Members of the review team undertook searches of recently published theses at Auckland College of Education, Massey University, Waikato University, and Victoria University.

Advice of non-science educational researchers

In several cases, the review objectives required us to search for New Zealand research outside the specific domain of science education, in areas such as early childhood education, gifted education, Maori education, and curriculum integration. Where necessary, the review team drew on a wide network of colleagues in the education research community for critical advice and for their suggestions of studies of relevance to the review objectives.

2.4.4 Analysis and writing

Analysis of the literature and writing of draft chapters began during the second phase. The writers divided the draft writing of chapters between them and worked both in parallel and in collaboration to develop the chapters with ongoing analysis and input from the review team. Developing chapter drafts were shared between the writers and the review structure was adjusted and refined to accommodate the addition of new literature and to synthesise coherent themes as they emerged during writing. The developing draft structure was repeatedly checked against both the original review objectives and records of subsequent feedback from the advisory group and the Ministry from each milestone stage.

2.4.5 End of second phase: review of working draft document

A seven-chapter draft version of the review was presented for discussion to the advisory group at the beginning of November 2001. Although most of the chapters were substantially complete, the tight schedule for the production of the first draft meant that synthesis and integration of the chapters was still only partial. General and specific feedback from the Ministry at this milestone stage suggested that several of the key threads developing in the review were not yet clear enough in the draft for non-science education readers to follow. Further discussions with the Ministry enabled us to identify areas in which further work and/or the addition of further material was necessary to make these threads more explicit.

2.4.6 Third phase: synthesis and integration of review findings

The third phase consisted of synthesis and integration of the key threads of the review, final searches for additional material, the addition of devices such as graphs, tables, and boxes, and other linking devices to enable ease of reading of the review. This phase culminated in the production of a ten-chapter draft document which was distributed to the advisory group in December 2001. Following a period of review, the draft was returned with additional comments and several structural changes were made before the final version was presented to the Ministry of Education in March 2002.

2.5 Characteristics of "effective pedagogy" in science education

The literature searches described in section 2.4 yielded a massive quantity of international and New Zealand literature, leaving us with the difficult task of developing an appropriate selection criteria for determining what to include and how to structure the review. The analysis was derived from the framework and process described in the sections above. A clear Ministry directive was that the review was to provide a synthesis of evidence about effective practice that is explicitly linked to positive outcomes for students. Therefore, in analysing the research literature, the review needed to embody and use strong evaluative criteria based on quality of methodology for illuminating links between pedagogy and student outcomes. However, one of the challenges we encountered during the review process was to determine exactly what could count as evidence of "effective pedagogy" in relation to student science achievement. For example, it was often difficult to isolate studies in which positive student outcomes could be linked to pedagogical practices without also being strongly associated with other variables such as the curriculum in use or the assessment activities occurring in classrooms. Another challenge was to clarify the nature of the outcomes that science education either *can* produce, *does* produce, or *should* produce. We discuss current thinking about outcomes in section 2.6.

Evidence of "effective pedagogy" in science education: large-scale approaches

A recent literature review produced for the Ministry of Education (Carr *et al.*, 2000) demonstrated the complex interactions between curriculum, assessment, and pedagogy and the effect of these interactions on student educational and social outcomes. Carr *et al.*'s review adopted an analytical framework giving a central place to the teaching and learning process. The framework depicted the teaching and learning process as dependent on the interactions between curriculum, assessment and pedagogical approaches. The intervening role of the teacher in the framework was clearly stated:

> The teacher is crucially at the centre of this system because the links between:
>
> - curriculum and pedagogy,
> - curriculum and assessment,
> - pedagogy and assessment,
> - curriculum and learning outcomes,
> - curriculum and social outcomes,
> - pedagogy and learning outcomes,
>
> come from the teacher playing a major role in interpreting curriculum, in fashioning pedagogy, and in devising assessment activities (Carr *et al.*, 2000)

The benefits and limitations of the meta-analysis approach

In educational effectiveness research a tension can arise between the use of large-scale studies and meta-analyses which substantively identify important general issues, and the use of small contextualised case studies, which may provide illustrative or locally based detail but yield less generalisable information. Despite the centrality of the teaching-learning interaction in Carr *et al.*'s review framework, their analysis was limited to large-scale reviews of research and meta-analyses of international and New Zealand literature which addressed the links and relationships between each of the variables. Consequently, their review was able to clearly identify some of the significant generalisable features of the interplay between curriculum, assessment, pedagogy and learning outcomes. Similarly, the "teaching effectiveness" factors identified in the review tended to be broad and general. These included, for example: teachers having high expectations of all students; having a wide range of pedagogical strategies; having sound content knowledge of their subject; having a broad understanding of curriculum aims and objectives; recognising student success; and providing good feedback to students.

On the other hand, more specific variables related to classroom practice such as: teaching expertise; the specific teaching approaches used; the nature of teachers' interaction with students; the assessment processes used; and the consequences for individual students of all these factors, were often invisible within the wide focus of the meta-analysis. Carr *et al.* point out that the inclusion of case studies would have assisted their review by providing localised, contextualised knowledge to elaborate and explain the findings from large, quantitative surveys (Carr *et al.*, 2000, p. 15).

A related tension in educational effectiveness research exists between identification of generic (across subject) features of effective pedagogy, and the identification of subject-specific features of pedagogy that could effectively raise student achievement within a given subject area such as science. In this review we have followed a brief to focus on effective pedagogy and its relationship to student achievement in science education, with an emphasis on issues that apply specifically to the New Zealand context. Findings from reviews such as Carr *et al.* (2000) point to important factors which influence and impact upon pedagogical approaches and student outcomes in general terms. General research literature on "effective pedagogy" has been well discussed elsewhere (for example, see Brophy and Good, 1986; Doyle, 1992). The current review's more restricted focus on "effective pedagogy" and its location within *science education* allows us to concentrate on the special features which distinguish science pedagogy from pedagogies in other curriculum areas.

Selection criteria for evidence of effectiveness

To judge whether studies provide credible evidence of positive student outcomes (including knowledge, skills, attitudes, and values) linked to particular practices, we have looked at whether or not studies exhibit some or all of the following characteristics:

- Quantitative measures of increased student understanding (e.g. improved test scores).
- Quantitative or qualitative evidence of increased performance on authentic tasks.
- Qualitative evidence of increased student understanding (e.g. shown in interview data, or evident in quality or depth of student conversations in naturalistic classroom data).
- Quantitative or qualitative evidence of improved student attitudes or confidence towards engaging in science in the classroom.
- Quantitative or qualitative measures of *long-term effects* on student performance (e.g. identified by any combination of the above forms of measurement).

Descriptive or propositional discussion of pedagogy, without empirical evidence (e.g. teacher self-report data) are considered to be of less evidential value.

The review is intended to identify some of the effectiveness issues that apply specifically to New Zealand science education. Wherever possible, New Zealand studies which meet the above criteria have been woven in through the international literature to reflect the way that studies conducted in the New Zealand context are either coherent with, or differ significantly from, findings in the international research. Where evidence of the effectiveness of various approaches is limited or as yet undemonstrated, we have indicated that this is the case. Where New Zealand studies fall outside the above criteria but may contribute understandings with further research, this has also been indicated.

2.6 Characteristics of potential student learning outcomes

As part of the process of analysis of the review findings, we used the international literature to check that we had comprehensively identified the full range of outcomes that have been advocated for science education. These include:

- outcomes related to conceptual and/or factual understandings (frequently called "content" learning outcomes);
- outcomes related to the development of investigative skills (sometimes called "process" learning outcomes); and
- outcomes related to attitudes and values.

Possible variations in teaching emphasis for each of these broad groups of outcomes are outlined in the following paragraphs. However, since some of these outcomes may be seen as having priority over others within the policy context, we decided we also needed to canvass the literature for indications of possible variations in the balance of emphasis between these diverse outcomes, and to check these possibilities against New Zealand's curriculum documents. Such a balance is inevitably linked to visions of the purposes a curriculum subject ought ideally to serve. Accordingly, in order to take account of this complexity, we also briefly sketch in this section debates about the range of contested purposes for an education in science.

2.6.1 The range and diversity of potential outcomes

An analysis of New Zealand's *intended* curriculum in science indicates the range of outcomes that could be achieved. Guidelines to these outcomes are embodied in the following documents:

- *Science in the New Zealand Curriculum* (Ministry of Education 1993a)
- *Pütaiao i roto i Te Marautanga o Aotearoa* (Ministry of Education, 1996a)
- *The New Zealand Curriculum Framework* (Ministry of Education, 1993b)

'Content' learning outcomes

Science in the New Zealand Curriculum (SNZC) specifies knowledge components within four "Contextual Strands": *Making Sense of the Living World;, Making Sense of the Material World; Making Sense of the Physical World*; and *Making Sense of the Planet Earth and Beyond.* (These are reduced to three strands in the *Pütaiao* curriculum where parts of the Planet Earth strand are integrated with the Living World and Physical World respectively). Within each of these strands, four unifying Aims have been identified and then elaborated as Achievement Objectives at eight curriculum levels.

These objectives sketch very broad conceptual understandings of key ideas within each of the four identified sub-disciplines of science. As such they are not intended to constitute a definitive list of "facts to be learnt" and thus the *actual outcomes* for students that are seen as desirable are open to interpretation. In principle, this is a curriculum designed to have the flexibility to allow New Zealand teachers to meet the particular needs of their mix of students. However, in practice informal evidence suggests that there is considerable variation between the intended curriculum and the curriculum actually achieved within different schools and at different school levels. While we have found no systematically collected data on this situation, the Mathematics and Science Task Force (established subsequent to the publication of the results of the first TIMSS survey) perceived that there was considerable variability in the "content" learning outcomes achieved in primary science. Task force members also felt that there was more uniformity in the secondary school, notwithstanding possibilities for differing interpretations of *SNZC*. This was attributed to the then relatively stable population of secondary science teachers who shared a culture of well-established teaching practice. Many of these teachers used key textbooks that were popular in New Zealand during the 1970s and 1980s and they drew on this common experience to inform their view of the range of 'content' that they should cover (Robyn Baker, personal communication, February 2002).

While noting the potentially unifying effects of a shared tradition of teaching practice, in principle there are many possibilities for science teachers at all levels to make varied interpretations of *SNZC* "content". These possibilities can be directly related to several key dimensions of debates in science education more generally:

- the relative emphasis given to each sub-discipline (physical, material, living world and earth science);

- the depth to which conceptual ideas are developed within each of these areas, including the degree to which content should be understood and explained 'as a scientist would explain it';
- possible variation in sub-discipline emphases/explanations for one concept (see for example commentary on the LISP Energy project in Chapter Four);
- the extent of linking within and between areas of content - that is, within-topic and within sub-discipline integration;
- how the content is sequenced, within a year group and across levels, and within each actual topic;
- the extent to which knowledge is to be presented as 'facts', and whether or not areas of active scientific inquiry (by working scientists) and genuinely open questions should be introduced into school curricula; and
- the relative emphasis given to the balance of content learning outcomes versus other kinds of outcomes (as elaborated below).

As already noted, actual indications of such variability in the content outcomes intended and achieved are largely anecdotal within New Zealand and could be worthy of more systematic research. However quantitative analysis, based on national and teacher-level feedback to the coordinating TIMSS researchers, found that that every nation has its own unique cultural mix of content (Cogan, Wang and Schmidt, 2001). Significantly for this review, these researchers found that New Zealand was one of only three nations that reported intending to teach all 79 identified "content standards" at Year 8. (The items in the actual TIMSS tests were drawn from this bank of standards. While nations did not know in advance which standards would be used in the test, even coverage across all potential areas was aimed for). By contrast, nations with whom New Zealand school students' achievement has been unfavourably compared intended a far lower coverage overall: Hong Kong, 22 of the 79 possible standards; Singapore, 38 of the 79 possible standards (Cogan *et al.*, 2001, p. 112). As the researchers pointed out, this may be because these countries "do not intend them [the other standards] to be covered during the eighth grade year" (Cogan *et al.*, 2001, p. 113). However, such a statement could not be unequivocally made about the content of *SNZC*, where the year levels are deliberately blurred to give emphasis to "students as individuals who learn at different rates and in different ways" (Ministry of Education 1993a, p. 15).

"Process" or "skills" learning outcomes

As well as learning the key ideas of science, students are expected to experience the 'doing' of science – that is, to take part in investigations of the natural world that are conducted according to selected characteristics of (more or less authentic) 'real' scientific inquiry. Achievement objectives for such activity are encapsulated with the *Developing Scientific Skills and Attitudes* strand of *SNZC*. Unlike the Contextual Strands, the *Developing Scientific Skills and Attitudes* strand is condensed into four sets of levels, and subdivided into four sets of skills: *Focusing and Planning; Information Gathering; Processing and Interpreting*; and *Reporting*. The integral nature of the inquiry aspects of science is reinforced by the use of verbs such as “investigate”, “group”, “research”, and “carry out” in the wording of the specified achievement objectives for the four contextual strands.

Although “attitudes” are specified in the title of the *Developing Scientific Skills and Attitudes* strand, these are not specifically described within the achievement objectives for that strand but rather are *implicit* within the “scientific ways of working’ that are outlined. The illustrative ‘possible learning experiences” on (pages 48 – 51) make the possible attitudes outcomes from ‘doing’ science somewhat more explicit, although they do not appear to be intended as a complete list of possibilities. Those specifically mentioned include ‘being open-minded’ (p. 48 and p. 50), “being persistent” (p. 48 and p. 49), “being willing to tolerate uncertainty” (p. 50).

The structure of *SNZC* signals that opportunities for learning in this strand should be *integrated* with content from one or more of the contextual strands. Thus skills/process outcomes should be achieved in tandem with the content outcomes, not separately from them (although they may be *assessed* separately, which raises issues of validity for comparative measures of national achievement). The widespread interpretation of the four sets of achievement objectives as specifying a sequential, linear visiting of each of the four skill sets during every practical investigation - often called ‘the scientific method’ - has been a subject of recent critique. For example, although many science teachers appear to refer to one unifying “scientific method”, in the actual world of working science the methods of inquiry are many and varied.

Internationally, the range of outcomes that might be achieved from the “doing of science” has also been the subject of critique, and is seen as strongly correlated with each teacher’s vision of the purposes for carrying out such activity in the first place. Wellington (1998) collects together commentary from a wide range of internationally known science educators who critique the outcomes that might be achievable from different types of practical work. This collection is strongly critical of the doing of “recipe” type practicals, in which students follow a set of instructions to discover a well-established phenomenon. Here the students’ experience of “doing” some science serves to consolidate a “content” learning outcome, rather than to assist students to develop their personal knowledge of the complexity and challenges of actual scientific inquiry.

Taken together, these areas of interpretation create a number of key dimensions for diversity in the outcomes intended/achieved in different school settings and by individual pupils. These include:

- the manner in which actual scientific inquiry is characterised and delimited from other types of human inquiry (including, but not limited to, whether or not it is envisaged as a linear, fixed sequence of steps);

- the degree of integration of process and content knowledge, and the variation of content area(s) linked to each specific achievement objective of the *Developing Scientific Skills and Attitudes* strand;
- the actual skill development in various specific techniques of scientific inquiry; and
- the extent to which investigations are linked to authentic questions/settings.

'Understandings about science' outcomes

The *SNZC* strand *Making Sense of the Nature of Science and its Relationship to Technology* is similar in structure to the four contextual strands, with eight levels and three sets of *Achievement Objectives* at each level, developed from three overarching *Achievement Aims*. It is an integrating strand, to be developed in tandem with content knowledge, as is the case for the *Developing Scientific Skills and Attitudes* strand. Broadly characterised, student learning outcomes from this strand fall into two key areas:

- understanding the "rules of the game" (Carr *et al.*, 1997) for the development of new scientific ideas (that is, the *epistemology* of science, as further elaborated in Chapter 6); and
- understanding the nature of interrelationships within communities of scientists as they seek consensus for their ideas, and between the scientific and wider community (that is, the *sociology* of science) (Ryder, 2001).

Taken together these two dimensions are intended to delineate science from other types of human inquiry and to justify its typical claim to being "certain and universal" knowledge about the natural world.

The complexity of these ideas is often short-handed by use of the phrase "the nature of science" (NOS). However many aspects of both the epistemology and sociology of science are in hot dispute amongst philosophers of science (Alters, 1997) and this largely philosophical area is typically neglected during a tertiary education in science (Gallagher, 1991). Unsurprisingly then, teachers are likely to hold NOS views that are more *implicit* than explicit. In this case, opportunities to develop NOS outcomes may be missed. For example, students may be encouraged to "observe as a scientist would" during practical work that is more or less integrated with related "content". However the explicit understanding that observation is "theory laden" and so scientific observation is very much bounded by relevant theoretical understandings of what *should* be observed, is seldom made explicit. These are the grounds on which the "process" movement of the 1980s, that advocated the separation of skills and content teaching/outcomes was discredited (Millar and Driver, 1987). We return to this issue in Chapter Six.

Because of the considerable uncertainties associated with NOS debates and actual teaching, it seems counter-productive at this point of the review to even begin to sketch the diversity of possible outcomes for this aspect of curriculum. In any case what little actual evidence is available suggests that it is an area of the curriculum that many New Zealand teachers simply ignore (Baker, 1999; Loveless and Barker, 2000). This is not to say that students will not develop some ideas *about* science as an outcome of their study of the subject. Rather it seems likely that these will be unintentional outcomes, not usually assessed, the nature of which neither the student nor the teacher may be consciously aware.

"Attitudes" outcomes

As already noted, although "attitudes" are incorporated into the title of the *Developing Scientific Skills and Attitudes* integrating strand, it is difficult to track explicit intentions for their development within that strand alone. Rather these are implicit in the actual achievement objectives and are elaborated in the accompanying material as attitudes related to "thinking like a scientist". This section, however, briefly sketches possibilities for the development of outcomes that include attitudes towards science as a school subject and as an area of active personal interest to take beyond school into adult life.

SNZC takes account of such attitudes by specifying the introduction of all knowledge and skills in contexts of relevance and familiarity to students (Ministry of Education, 1993a, p. 10). This could allow them to see the "relevance and usefulness of science to themselves and to society" (ibid.). This pedagogic approach is reinforced by the inclusion of "sample learning contexts" for every contextual strand, at each curriculum level. The approach is intended to support the development of positive attitudes to learning in science whilst also allowing for the development of constructivist approaches to content teaching and learning. (Personal constructivism as the philosophical underpinning of *SNZC* is strongly indicated by the frequent use of the phrase "Making Sense of..." in curriculum titles and in curriculum support materials subsequently developed. It is grounded in the early, world-renowned stages of the Learning in Science Project undertaken by researchers at Waikato University, as outlined in Chapter Four). The use of the phrase "science for all" (Ministry of Education, 1993a, p. 11) further reinforces the emphasis on the development of positive attitudes toward learning in science as an outcome.

Tensions between the development of specified content outcomes and the implementation of the true spirit of personal constructivist/"Science for all" approaches will be discussed in Chapter Five. Here they are mentioned in order to signal that the development of positive attitudes as a student outcome may be seen by some teachers and curriculum critics (Matthews, 1995) to be at the expense of scientifically acceptable content outcomes. (This review will take a different view and argue, as a strong conclusion drawn from the literature searched, that the development of personally meaningful understandings is a key feature of pedagogy for raising achievement in science – for conceptual *and* attitudinal reasons). Clearly, however, matters of balance and purpose become paramount to any analysis of outcomes in this area.

Values outcomes

The *New Zealand Curriculum Framework* specifies that "values" be developed within each curriculum document. However, these are described as:

> …internalised sets of beliefs or principles of behaviour held by individuals or groups. They are expressed in the ways in which people think and act. No schooling is value-free. Values are mostly learned through students' experience of the total environment, rather than through direct instruction (Ministry of Education, 1993b, p. 21)

In line with this directive the list of "General Aims of Science Education" on page 9 of *SNZC* makes no explicit mention of values. Despite this lack of specificity, within the existing structure of *SNZC* there is considerable potential for the development of values outcomes – if and when this is seen as desirable. As noted in the next section of this analysis, values outcomes are explicitly linked to non-traditional ways of conceptualising the overall purposes for the inclusion of science within the overall curriculum. As such, they are more future focused than are the other outcomes outlined in this section and have not yet been included in either national or international measures of achievement (Orpwood, 2001).

2.6.2 Balancing outcomes – visions of purposes

Uncertainties in the interpretation of *SNZC*, as outlined in the previous section, relate to relative weightings that teachers and others give to the various purposes for the inclusion of science in the overall curriculum. These in turn impact significantly on the suitability of the broad pedagogical approaches selected, and on the outcomes it is seen as desirable to achieve. Accordingly, differences in interpretations of the purposes for learning science also lead to differences in interpretation of what constitutes evidence for achievement in science. This is further discussed in Chapter Three.

To assist readers with clarification of this complex dilemma, two main types of purposes currently envisaged for an education in science, together with a brief analysis of the types of outcomes advocated for each, are outlined next. A third, future focused purpose has been included because of its gathering momentum, albeit largely outside education circles thus far.

Education for a subsequent career in science

Scientists, as a lobby group, have always seen the education of future scientists as the most important purpose for an education in science (DeBoer, 1991). However only the last two of the twelve *SNZC* general aims relate to this purpose:

- nurturing scientific talent to ensure a future scientific community (p. 9); and
- developing students' interest in and understanding of the knowledge and processes of science which form the basis of many of their future careers (p. 9).

However, many science teachers may never explicitly identify the overall purposes of their teaching. Rather they may implicitly support purposes to do with the education of future scientists by focusing on "content delivery" as the main aim of their classroom instruction (Ratcliffe, Osborne, Collins, Millar and Duschl, 2001). Small studies suggest many New Zealand teachers would prefer *SNZC* to be more explicit about the "content" that they should be teaching (Baker, 1999), although we have found no evidence that sought to link views about this to views about the purposes envisaged for learning in science generally.

However it is by no means clear that teachers *consciously* favour these aims and we have found no research that directly explores this as an issue for New Zealand.

When the preparation of future scientists and other workers who need some science for their careers is privileged as the main purpose for an education in science, the balance of outcomes has traditionally been weighted to *content.* Arguably knowing how to work 'like a scientist' – that is to achieve *process* and some *attitudes* outcomes – should also be seen as important (and is indeed the focus of several of the stated aims of *SNZC*).

More recently, however, those who advocate wider purposes for science education, as outlined next, have critiqued this traditional interpretation of intended outcomes as being inadequate for *any* future citizens, including all those who will become scientists.

Education for participation in democratic decision making

Beyond 2000, the influential British report on new possibilities for a school science education in the 21st century, succinctly captures this view of the purpose of science education:

> …school science education should aim to produce a populace who are comfortable, competent and confident with scientific and technical matters and artifacts. The science curriculum should provide sufficient scientific knowledge and understanding to enable students to read simple newspaper articles about science, and to follow up TV programmes on new advances in science with interest. Such an education should enable them to express an opinion on important social and ethical issues with which they will increasingly be confronted. It will also form a viable basis, should the need arise, for retraining in work related to science or technology in their later careers (Millar and Osborne, 1998, p. 9).

As already noted, the view that science education is primarily for the education of future scientists can be seen as an issue of curriculum interpretation rather than its actual policy specification. SNZC does intend that science should be "for all" and some of its aims encapsulate this intention, thus:

- developing students' understanding of the different ways people influence, and are influenced by, science and technology (p. 9);
- assisting students to explore issues and to make responsible and considered decisions about the use of science and technology in the environment (p. 9); and

- assisting students to use scientific knowledge and skills to make decisions about the usefulness and worth of ideas (p. 9).

In order to achieve such aims, learning about the nature of science (that is, its sociology and epistemology as already sketched) must be seen as important outcomes for students, to be achieved in conjunction with content learning outcomes. Furthermore, considered decision making about environmental issues implicates wider sets of values in teaching and learning (Barker, 2001), and so arguably values learning outcomes should also be measured if these aims are seen as important.

Education for a "knowledge society"

Jane Gilbert (2001) reviews a wide range of literature to describe the characteristics of knowledge that is likely to be valued in the type of "knowledge society" that is currently being advocated as an important goal of schooling for all New Zealand students (Science and Innovation Advisory Council, 2001). She lists such characteristics as including:

- an emphasis on flexibility, innovation, creativity, and risk taking;
- a breakdown of traditional subject boundaries with an increasing convergence between the arts and the sciences; and
- a focus on knowledge developed by teams on an "as-and-when-needed" basis.

In her view, the content that is currently taught in science encapsulates "old" knowledge, not likely to be relevant or valued in the "knowledge society" of the future.

It is not possible to critique either the aims or the intended outcomes for an education in science at this present time against this future focused view. The *New Zealand Curriculum Framework*, *SNZC* itself, and all current measures of international and national achievement are set within traditional subject-bounded views of curriculum. We note this recent line of argument here to signal that future debates about desirable outcomes may take a quite different shape.

Section 2.6.2 has attempted a necessarily brief outline of key issues for the hotly contested area of science curriculum policy, with its attendant implications for the outcomes that are seen as desirable. It should also be noted that some nations who have achieved highly in current international comparisons of outcomes achieved by their students have expressed dissatisfaction with the balance they have achieved (see section 3.6.1 in the next chapter). Many of these countries are also debating the issues outlined here.

2.7 Summary of Chapter Two

The title of this review is "Curriculum, Learning and Effective Pedagogy". This chapter has dealt with two parts of this triad: "Curriculum" (in terms of the structure of *SNZC*) and "Learning" (in terms of possible student outcomes from science education). The third part, classroom evidence of "Effective Pedagogy", will be the focus of Part II of this review (Chapters Five to Seven).

For reference, key points from section 2.6.2 are summarised in table 2.1 below. The first and second columns list and describe each of the possible student outcomes described in this chapter. The third and fourth columns indicate how each of these outcomes are expressed in New Zealand science education, both in the curriculum document itself and, as suggested in international and New Zealand literature, how this is likely to be implemented through pedagogy in New Zealand classrooms. We suggest that, although there is potential within the structure of *SNZC* for each of the outcomes discussed in this chapter to be met in New Zealand science education, the fulfilment of this potential in classrooms remains problematic. An underlying question is how **effective pedagogy** can enable the flexibility structured in to *SNZC* (the **curriculum**) to be operationalised in the classroom to promote an appropriate balance of outcomes (**learning**) for all New Zealand students. The last column on table 2.1 indicates the chapters in which international and New Zealand research is reviewed to explore the effectiveness of pedagogies in promoting each kind of outcome.

Table 2.1 Multiple possibilities for student outcomes via *SNZC*

	Nature of outcome(s)	**How the outcome(s) are expressed in New Zealand science education:**		**Relevant review chapter**
		• in the document (*SNZC* as intended)	**• in classrooms (*SNZC* as implemented)**	
“Content” learning outcomes	Increased **content** knowledge (recall and/or understanding).	Emphasised via four contextual strands.	Major focus.	Chapter Five, Chapter Six.
“Process” or “skills” learning outcomes	Knowing about **processes** of science investigation, including being able to implement relevant skills.	Specified via integration of skills and attitudes with contextual strands. Implied through the verbs used in the achievement objectives of the contextual strands (e.g “investigate”, “research”, “carry out”)	May result in the doing of “recipe practicals” and/or “fair testing”.	Chapter Six.
“Understandings *about* science” outcomes	Understanding the **nature of science,** including both the *epistemology* and the *sociology* of science.	Specified via integration of *Understanding about the Nature of Science*[2] strand across contextual strands	Implicit rather than explicitly taught at both primary and secondary levels.	Chapter Five, Chapter Six, Chapter Seven, Chapter Eight
“Attitude” outcomes	Development of “scientific” **attitudes** and/or positive attitudes towards science.	Implicit in “science for all” approach and in some skills strand achievement objectives.	Usually implicit rather than consciously addressed.	Chapter Five, Chapter Six, Chapter Seven, Chapter Eight, Chapter Nine.
“Values” outcomes	Awareness of the interplay of **values** in science and democratic decision making.	Not addressed explicitly, although could be read as implied in some of *SNZC*’s aims and achievement objectives	An underdeveloped area of research in New Zealand.	Chapter Eight, Chapter Nine.

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[2] The full title of this strand is *Understanding the Nature of Science and its Relationship to Technology*

PART I: BACKGROUND

Chapter Three: New Zealand Student Achievement in Science – Evidence from National and International Studies

3.0 Introduction

Two large assessment projects provide extensive data on New Zealand students' achievement in science during the review period 1991-2001: the National Education Monitoring Project (NEMP) and the Third International Mathematics and Science Studies (TIMSS). This chapter describes the assessment approaches used in both TIMSS and NEMP (section 3.1), and then gives a detailed report on New Zealand students' TIMSS and NEMP achievement results, both in overall terms (section 3.2), and in relation to gender and ethnicity groupings (section 3.3).

As well as reporting on student achievement, TIMSS and NEMP also provide extensive data on factors that are thought to have an important effect on student achievement, including: students' attitudes to science; home resources; home language; and other factors related to schooling and teaching, including: the proportion of the timetable devoted to teaching science; and teacher qualifications, experience, and confidence teaching science. Section 3.4 reviews findings on these issues and investigates the nature of their relationship to New Zealand students' achievement in TIMSS and NEMP.

Section 3.5 summarises the key TIMSS and NEMP findings that have emerged from sections 3.1, 3.2, 3.3, and 3.4. Taken together, the TIMSS and NEMP data provide a valuable insight into New Zealand students' achievement in science, and also indicate several important factors which contribute to students' achievement, and which may also account to some extent for the varying levels of achievement observed across different sectors of New Zealand's student population. The major objective of this review is to provide a synthesis of research evidence about effective pedagogies, practices, and policies that might improve the learning of science for all New Zealand students (see section 2.2 "Review purpose and objectives" in Chapter Two). In section 3.5, we highlight some emergent themes which we see as key drivers underlying this objective.

As Chapter Two describes (see sections 2.4.2 and 2.4.3), the approach taken throughout this review has been to start with a wide focus, that is, to identify large-scale trends and issues related to teaching, learning, and achievement in science; and then to look in fine-focus at the teaching and learning interactions occurring at the teacher-student-classroom level. A close analysis of the TIMSS and NEMP data at this level requires an examination of the actual content of the assessments tasks, and to consider:

- what kinds of knowledge and skills students need in order to successfully complete these assessment tasks;
- why some students appear to do well on these tasks while other do not; and
- what relationship students' performances in TIMSS and NEMP have to current New Zealand teaching and learning in science.

Section 3.6 takes this approach and, in seeking to interpret the substance of New Zealand students' performance in TIMSS and NEMP, provides a powerful indication of the precise nature of the difficulties that New Zealand students encounter in such assessments of their science knowledge and understanding. The final part of this chapter (section 3.7) indicates how this review will seek to address these issues through a review of research which will inform the goal of developing more effective and equitable pedagogies in New Zealand science education.

3.1 Assessment Methodology: TIMSS and NEMP

Table 3.1a summarises the years in which TIMSS, TIMSS-R (TIMSS repeat), and NEMP data was collected and the age levels of the students involved in each of these studies. Briefly, NEMP is a nation-wide assessment project that involves small random samples of New Zealand students in Year 4 and Year 8. TIMSS is a large multi-nation study which provides international achievement comparisons of samples of:

- 9-year-old (Year 4/5) children from 26 countries;
- 13-year-old students (Year 8/9) from 39 countries; and
- students in their last year of secondary school (Year 12/13) from 22 countries

A repeat of TIMSS (TIMSS-R) was completed in 1998 at the Year 9 level and a national repeat sample was taken at the Year 5 level.

Table 3.1a: TIMSS and NEMP cycles during the review period 1991-2001

	Year(s)	**Levels assessed**
NEMP	1995, 1999	Year 4 and Year 8
TIMSS	1994/95	Year 4/5, Year 8/9, Year 12/13
TIMSS-R	1998/99	Year 5, Year 9

Taken together, the data from TIMSS and NEMP provide some insight into New Zealand students' achievement and, in some cases enable the identification of broad trends in student achievement over time. However, some caution must be used when treating these studies as trend data because the data from two cycles in each study provide indicative data only. Furthermore, the different approaches used in NEMP and TIMSS means that results are not directly comparable. There are also differences within the TIMSS studies that limit comparisons. For example, the national repeat of TIMSS at Year 5 in 98/99 did not collect, or at least report upon, teachers and schools, as did TIMSS-94/95. It needs to be kept in mind that TIMSS initially involved two class levels (Year 4 and 5; and Year 8 and 9) and later involved only Year 5 and Year 9. Subsequently, a re-scaling was undertaken by the TIMSS analysts of the initial results so that direct comparisons could be made with the narrower population used for TIMSS-98/99. This involved the presentation of achievement results in the form of *Item Response Theory (IRT) scale scores,* which for both TIMSS studies, provide a reporting scale with a mean of 500 and a standard deviation of 100.

TIMSS assessment methodology

TIMSS is intended to enable the collection of data which describe students' achievement in relation to the national, local, or regional contexts of each participating country, as well as allowing comparison of student achievement between the 46 participating countries. To accommodate these comparisons, the conceptual framework for TIMSS uses the concepts of the *intended*, *implemented*, and *attained* curricula (Chamberlain, 1997). The *intended* curriculum is that which is mandated in the official curriculum statements. This was identified by a curriculum mapping exercise, which later was used alongside the TIMSS test items so that the subsequent results could be aligned with the degree of "fit" with the intended curriculum. TIMSS 94/95 included science content within the areas of: *Earth Sciences; Life Sciences; Physical Sciences; Science, Technology, and Mathematics; History of Science and Technology; Environmental and Resource Issues Related to Science; Nature of Science;* and *Science and Other Disciplines.* The content reporting categories for TIMMS-94 are summarised in table 3.1b.

Table 3.1b: The Science Content Reporting Categories TIMSS – 94 (refer Chamberlain, G., 1997, pp. 109-110)

Earth Science

a. *Earth Features* – with particular emphasis on the Earth's landforms, atmosphere, and rock and soil types.
b. *Other Earth Science* – Earth processes including, for example, weather and climate, earth processes (e.g. water cycle), and earth in the universe.

Life Science

c. *Human Biology* – including many of the life science categories but specifically focusing on organs and tissues (e.g. circulatory systems, eyes, ears), and energy handling (e.g. respiration, digestions).
d. *Other Life Science* – diversity, organisation, structure of living things, life processes and systems enabling life functions, life spirals, genetic continuity and diversity, and interactions of living things.

Physical Science

e. *Energy and Physical Processes* – an emphasis on energy types, sources, and conversions.
f. *Other Physical Sciences* – including matter, physical transformations, chemical transformations, and forces and motions.

Environmental Issues and the Nature of Science

g. *Environmental* – environmental and resource issues related to science including pollution, conservation, world population, food production and storage, and effects of natural disasters.
h. *Other Science content* – concepts of technology, interactions of science, mathematics, and technology; and interactions of science, technology, and society.

The content areas in TIMSS-98/99 differed slightly from the earlier study and as a result, unlike the main science scale, the content area sub-scales between the two studies are not directly comparable. The six TIMSS-98/99 science sub-scale content areas were *Earth Science, Life Science, Physics, Chemistry, Environment and Resource Issues, and Scientific Inquiry and the Nature of Science*.

The second aspect of curriculum, the *implemented* curriculum, is that which is taught or delivered in schools. Data on the implemented curriculum was gathered from questionnaires completed by school principals, teachers of science and students. This gives, for example, information on teachers' academic and professional backgrounds, instructional practices and resources, and about their attitudes to teaching science.

Thirdly, the *attained* curriculum is defined as that achieved by students. This was examined in three ways: (1) by the use of 'pencil and paper' tests including questions in both free-response and multiple choice format; (2) for selected students in a small number of schools, by a series of hands-on performance tasks; and (3) by student questionnaires designed to elicit attitudes to science, students' perceptions of their abilities in science, and other student characteristics such as school and home activities.

NEMP assessment methodology

In contrast to TIMSS, the NEMP assessment framework for science has a central organising theme, *Science in everyday contexts*, supported by three interrelated aspects. The *content* aspect relates to the four contextual strands of *Science in the New Zealand Curriculum* (Ministry of Education, 1993a); the *process* aspect involves the six essential skills for science[2] that students are expected to demonstrate as they interact with content; and the *motivation* aspect includes scientific attitudes, participation, interest and habits of mind. NEMP requires students to complete a number of tasks that are administered using three different approaches: (1) students complete the majority of tasks in a one-to-one interview undertaken by teachers trained for this work; (2) they also work with other students in a small group to complete a number of tasks together; and (3) they undertake a series of stations where they work independently on a series of pen and paper tasks, many of which require hands-on materials or visual information.

NEMP reports the achievement of students task by task, with about two-thirds of the tasks and components in each assessment being reported in detail. The remaining tasks, called "link tasks" are used to compare performance over successive cycles of assessment and so detailed descriptions are withheld from publication.

3.2 The measurement of overall student achievement in science: TIMSS and NEMP

3.2.1 Student achievement at year 5 (TIMSS)

The mean performance in science of New Zealand Year 5 students in TIMSS-94/95 was about the same as the international mean, and the results of TIMSS-98/99 indicated that there was little change in overall performance over the four years. Table 3.2 shows New Zealand Year 5 students' mean achievement scores overall, and by ethnic group.

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[2] Using information and knowledge; communicating: talking, writing, explaining; enquiring, asking questions, investigating; analysing, solving problems; using equipment, tools and procedures; scientific thinking: considering and arguing evidence.

Table 3.2: TIMSS - Year 5 students' mean science scores[3]

Year of assessment	Pakeha/ European	Maori	Pacific	Asian	Other	Total
1994	534 (3.9)	457 (12.0)	441 (14.9)	493 (16.7)	521 (14.2)	505 (5.3)
1998	541 (4.8)	478 (8.0)	436 (13.8)	517 (10.0)	497 (23.0)	514 (5.9)

Note: standard errors (s.e.) in parentheses

New Zealand Year 5 students in 1994 performed best relative to the students of other countries in the content areas of *Environmental Issues* and the *Nature of Science*. The area in which they were weakest internationally was *Physical Science* (Chamberlain, G., 1997 p. 133). It is not possible to comment on performance in the first two areas (*Environmental Issues* and the *Nature of Science)* in TIMSS-98/99, because items were regrouped into different categories from those first reported in publications about TIMSS-94/95 in order to enable relative sub-scale scores to be calculated for each of the reporting categories (Chamberlain, Chamberlain and Walker, 2001).

The rescaled 1994/95 achievement data and the scaled 98/99 data indicate that Year 5 students made a small, but not significant gain across the four-year period in all three reporting categories for science. The largest gain was in *Earth Science* (18 scale score points) with smaller improvements for *Life Science* (13 points) and *Physical Science* (10 points). *Physical Science* continued to be an area of relative weakness. Table 3.3 shows New Zealand Year 5 students' mean scores in the three reporting categories in 1994 and 1998.

Table 3.3: Year 5 students mean scores for each reporting category

	Earth Science			Life Science			Physical Science		
Year	girls	boys	overall	girls	boys	overall	girls	boys	overall
1994	508 (5.5)	514 (6.3)	510 (5.4)	521 (5.4)	497 (7.0)	509 (5.6)	500 (5.6)	492 (7.8)	496 (5.8)
1998	516 (6.1)	541 (6.8)	528 (6.0)	526 (5.9)	519 (6.0)	522 (5.5)	501 (5.9)	511 (6.7)	506 (5.9)

3.2.2 Student achievement at Year 9 (TIMSS)

The New Zealand mean science score for year 9 students was not significantly different from the international mean and there was virtually no change in scores between 1994 and 1998. Table 3.4 shows the mean scores overall and by gender.

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[3] Achievement scores are presented in the form of Item Response Theory (IRT) scale scores. IRT scale scores incorporate information about the characteristics of both the test item (e.g. difficulty) and the students

Table 3.4: Year 9 students' mean science scores in 1994 and 1998, by gender

Year 9 Students	1994 mean science score (s.e.)	1998 mean science score (s.e.)
Girls	497 (5.6)	506 (5.4)
Boys	524 (6.1)	513 (7.0)
Overall	511 (4.9)	510 (4.9)

However, New Zealand's relative performance in science decreased slightly from middle primary to lower secondary over the four years compared to 16 other countries that participated at these two educational levels in 1994/95 and 1998/99. Further, achievement relative to countries such as Australia and Canada was somewhat poorer (change in mean score from 1994/95 to 1998/99 was –1 for New Zealand, +23 for Australia, and +19 for Canada).

There were relatively large differences in Year 9 students' performance on different content areas in 1994/95. For example:

- Students achieved best on items from *Human Biology*, *Light*, and *Environment*.
- *Earth Science* was an area of relative weakness.
- Students performed least well on *Chemistry.*

However, about one-third of the chemistry items for Year 9 were found to be not in the intended curriculum, and opportunities for learning chemistry other than in the classroom are limited (Chamberlain, M., 1996, p. 88). Year 9 students also, on average, attained low scores on *Energy Types*, and the mean performance in two other areas, *Other Life Science* and *Other Science Content,* was low relative to the proportion of items in the intended curriculum.

Table 3.5 shows year 9 students' mean scores by content area in 1998. Direct comparisons between the 1994 results and the 1998 results are not possible because of the regrouping of science categories. However, in all content areas New Zealand students achieved a mean score higher than the international mean; but only in *Scientific Inquiry and the Nature of Science* was the difference statistically significant (Chamberlain and Walker, 2001).

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taking the test, and allow for the fact that each student received one of the eight randomly assigned test booklets.

Table 3.5: Year 9 students' mean scores for science content reporting categories in 1998, by gender and overall

Content reporting category	Mean scale scores (s.e.)		
	girls	boys	overall
Earth Science	499 (8.6)	510 (7.9)	504 (5.8)
Life Science	506 (6.4)	496 (7.7)	501 (5.6)
Physics	494 (4.9)	504 (6.4)	499 (4.7)
Chemistry	497 (7.6)	509 (6.3)	503 (4.9)
Environment Resource Issues	499 (6.7)	506 (6.6)	503 (5.2)
Scientific Inquiry & Nature of Science	530 (6.6)	513 (11.4)	521 (6.8)

Using Levels 4 and 5, and in some cases Level 3, of *Science in the New Zealand Curriculum* (Ministry of Education, 1993a), the content of 77 percent of the science items was judged to be in the intended curriculum, for the majority of Year 9 students (Chamberlain and Walker, 2001). It is tempting to conclude that better scores for *Scientific Inquiry and the Nature of Science* is the result of over 90 percent of the test ideas being in the intended curriculum (compared, for example, with the fact that only two-thirds of the *Earth Science* test items were in the intended curriculum). However, as argued by Chamberlain and Walker (2001), this issue is somewhat more complex because 90 percent of the *Physics* items were also found in the intended curriculum, yet the relative performance of New Zealand students in this area was clearly weaker than in *Scientific Inquiry and the Nature of Science.* Chamberlain and Walker suggest a possible explanation may be found by examining the relative emphasis that other countries in the study placed on these areas. For example, if most other countries place considerably more emphasis on *Physics* than they do on *Scientific Inquiry and the Nature of Science,* this difference in emphasis may account for New Zealand students' better performance on the latter, relative to their international counterparts (Chamberlain and Walker, 2001, p. 70).

In an attempt to more fully describe the actual science achievement, student performance on the test items at Year 9 in TIMSS-98/99 was analysed within the 90th percentile; the 75th percentile; the 50th percentile; and the 25th percentile. Descriptors, referred to as 'benchmarks', were constructed for each category. For example, students who reached the median benchmark on the TIMSS-98/99 scale, the point above which the top half of the students scored, could:

> recognise and communicate basic scientific knowledge across a range of topics. They recognised some characteristics of the solar system, ecosystems, animals and plants, light reflection and radiation, energy sources, sound, force and motion and human impact on the environment. They could apply and briefly communicate knowledge to practical situations, extract tabular information, and interpret representational diagrams (Chamberlain & Walker, 2001, pp. 28-29).

Table 3.6 shows the proportions of New Zealand students reaching each of the benchmarks compared to students from 23 trend countries*.

Table 3.6: Percentages of New Zealand students reaching the TIMSS-98/99 international benchmarks of science achievement

International Benchmark	TIMSS-94/95		TIMSS-98/99	
	Proportion of NZ students (%)	International mean for 23 trend countries (%)	Proportion of NZ students (%)	**International mean for 23 trend countries*** (%)
Top 10%	11	13	12	14
Upper Quarter	30	34	32	35
Median	62	65	61	66
Lower Quarter	87	88	86	89

** International means were calculated for the 23 countries that participated and met sampling guidelines in both 1994/95 and 1998/99.*

There were six main factors that seemed to differentiate performance among the four levels. These were: the depth and breadth of content knowledge; the level of understanding and use of technical vocabulary; the context of the problem (progressing from practical to more abstract); the level of scientific investigation skills; the complexity of diagrams, graphs, tables, and textual information used; and the completeness of written responses (Martin, Mullis, Gonzalez, Gregory, Smith, Chrostowski, Garden and O'Connor, 2000).

Knight (2001) draws attention to the importance of the median benchmark and argues that the fact that 75 percent of Australian and Canadian students reached the median benchmark shows that it should be an achievable goal for more New Zealand students. He suggests that the New Zealand results of 62 percent achieving the international median benchmark indicate that a closer study of the bottom quartile of science achievers would be of value.

3.2.3 Student achievement at Year 5 and Year 9 (TIMSS): performance assessment

Paper-and-pencil tests were administered in more than 40 countries in TIMSS-94/95, but only about half of these countries administered performance-assessment tasks. These are tasks in which "students are required to carry out 'hands-on' activities with equipment to show how well they are able to apply strategies and procedures to investigate and solve problems in practical settings" (Garden, 1997a, p. 3). In most cases the rank position of countries was about the same on the performance assessment as on the written test. New Zealand students reflected the trend of other countries with students demonstrating greater knowledge of 'using scientific procedures' and 'scientific investigating' than 'scientific problem-solving and applying concept knowledge'. This was more pronounced at the Year 5 level in all countries which led Garden (1997a) to suggest that problem-solving approaches to teaching may not be appropriate for students at this level. Further analysis of the test items and students' responses would be required to determine the nature of the difficulty and whether the test items themselves are a valid test of students' problem-solving abilities.

The correlation between New Zealand students' scores on the written tests and performance assessments were relatively low for Year 9 science ($r=0.49$, $p<0.0001$), indicating that performance assessment is adding a substantial amount of information to that provided by the written test. Garden (1997a) suggests that more work is needed to determine the extent to which this extra information is attributable to science teaching, and that there is certainly a prima facie case for including hands-on tasks at national level, depending on the uses to which the resulting data will be put (p.106). At the same time, these results need to be viewed as indicative, as general statements about the achievement of individual students cannot be made on the basis of two or three tasks. Garden (1997a) cites Shavelson *et al.* (1992) who estimated that at least two and a half hours (or 10 tasks for each student) were needed for generalisability (p 106). Further, individual performance on hands-on tasks has been found to be task-specific (Shavelson *et al.*, 1992 in Garden 1997a) as performance varies from task to task depending on the past experience, and interest of students. TIMSS data indicates that this is also true at a country level. That is, the student mean for a country can be relatively high compared to other countries on some tasks, but relatively low on others.

3.2.4 Student achievement: Science literacy at Year 12/13 (TIMSS)

All students who were in their last year of schooling, not just those studying science, were included in the science literacy sample in TIMSS-94/95. The assessment of scientific literacy involved the use and application of key scientific concepts within everyday, relevant contexts. New Zealand senior secondary school students performed above the international mean, and were ranked 6th out of 21 countries. The New Zealand sample included 70 percent of the school leaving age cohort, which was in the middle percentage range for participating countries. Even taking into account the absence of some countries whose students regularly score very well in such studies, New Zealand students showed an improvement in performance relative to those of other participating countries over the course of schooling. The recently released (December 2001) Programme for International Student Assessment (PISA) study that also assessed scientific literacy, this time of 15-year-olds in 32 countries, provided similar evidence, with New Zealand students' achievement the sixth highest mean score, (Ministry of Education, 2001d).

3.2.5 Student achievement at Years 4 and 8: (NEMP)

- The 1999 NEMP cycle included a number of tasks used in 1995 in an identical form to enable the examination of trends in student performance.
- In the *content* aspect there was no significant difference in performance in either Year 4 or Year 8 between 1995 and 1999.
- The comparison of Year 4 and 8 students' performance on common tasks between 1994 and 1999 indicated that, on average, students made reasonable progress between year 4 and 8 in the skills assessed by the tasks set within the *Living and Physical Worlds* (13 percent and 12 percent), more substantial progress within the context of the *Material World* (15 percent), and only modest progress with *Planet Earth and Beyond* (9 percent).
- In the *Living World*, students at both levels were less successful in providing explanation for living world phenomena than in demonstrating their knowledge of the phenomena or being able to classify and identify observable features of living things (Crooks and Flockton, 2000b, p. 12).
- Similarly, in the *Physical and Material World* content area students at both levels were more successful in carrying out experimental procedures and reporting results than in demonstrating their knowledge or giving explanations.

Knight (2001) summarised these findings into areas of relative strengths and relative weaknesses. Strengths include: experimenting, demonstrating, observing, and reporting. Weaknesses were planning and explaining (p. 5). A further weakness is students' apparent lack of understanding of the importance of replication of results within a scientific investigation. While these findings give some clear direction for the teaching of science, they need to be treated as indicative only. Just as performance assessment in science is task specific (see above) the skill of explaining is dependent upon the context in which the student is asked to give an explanation. Knight gives the example that in the Science 1995 assessment, only 1 percent of Year 4 students were able to provide a good explanation in one question, but 92 percent in another (p. 7).

In 1995, and again in 1999, students' skills in the use of graphs, tables, and maps were assessed. While these are taught and learnt within a number of subject areas they are key skills in science and so need some comment. There was a 12 percent improvement in Year 4 performance of 1999 in the NEMP trend tasks. As Knight (2001) points out, however, most of this improvement was attributed to a large improvement on one task involving pie charts and no other changes were significant.

Because one of the major objectives of this review is to provide evidence to link pedagogy with student achievement (see chapter 2), a further caution is required when seeking solutions from the NEMP results. While the trend data does enable comparisons over time of students in Year 4 and Year 8 a major focus of NEMP is measuring growth from Year 4 to Year 8. As a result a number of tasks completed are the same at Year 4 and Year 8 which means, of course, that the Year four students have not been taught some of the areas covered by the trend tasks. Hence, for example, "it is reassuring to note that some of the largest differences between year 4 and year 8 occurred with line graphs, which are not usually taught until after year 4" (Crooks and Flockton, 2000a , p. 4). As Knight (2001) indicates, assessing students on tasks they may not have yet learned at school is consistent with the main goal of the national monitoring project which is: to provide detailed information about what New Zealand's children know and can do, regardless of what may or may not have been formally taught in schools. However, it makes the findings less useful for the purposes of this review which is seeking to determine how activities of teachers might make a difference to student achievement. But it is a reminder of the importance of experiences outside school and how these influence achievement at school.

3.2.6 Summary of overall student achievement in science: TIMSS and NEMP

- The mean performance in science of New Zealand Year 5 students is about the same as the international mean and there has been a small, but statistically insignificant increase in the mean achievement between 1994 and 1998.
- The mean performance of New Zealand Year 9 students, on average, is significantly above the international mean and there has been relatively little change in achievement between 1994 and 1998.
- New Zealand Year 5 students' performance is relatively strong in the area of *Earth Science* and weak in *Physical Science.*
- New Zealand Year 9 students show strengths in their relative understanding of *Scientific Inquiry and the Nature of Science* and weakness in the area of *Physical Science.*
- NEMP indicates that students make progress in all content areas between year 4 and Year 8, with greatest growth in the *Living* and *Physical Worlds*, and least in *Planet Earth and Beyond.*
- Students appear to have strengths in the areas of experimenting, demonstrating, observing and reporting but weaknesses in planning, explaining and recognising the importance of replication in scientific investigations.
- New Zealand students show an improvement in performance relative to other TIMSS counties over the course of schooling.

3.3 The measurement of student achievement in science: TIMSS and NEMP analysed by subgroups

3.3.1 Gender

Gender: TIMSS-Year 5

TIMSS-94/95 indicated gender differences in Year 5 science achievement favouring boys in almost all countries. New Zealand was one of three countries where the difference was in favour of girls although this result was not statistically significant. The science performance of boys between 1994 and 1998 improved significantly but there was no change in achievement for girls (see Table 3.3). In fact, from 1994 to 1998 there were no significant changes in girls' mean scores in any of the science content reporting categories. At the same time, boys' mean scores did increase significantly in both *Earth Science* and *Life Science* (27 and 22 scale points respectively). Overall, *Physical Science* remains an area of relative weakness for both groups, with boys showing relative strength in *Earth Science* and girls in *Life Science* (see Table 3.3)

Gender: TIMSS-Year 9

Year 9 male students in TIMSS-94/95 scored significantly higher than girls on more than two-thirds of the content areas. *Life Science* (including Human Biology), was the one area where the differences in mean achievement between male and female students were negligible. Table 3.7 shows year 9 students' scores four years later in the 1998 TIMSS-repeat. Interestingly, in 1998 there was no significant difference between Year 9 boys' and girls' mean scores or scores by content area. As found in the 1999 NEMP there were gender differences favouring boys at the item level but this was not evident in overall achievement.

Table 3.7 Year 9 students' mean scores for science content reporting categories in 1998/99, by gender and overall

Content reporting category	Mean scale scores (s.e.)		
	girls	boys	overall
Earth science	499 (8.6)	510 (7.9)	504 (5.8)
Life science	506 (6.4)	496 (7.7)	501 (5.6)
Physics	494 (4.9)	504 (6.4)	499 (4.7)
Chemistry	497 (7.6)	509 (6.3)	503 (4.9)
Environment Resource Issues	499 (6.7)	506 (6.6)	503 (5.2)
Scientific Inquiry & Nature of Science	530 (6.6)	513 (11.4)	521 (6.8)

Comparisons with the international data indicated that there were no significant differences between the mean score of boys and the mean score of girls on any of the six science content area sub-scales. New Zealand girls achieved mean scores above the international means for girls in each of the six content reporting areas but only *Physics* and *Scientific Inquiry and the Nature of Science* were significantly different. New Zealand boys achieved a mean score above the international mean for boys in every science content area but none of these differences were statistically significant.

In TIMSS-94/95, the test items were analysed to see if there was an effect by gender of the *type* of test item used. Although previous research had suggested that boys might be unduly advantaged by the use of multiple-choice items for assessment purposes, the results suggest that neither sex was significantly disadvantaged by the use of either multiple-choice or free-response item format at year 5. A similar finding was reported for year 9 (Chamberlain, 1996). TIMSS-94/95 Year 5 science survey included 27 free-response items. New Zealand students achieved significantly above the corresponding mean on nine items, and significantly below on four items. *Life Science* was the best topic for New Zealand students, but no topic was found to be particularly strong or particularly weak. Nearly half of the items produced significant gender differences – nine in favour of girls, three in favour of boys.

TIMSS-94/95 at year 9 included 38 free-response items in all. On 24 items, New Zealand year 9 students achieved significantly above the international means, whereas there were only three items for which New Zealand scored significantly below. About 60 percent of the items produced significant gender differences – eight in favour of girls, fifteen in favour of boys. Male students, on average, did particularly well in the *Physics* and *Chemistry* areas (Chamberlain, Chamberlain and Garden, 1998, p171).

TIMSS-94/95 also involved a sub sample who completed a series of performance tasks. Although most differences were not statistically significant, girls consistently out-performed boys on the practical tasks. Garden (1997a) suggests that it may be that the reading and writing components of the task advantaged girls, who have been shown to be considerably more skilled than boys in these areas, and that this outweighed any differences related to science context (p108). He also observes that given the relative success of New Zealand in international assessments of reading, better writing skills could have been expected. As it was, New Zealand students, in common with students in some other countries, found it difficult to write descriptions or explanations for what they had done.

The results for boys and girls at the Year 5 and Year 9 levels give no clear overall picture of achievement differences by gender. This is not true of the findings in the final year of schooling where there were large, statistically significant gender differences favouring males. At this level Pakeha/European, Asian and Maori males, and Pakeha/European females had results higher than the international mean. The result for Maori males is somewhat deceptive, because the lower participation rate in senior secondary school gives a misleading impression of Maori males' overall achievement levels in science. The overall result of the gender analysis is in contrast to the national data from examinations (SC, 6th Form Cert and Bursary), which have indicated that girls have been achieving, on average, more highly than boys in science. Alton-Lee and Praat (2000) note that the discrepancies between the average achievement of male and female students in the senior secondary school in the 5th, 6th and 7th form assessments appear to have increased by a slight margin in favour of girls over the decade (p 72).

Gender: NEMP

In both phases of the NEMP science monitoring there have been gender differences on task performance in favour of boys at year 4 and at year 8.

- In 1995 Year 4 boys performed better than girls on 3 of the 31 individual tasks.

- In 1999 this had increased to 14 of the 50 tasks, with 6 of these tasks relating to *Planet Earth and Beyond.*
- In 1994 Year 8 boys outperformed Year 8 girls on 10 of the 33 tasks.
- In 1999 there were differences in favour of boys in 13 of the 48 tasks, with rather more in the *Physical World* and *Planet Earth and Beyond.*

3.3.2 Ethnicity

Ethnicity: TIMSS - Year 5

The TIMSS results were also analysed in terms of ethnic groupings with students being identified as Maori, Pakeha/European, Pacific Island, Asian and Other.

- In 1994/95 the best scores for Maori students in Year 5 matched that of the Pakeha/European and Asian groupings but more than three-quarters of the Maori students scored below the means for these other groups.
- The largest increases in Year 5 mean achievement from 1994/95 and 1998/99 were observed for students in the Maori and Asian groupings (21 and 24 scale points respectively-see Table 3.2).
- In contrast there was virtually no change in the mean scores for Pacific and Pakeha/European Year 5 students over the four-year period.
- The mean achievement of Pacific students was lowest of any ethnic group, with approximately one-half of the students in the bottom 20 percent (this result is similar to the Year 9 results).

Despite the considerable difference in achievement between these sub-groups, the patterns of relative strength and weaknesses on content areas were similar across all ethnic groups (see Table 3.8).

Table 3.8 Year 5 students' mean scores for each science reporting category in 1994 and 1998, by ethnic grouping

Ethnic grouping and year of assessment	Mean science sub-scale scores (s.e.)		
	Earth Science	Life Science	Physical Science
Pakeha/European			
1994	536 (4.3)	538 (4.3)	527 (4.6)
1998	554 (5.2)	548 (4.9)	532 (5.2)
Maori			
1994	468 (11.1)	462 (11.8)	445 (11.4)
1998	493 (7.7)	488 (7.4)	468 (8.6)
Pacific			
1994	448 (13.6)	447 (15.5)	429 (14.4)
1998	449 (13.8)	449 (12.6)	435 (12.2)
Asian			
1994	503 (17.4)	492 (17.0)	480 (19.2)
1998	530 (12.7)	518 (10.4)	508 (10.2)

A significant gender difference in favour of Maori girls in 1994 (46 scale score points) was no longer evident in 1998 as a result of the significant improvement in mean science achievement of Maori boys and the absence of any change for Maori girls. There were also small increases in the differential between girls' and boys' mean achievement over the four years in favour of boys in both the Pacific and Asian groupings.

Ethnicity: TIMSS- year 9

A parallel pattern of results is evident in Year 9, with similar relationships between relative levels of achievement according to ethnic groupings observed in 1994 and 1998 (see Table 3.9).

Table 3.9 Year 9 students' mean science scores in 1994 and 1998, by ethnic grouping

	Mean science scale scores (s.e.)			
	Pakeha/European	Maori	Pacific	Asian
1994	533 (4.4)	472 (5.6)	430 (8.5)	498 (12.0)
1998	534 (4.5)	472 (6.0)	430 (12.0)	515 (9.9)

This stability is also evident in the relative achievement patterns between ethnic groupings in the content area sub-scales. These patterns generally reflect the pattern for the overall science scale, although there were some notable differences. For example, Pakeha/European students achieved significantly higher means than Maori and Pacific students in all six-science context areas. Maori significantly outperformed Pacific students only in *Chemistry*, and only in *Earth Science* and *Physics* did Asian students significantly outperform Maori students (Chamberlain & Walker, 2001, p 71).

Ethnicity: NEMP

The NEMP results indicate an improvement in performance for Maori students, not only in middle primary (as TIMSS) but also in Year 8.

- In 1995 Maori students performed less well than non-Maori students in 61 percent of the tasks at the year 4 level and 57.6 percent of the tasks at year 8 level.
- By 1999 this had dropped to 12 percent at Year 4 and 44 percent at Year 8.

This increase in achievement on more than half of the NEMP tasks is of some significance and it is not paralleled with a similar increase by students in low decile schools.

In 1999, assessment of students' learning in Maori immersion programmes was added to the national monitoring programme at Year 8 only. In this first year the focus included science and graphs, maps and tables. Some caution is needed in interpreting the results because the sample included a number of students who had quite limited *te reo Maori* and so they may not have been able to convey the full extent of their scientific understanding in any one activity. Furthermore, as the tasks took longer to complete, the teachers administering them either omitted tasks or modified them in a way that made their marking invalid. Ultimately this led to the exclusion of 15 of the 33 science tasks. Sixteen tasks were used to compare the performance of Maori students in general education with those in Maori immersion settings. The two groups of students performed equally well on 12 tasks, with students in immersion programs scoring statistically significantly higher on one task and Maori students in general education scoring significantly higher on three tasks. However, as already highlighted, language difficulties alone may account for these differences. Similar results were elicited in the assessment of performance in graphs, maps and tables with the two groups of students performing equally well on 17 tasks, students in immersion programmes scoring significantly higher on one task and Maori students in general education scoring significantly higher on four tasks.

The sampling technique did not allow for direct consideration of Pacific students'achievement in 1995. In 1999 for year 4 students, there were statistically significant differences in performance among the three identified student groups (Pacific Island, Maori and Other) on 23 of the 50 tasks. Pacific students scored lower than Maori students on 7 tasks and lower than "Other" students in 20 tasks. For Year 8 students there were differences in 19 of the 48 tasks. The Pacific students did not score significantly lower than the Maori students on any tasks, but were lower than the "Other" students on 18 tasks.

3.3.3 Summary of student achievement in science by gender and ethnicity: TIMSS and NEMP

- The NEMP data at Year 4 and TIMSS at Year 5 indicates an improvement from 1994/95 to 1998/99 in the achievement of boys relative to girls. Both studies illustrate boys' strength in *Earth Science*. TIMSS demonstrates girls' strength in the *Life Sciences*, although the difference in achievement is less in 1998 than 1994.
- The data from NEMP at Year 8 and TIMSS at Year 9 provides a complex picture. NEMP indicates that boys' performance in science is higher than that of girls. *Life Sciences* continues to be strength for girls, with boys showing higher achievement in the areas of *Planet Earth and Beyond* and in the physical sciences. In contrast, the performance difference in favour of boys evident in TIMSS-94/95 no longer exists in 98/99.
- The results in the final year of schooling (TIMSS-94/95) are similarly contradictory, with boys' achievement significantly higher than girls'. This finding contrasts with girls' achievement in the national examinations at this level. The PISA results give yet another perspective with the results indicating a small difference in favour of girls at this middle stage of high school.
- At Year 5 Pakeha/European students achieve the highest mean science scores, followed by Asian, Maori and Pacific. The largest increases in achievement from 1994 to 1998 were in the Maori and Asian groupings; there was virtually no change in the mean scores for the other two groupings. A similar improvement in the performance of Year 4 Maori students was evident in NEMP between 1995 and 1999. There was no corresponding increase in performance at Year 9 in TIMSS-1998/99, although there was a slight improvement for Maori students at Year 8 in NEMP 99.

3.4 Other significant issues in relation to student achievement

TIMSS and NEMP provide information on a number key factors that are thought to influence student achievement. These include attitudes to science, home resources or socio-economic factors, language and communication skills and class/teacher related factors.

3.4.1 The measurement of student attitudes to science: NEMP and TIMSS

TIMSS and NEMP report on data concerning student attitudes and beliefs. TIMSS distinguishes between students' attitudes to science and their self-confidence in science. TIMSS reports this through the use of two indices, PATS (positive attitudes to science) and SCS (self-confidence in science). In NEMP students complete a science survey, which elicits data such as attitudes to science, confidence in doing science, interest in science and the nature of activities undertaken in science at school.

TIMSS: Student attitudes towards science

There are numerous reports claiming that student attitudes influence student achievement (see Nash and Harker, 1997) and the TIMSS data similarly indicates a relationship between achievement in science and attitudes to science.

In 1998/99, 52 percent of Year 5 students were found to have relatively positive attitudes. Table 3.10 shows the proportions of Year 9 students measured as having low, medium or high attitudes to science as measured by the PATS test, compared to mean science scores. Overall, the proportions of students at each level of the PATS index are relatively constant between 1994 and 1998.

Table 3.10 Proportions of year 9 students at each level of the positive attitudes to science (PATS) index in 1994 and 1998, by gender

	1994				1998			
	Girls	Boys	Overall		Girls	Boys	Overall	
Level of the PATS Index	% of students	% of students	% of students	Mean science score (s.e.)	% of students	% of students	% of students	Mean science score (s.e.)
Low	21	14	17	489 (5.7)	18	14	16	493 (5.7)
Medium	56	54	55	509 (4.9)	58	54	56	511 (5.3)
High	23	32	27	536 (6.7)	24	32	28	525 (7.3)

For TIMSS-98/99 indexes were constructed to provide an indication of attitudes to science and of students' self concept of ability in science. With few exceptions the relationship between attitudes to science and science achievement was linear – those students who scored low on the PATS Index within a country had lower mean science achievement than those higher on the index.

TIMSS: Attitudes and gender

In both 94 and 98, Year 9 boys held more positive attitudes than their female counterparts. In commenting on the decline in New Zealand girl's attitudes to science during middle primary to early secondary Garden (1997b) reports that 'there is also a strong suggestion that although standard 2 and 3 [Years 4 and 5] girls' performance in science relative to boys is very good, even at this level their attitudes and achievement are beginning to deteriorate, so that by the time they reach forms 2 and 3 [Years 8 and 9] , girls' average science achievement lags behind that of boys and many girls have developed negative attitudes to the subject' (p251). Alton-Lee and Praat (2000) cite Weinburgh (1995) who found a stronger correlation for girls than boys between attitudes and achievement, and concluded that "a positive attitude is more necessary for girls in achieving high scores".

TIMSS: Attitudes and ethnicity

Table 3.11 shows the proportions of year 9 students at each level of the PATS index according to ethnic grouping. A slightly higher proportion of Maori students were at the low level of the PATS Index than was the case for the other three groupings. Asian and Pacific students had higher proportions of students at the high level of the index, although because of the small numbers of students involved it is not possible to reach any definitive conclusion from these results.

Table 3.11 The proportions of year 9 students at each level of the positive attitudes to science (PATS) index in 1994 and 1998, by ethnic grouping

Ethnic Grouping	Proportion (%) of students at each level of the PATS Index in 1994			Proportion (%) of students at each level of the PATS Index in 1998		
	Low	Medium	High	Low	Medium	High
Pakeha/ European	18	55	27	17	55	28
Maori	22	54	24	18	60	22
Pacific	12	55	34	12	52	36
Asian	10	53	37	11	53	37

Students were also asked a series of questions about their views of themselves in relation to science (Self concept in science – SCS) and on the basis of their responses were then categorised into low, medium and high self-concept. A discernable association was found between self-concept in science and achievement. However, Chamberlain and Walker (2001) indicate that it is important to remember that the association does not imply causation and, on the basis of these figures alone, it is not possible to determine the degree to which a high self-concept in science ability contributes to, or is reflective of, higher science achievement (p 96). Further, they suggest the possibility of cultural factors influencing the responses to this question as some countries with higher mean science achievement had lower proportions of students with high self-concept in science. An analysis of the reported self-concept in science at Year 9 found no statistically significant difference between boys and girls at any of the three levels of the index. The Pakeha/European grouping, however, had a far greater proportion of students categorised as high on the index than the other three ethnic groupings and there was a fairly linear relationship between students' self concept in science and their science achievement across all four ethnic groupings (p 97).

NEMP: Student attitudes towards science

The students in the NEMP monitoring programme are asked to respond to eleven questions designed to elicit their views about curriculum preferences, their perceptions of their achievement and potential in science, and their involvement in science related activities within school and beyond.

Year 4 students are generally very positive about doing science at school.

- Almost all reported that they liked science *heaps* or *quite a lot* with (92 percent of students in 1995, and 91 percent in 1999)
- Most said they would like to do more science at school (58 percent in 1999; 66 percent in 1995)

Year 8 students were less inclined to select the positive categories (a pattern common in national monitoring surveys) but Crooks and Flockton (2000b) suggest that "older students can be expected to be more discerning and critical, as well as more realistic about their own abilities" (Crooks & Flockton, 2000b, p 64).

- In Year 8, 92 percent of students in 1995 and 85 percent in 1999 reported that they liked doing science *heaps*
- However, there was less enthusiasm for doing more science (39 percent in 1999 and 47 percent in 1995).

Interestingly, students' judgments about how good they thought they were in science were more polarised in 1999 than 1995. Crooks and Flockton (2000b) suggest that perhaps by 1999 students were receiving more teacher judgments on their performance in science than they were four years earlier, leading to sharper perceptions of themselves as science learners (p 64).

Students' relatively stable positive response to learning science at school is also evident in the ranking given to it in relation to all the other curriculum areas in the first cycle of monitoring data. With 92 percent of Year 4 and 8 students reporting that they liked science, this subject area was fourth (out of 9 areas) for Year 4 students and third for Year 8. As noted above there was little change in response by Year 4 students from 1995 to 1999, but the 7 point drop in rating by Year 8 students (92 percent to 85 percent) is of some significance.

NEMP: Attitudes and gender

In 1995 at the Year 4 level the results were similar for girls and boys in all but two areas: girls were less positive about their ability in science and their suitability to be a scientist when they grew up. In 1999 there were no differences in the responses of girls and boys to the Science Survey questions. By Year 8, however, there were statistically significant differences between boys and girls. In 1995 this was evident on seven of the eleven questions, in 1999 in 3 of the questions. For instance, in 1995 41 percent of boys reported that they like doing science "heaps" compared with 23 percent of girls. In 1999 compared to girls, boys reported greater enjoyment of doing science at school, greater expertise at science, and greater involvement in doing good things in science in their own time.

NEMP: Attitudes, ethnicity and socio-economic status (SES)

Maori students showed no statistically significant differences in attitudes with other students at either Year 4 or 8 in NEMP-95. In 1999 there was one difference at Year 4, with Maori students judging that their class more frequently did really good things in science. There were also differences in Year 8, with Maori students reporting less experience in conducting science experiments with everyday things at school, and they were less inclined to believe that they would make a good scientist in the future. However, a comparison of Maori students in general education with those in immersion settings revealed much higher proportions of immersion students who were very positive about how good they thought they were at science and about their suitability to be good scientists when they grew up. The immersion students also reported that their school programmes included higher levels of field trips, visits to science activities, and experiences with everyday things.

On the Science Survey at Year 8 (1995) students in low SES schools were most positive and students in medium SES schools least positive about studying more science in school.

3.4.2 Socio-economic factors and science achievement

It is well documented that low socio-economic status, of both families and communities, is associated with relatively poor science performance in school (Chamberlain and Walker, 2001). There are number of methods used to measure such status. TIMSS-94/95 used indirect methods such as measuring home resources (such as books) and linking parental education to achievement. TIMSS-R in 1998/99 included the construction of an index of students' Home Educational Resources. Subsequently, the New Zealand achievement data for TIMSS-98/99 was analysed in relation to the decile rating allocated to the school involved. NEMP also undertakes an analysis in relation to decile ratings. The results of these analyses are detailed below.

TIMSS: correlations with SES

TIMSS-94/95 and 98/99 data confirm that the number of books in students' homes is associated with science achievement at both Year 5 and Year 9. The Pakeha/European students were the group with the largest proportion of students reporting that they had more than 100 books in their homes and Maori and Pacific groupings have the largest proportion of students reporting that there were 10 or less books in their homes (Martin, 1997p 144). TIMSS data indicate higher numbers of books in the homes of New Zealand Year 5 students than for all but two other participating countries.

A significant relationship between students' achievement and parents' education was found at Year 9 TIMSS-94/95. Those students who indicated that their mother or father had attended university, college of education or polytechnic achieved higher science scores on average than students who reported that their parents did not attend a tertiary institution. Likewise, those students who had higher aspirations for future education showed greater achievement. The Year 9 students in 1998/99 reported higher educational aspirations than their Year 9 counterparts four years earlier. Asian students were more likely to aspire to go to university than students in the other three groupings, while Maori were more likely to report that they did not know what their future educational plans were.

For TIMSS-98/99 an index of student's Home Educational Resources was constructed to summarise students' responses to questions on the number of books in their home, the number of educational aids in their homes (computer, study desk, dictionary), and their parents' highest level of education.

- Students who were categorised as high on the index reported having at least 100 books, three core study aids in their home, and that they had at least one parent who had completed university.
- Students categorised as low on the index reported 25 or fewer books in the home, did not have all three core study aids, and indicated that neither parent finished secondary school.

For the 35 countries where it was possible to compute the index, only 12 were found to have at least 10 percent of students categorised as high on the HER Index, including New Zealand with 18 percent. The difference in mean achievement scores for those students high on the index and those categorised as low was more than 100 scale points (Chamberlain and Walker, 2001, p85).

A similar range of achievement is evident when the Year 9 achievement data was analysed in terms of the decile rating of the schools attended by the students involved. Table 3.12 shows the mean science scores of year 9 students according to decile rating.

Table 3.12 Year 9 students' mean science scores in 1994 and 1998, by TFEA[4] decile band

Schools' TFEA decile band	1994		1998	
	% of students	Mean science score (s.e.)	% of students	Mean science score (s.e.)
Low (deciles 1-3)	25	470 (8.0)	18	471 (11.0)
Medium (deciles 4-7)	50	508 (5.9)	48	498 (6.6)
High (deciles 8-10)	21	556 (8.8)	30	544 (7.5)
No TFEA indicator (ie, private schools)	4	554 (22.0)	4	558 (8.7)

Within each decile band, there was no statistically significant difference in the mean science scores achieved by students in 1994/95 and 1998/99. Chamberlain and Walker (2001) indicate, however, that although there are associations between the socio-economic status of the community and the science achievement of students, there are high and low achieving students throughout all types of schools and communities.

NEMP: Correlations with SES

NEMP also analyses student performance in relation to a socio-economic index using three groups: bottom decile 1-3; middle decile 4-7; and top decile 8-10. Statistically significant differences between decile groups at Year 4 were evident in 20 of the 37 tasks (1995) and 30 of the 56 tasks (1999), with performance lowest for students in the low SES group. In year 8 there were significant differences among the three subgroups on 22 of the 39 tasks (1995) and 34 of the 54 tasks (1999). While students from high decile schools generally did better than students from medium SES schools, these differences were usually smaller than the differences between students from low and medium SES schools. This finding differs from the TIMSS –98/99 results at Year 9 which found no difference in mean achievement between low and medium decile schools but a significant difference in mean achievement between high decile school and with both medium and low decile schools.

3.4.3 Language and communication

TIMSS –94/95 indicated that students who are less familiar with the language of instruction are more likely to be achieving poorly in science. Table 3.13 shows year 5 students' mean science scores by ethnic group and by degree of English spoken in the home. In Year 5 there was a clear advantage in science achievement for those students who said they spoke English "always or almost always" at home (a 16 percent difference). There was a similar result at Year 9, where there was a 12 percent difference for students who spoke English at home on a frequent basis

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[4] Targeted Funding for Educational Achievement

(Chamberlain, 1996). An interesting result in the repeat TIMSS-98/99 at Year 5 was the significant increase in science achievement by students who reported that English was spoken only rarely at home (see Table 3.13).

Table 3.13 Year 5 students' mean science scores in 1994 and 1998, by the degrees that English is spoken in the home and ethnic grouping

Home language grouping	Mean science scores (s.e.)			
	Pakeha/European	Maori	Pacific	Asian
1994				
Always/almost always	539 (3.7)	471 (12.4)	477 (15.4)	547 (21.3)
Sometimes/never	445 (14.4)	411 (14.6)	389 (20.2)	459 (16.1)
1998				
Always/almost always	544 (4.9)	488 (7.3)	468 (14.7)	534 (18.5)
Sometimes/never	481 (17.0)	426 (14.2)	405 (16.4)	509 (11.2)

In TIMSS-98/99 more than half of the New Zealand Year 9 Asian students and two-fifths of Pacific students reported that they only "sometimes" or "never" spoke English in their homes (these students account for about 7 percent of the entire Year 9 population). These figures are similar to TIMSS-94/95, although the figure for Pacific students has increased from 34 percent to 40 percent. Given that students who had very limited English were excluded from the testing, fluency in the language of instruction is clearly a factor that is associated with lower mean achievement for Maori, Pacific and Asian students, with the results being statistically significant for the latter two groups. (Chamberlain and Walker, 2001, p81). Unlike the change evident in the Year 5 sample, at Year 9 the language of instruction is still clearly a factor associated with lower mean achievement for Maori, Pacific and Asian students. Interestingly the PISA results indicate that New Zealand has the fifth highest (5/32) proportion (10 percent) of students who do not speak the language of the test at home. The impact of this on achievement has yet to released but will need to be analysed in the context of these findings from TIMSS.

There is also some evidence that it is not only students for whom English is not commonly spoken in the home who struggle to communicate their ideas in science. Garden (1997a) commented that a shortcoming common to both age groups in TIMSS-94/95, which was also apparent across countries, was an inability to write clear explanations or to write clear descriptions of processes, even when they had been carried out successfully (in the case of performance assessment). He suggested that "for students to do these things they must obviously have been exposed to, and mastered, the needed technical vocabulary, and had practice in using it in both oral and written work" (Garden, 1997a, p. 107). This issue is discussed again in section 3.6 of this chapter and again in more detail in Chapter Seven.

3.4.4 Class/teacher influence on student achievement

There is mounting evidence for the importance of instructional effects at the class/teacher-level on student achievement (Rowe, 2001). Rowe argues that one of the more significant studies regarding the importance of class/teacher effects was that of Scheerens *et al.* (1989). The study presented the findings from a secondary analysis of data from the Second International Mathematics Study which compared class/teacher and school-level effects once the scores were adjusted for fathers' occupations. The findings indicated that for eight of the nine countries in which between-class/teacher information was available, estimates of the contribution of class/teacher effects on students' achievement exceeded 40 percent, while school effects were significantly smaller, ranging between 0 percent-9 percent. The New Zealand results were 42 percent class/teacher effects and 0 percent school-level effects.

Information relevant to this review about schools, classes and teachers, elicited from the TIMSS and TIMSS-R, is described below.

School factors: Class size

Student achievement is often attributed to the effects of class size, school size and school type. The study undertaken by the Education Review Office (2000) however, found no conclusive evidence that these factors explain the significant differences in achievement between Ireland, the Netherlands, Korea, Singapore and New Zealand as measured by TIMSS-94/95. Further, as suggested by Chamberlain and Walker (2001), issues such as the relationship between class size and achievement is difficult to disentangle given the variety of policies and practices operating in these countries, and the fact that smaller classes can be used for both advanced and remedial learning.

In an attempt to seek evidence of what might influence student achievement TIMSS investigated a number of factors, such as the time spent learning science, a related issue - the frequency of outside interruptions during science lessons reported by students, and the amount of homework completed by students.

School factors: Time spent teaching science

TIMSS-94/95 Year 5 teachers in New Zealand reported spending 5-6 percent of their time teaching science (mean number of minutes/week = 81.3). Most other TIMSS countries, reported more teaching devoted to science. In ten countries the median time allocated was at least twice that for New Zealand (Garden, 1997a, p 210). TIMSS-98/99 found that in most countries where science is taught as separate studies in Year 9 there were over 150 hours of science instruction per year, and many had over 200 hours. In contrast, in countries where science is taught as a single subject, the total science instructional time ranged from 65 hours in Tunisia to 252 in the Philippines, with many countries reporting between 90 and 150 hours (New Zealand: 131 hours).

The Educational Review Office has been critical of the time spent teaching science in the primary sector. ERO (1996) reports that the allocation of an average of one hour or less to science a week (evident in 19 of the 70 schools investigated) was insufficient to enable coverage of the curriculum and the development of the appropriate skills. This concern was echoed in a later publication, *In Time for the Future,*(Education Review Office, 2000) which reported that New Zealand teachers spend less time teaching science than do teachers in Singapore and Korea, once science appears in their curricula. However, it was pointed out that the time given to teaching science was not consistent in the Netherlands or Ireland, and there was no indication that differences in instruction time could explain any of the differences between the achievement levels of primary students in New Zealand and these two countries (p 68). The researchers did find that New Zealand is the only country in the study where science is taught in blocks of time each term, rather than every week (ERO 2000, p 69) and the impact of this on learning science might be worth exploring further.

School factors: Interruptions

It is not only the amount of time *allocated* to science teaching that might be important but also the amount of time *realised* teaching science. TIMSS-98/99 found that on average internationally, 23 percent of students in the general/integrated science countries reported interruptions to class “pretty often” or “almost always” and this was the case for one-third or more of students in Jordan, New Zealand, the Philippines, and South Africa. Less frequent interruptions were reported in countries with separate sciences. Among all the countries, more than half the students in Hungary, Japan, Korea, and Tunisia were in science classes that were never interrupted. Internationally, the frequency of interruption appears to be related to achievement, both for general/integrated and separate sciences. While students who reported interruptions “once in a while” or “never” had similar achievement, they tended to outperform those who reported interruptions “pretty often” or “almost always” (Martin *et al.*, 2000, p210-211). New Zealand results indicated that lessons were interrupted “pretty often” by 24 percent of the students and “almost always” by 13 percent.

Teachers: Experience and qualifications

It is often hypothesised that teaching performance improves with experience but the TIMSS-94/95 data at the Year 5 level found no significant direct relationship between teaching experience and student achievement (Chamberlain, 1997, p181). However, it was noted that teachers who had been teaching the longest tended to have the lowest scoring students. Chamberlain suggests that this could be the result of low achieving students being allocated to experienced teachers or that teacher effectiveness peaks some years before retirement. Similarly, no direct relationship was found between the general qualifications of teachers in Year 5 and their students' achievement in science but there was a significant positive relationship at the Year 9 level. There have been concerns expressed about teacher knowledge (see Task Force report, Ministry of Education, 1997) and it was an issue highlighted in *In Time for the Future* (ERO 2000). This report identified a number of strategies for improving the teaching of science, especially in primary schools; for example, and included were teachers' subject content knowledge and science education pedagogical content knowledge.

Teachers: Emphasis on scientific reasoning and problem-solving

TIMSS-98/99 did make an attempt to determine the value teachers at Year 9 placed on approaches designed to enable their students to use higher-order thinking skills, scientific reasoning and problem solving activities. An index of teachers' emphasis on scientific reasoning and problem solving was created based on teachers' reports about how often they asked students to:

- explain the reasoning behind an idea;
- represent and analyse relationships using tables, charts and graphs;
- work on problems for which there is no immediately obvious method of solution;
- write explanation about what was observed and why it happened;
- put events or objects in order and give a reason for the organization (Martin *et al.*, 2000. p 22).

On average internationally, 16 percent of students had teachers who placed a high emphasis on scientific reasoning and problem solving, with a range from 4 percent (New Zealand and Belgium) to about one third in Japan and the Philippines. While the emphasis on scientific reasoning and problem solving was associated with achievement in some countries, there was no strong or consistent relationship across countries. It must be of some concern, however, that New Zealand teachers place such a low value on such approaches.

Teachers: emphasis on scientific investigation

In order to measure the emphasis placed on scientific investigation, TIMSS-98/99 developed an Emphasis on Conducting Experiments in Science Classes (ECES) Index. It was based on responses from both teachers and students to questions about conducting experiments in science lessons. Internationally on average, 38 percent of students in countries with general/integrated science had classes with high emphasis on experiments, with a range from two percent in Italy to 78 percent in Hong Kong. Fifty-two percent of New Zealand students were being taught science where there was a high level of emphasis given to conducting experiments in science.

Teachers: Confidence in science teaching

TIMSS-98/99 also investigated teachers' confidence by asking them how well prepared they felt to teach each of the 10 science topics. New Zealand Year 9 teachers reported that they did feel confident (29 percent very well prepared; 53 percent somewhat prepared; and 19 percent not well prepared). When comparing this, for example with teachers in Singapore, a country whose students achieve very highly in TIMSS (18 percent very well prepared: 44 percent somewhat prepared: 38 percent not well prepared), it appears that New Zealand teachers may have a confidence not supported by their actual practice.

- Internationally, teachers were most confident in their preparation to teach biology topics, with more than 50 percent of students having teachers who reported feeling very well prepared to teacher these topics (New Zealand 70 percent and Singapore 52 percent).
- Teachers had less confidence in their preparation to teach earth science topics (New Zealand 44 percent; Singapore 13 percent), particularly about the solar system and the universe, for which only 32 percent of students had teachers who felt they were well prepared to teach it (New Zealand 43 percent: Singapore 11 percent).
- Between 45 and 51 percent of students across countries had teachers who reported feeling very well prepared to teach chemistry or physics topics (New Zealand Chemistry topics rated 74 percent and 62 percent: Singapore 63 percent and 57 percent: Physics topics rated New Zealand 62 percent and 56 percent: Singapore 58 percent and 57 percent).
- This compares with 39 percent of teachers feeling well prepared for environmental and resource issues (New Zealand 47 percent: Singapore 30 percent) and 34 percent for scientific methods and inquiry skills (New Zealand 61 percent: Singapore 35 percent) (Martin *et al.*, 2000, p 203, 310 & 311).

3.5 Summary of sections 3.1, 3.2, 3.3 and 3.4: Key findings from TIMSS and NEMP

The analyses of the TIMSS and NEMP studies in sections 3.1 to 3.4 provide very useful indicative information about student achievement and signal areas for further investigation. The major findings from these studies are summarised below, with key themes indicated in boldface.

3.5.1 Overall achievement

While there is an overall improvement in achievement relative to that of many other countries through the years of schooling it is of some concern that the TIMSS results of 98/99 indicate relatively little change in the performance of Year 5 and Year 9 students. As pointed out by

Knight (2001) this result differs from that of Australia and Canada where there was a marked improvement at the Year 9 level over the four years (from TIMSS-94/95 – 98/99).

- **New Zealand students appear to have relative strengths in scientific inquiry, although there is a need to improve their knowledge of planning and giving scientific explanations for the results of their investigations. The physical sciences are an area of relative weakness.**

- **The achievement of the lower quartile (as measured for Year 9 in TIMSS-98/99) is also of concern but further information is needed about the composition and attributes of this group before any solutions can be proposed about strategies for improving their performance in science. It is likely, however that as language related skills are key factors that influence science achievement, more information about the literacy skills of these group of students would assist in the identification of approaches that might improve performance in science.**

In addition, the PISA results indicate that New Zealand has a wider distribution of scores than many other high performing countries and that this spread of scores is generally wide within individual schools. Further analysis is required to determine the factors that are influencing poor achievement, including probing into the responses given by the lower achieving students in order to determine the actual weaknesses with respect to the knowledge and skills assessed within the context of scientific literacy.

3.5.2 Gender and science achievement

There is mixed evidence regarding the achievement of girls and boys in relation to science. The NEMP data at both Years 4 and 8 indicates a bias in favour of boys, as do the TIMSS results in the final year of schooling. In contrast, the TIMSS data at Year 5 in 94/95 indicated a bias towards girls but this bias was no longer evident in 98/99. While the greatest improvement was evident with Maori boys there were small increases in the differential between boys' and girls' mean achievement in all groupings. At the Year 9 level the opposite has occurred with the bias in favour of boys of 94/95 no longer evident in 98/99. It is the less positive attitudes of girls to science, and the apparent decline in positive attitudes from year 5 to year 9 that is most obvious for girls that are, however, issues of concern as is the fact that they are less likely to see themselves as a scientist. Similarly, the relatively poorer improvement in achievement for girls than boys over the four-year period from TIMSS-94/95 – 98/99 is of significance and needs to be taken into account when seeking solutions for improving overall achievement.

3.5.3 Ethnicity and science achievement

Key issues emerging from these results are: the improvement in performance of Maori students; and the lack of change for Pacific students who continue to achieve relatively low mean scale scores. The improvement over time of Maori students, evident at both Year 4 and Year 8 in NEMP and at Year 5 in TIMSS, particularly for boys, merits further investigation. The results of a few more cycles of the science monitoring will be required to indicate if there is, indeed, an actual effect.

- **While achievement of Maori students may be, in general, lower than other students, this is not reflected in their attitudes to science. Also, Maori students in immersion settings have a clearer sense of identity with regard to being a scientist.**

- **Immersion students reported that their school programmes included higher levels of field trips, visits to science activities, and experiences with everyday things.**

- **Since there is commonly a link between attitudes and achievement, working to improve achievement through continuing to foster positive attitudes to "doing science" would be a constructive approach.**

3.5.4 Socio-economic factors and science achievement

Using a range of measures of socio-economic status, the TIMSS and NEMP evidence clearly points to an association between low socio-economic status and poor performance in science in school. It is difficult to explain the difference between the NEMP findings which suggest a bigger difference in performance between students in mid and low decile schools than between high and medium and TIMSS, which found the biggest difference between high and medium decile schools. However, it should be remembered that while NEMP studies are within the primary sector, the TIMSS results that give the finding reported above were elicited from Year 9 students in their first year in secondary school. The way decile relates to achievement in the secondary sector may be different from primary. The difference in the findings of the two studies may also be the result of different assessment approaches used. Students complete NEMP tasks in a supportive, small group environment which may enable students to more successfully access the knowledge they have. Assuming that students in mid decile schools are more likely than students in low decile schools to have had every day experiences that provide them with science knowledge the NEMP approach may work to assist those in the mid decile schools to improve their performance. The assessment approach of TIMSS is rather more of a blunt instrument and so makes it more difficult for students who are less confident with this more formal, impersonal approach to access the full extent of their science based knowledge. Section 3.6 provides a further examination of the degree to which the different assessment task formats used in NEMP and TIMSS can elicit what students know or can do in science.

- **Notwithstanding this difference, the differential in performance between low, mid and high decile school students is important. It may be that differences in background experience of students are a primary factor.**

The *Competent Children at 10 Project*, which has tracked more than 500 students from early childhood through primary school, also identified poorer performance of low-income students (in Mathematics, PAT Reading Comprehension, and writing). The associated analysis suggests that lower levels of maternal education, and few experiences of the kind which use and extend language and mathematics, are the factors that make the difference (Wylie, Thompson and Lythe, 2001).

Interestingly, children in low decile schools in this study also found school more interesting (as students in NEMP at Year 4 1999) – but more challenging – and the researchers suggest that this may result from school being so different from their home experiences.

- **Overall, it appears that it not socio-economic status per se, but factors associated with home resources and background experiences, which may affect students' achievement in science.**

3.5.5 Language related issues and science achievement

TIMSS does indicate a correlation between lower achievement levels in science and home language different to school language. Again, the significant improvement of Year 5 students from 1994/95 to 1998/99 is difficult to explain, although during this time there has been considerable ESOL support for schools and teachers who have students categorised as having English as their second language.

- **There is also the more general issue of the inability of students, across all age levels, to write clear descriptions and explanations, even in cases where task performance had been carried out successfully.**

This may appear perplexing in the light of stronger corresponding reading results generally (Garden, 1997). This issue is explored in some depth in the following discussion (3.6) as well as in Chapter Seven.

3.5.6 School/teacher effects and science achievement

The time allocated to science, particularly in the primary school appears to be one factor limiting students' development of an understanding in science.

- **The common practice of teaching science in blocks of time in the primary school, rather than on a more frequent basis, also may influence performance.**

The qualifications of teachers is a factor at the year 9 level, but more information would be needed before any conclusion was drawn from the lack of correlation found in TIMSS 94/95 at the Year 5 level.

- **The finding that New Zealand Year 9 teachers appear to place a rather low value on providing opportunities for their students to use reasoning and problem solving skills is an issue.**

- **Similarly, while confidence does not necessarily link to actual knowledge, the relative lack of confidence of Year 9 teachers in their ability to teach earth science, physics, environmental and resource issues and scientific methods and inquiry skills also needs further investigation.**

3.6 Interpreting New Zealand students' performance in TIMSS and NEMP: Implications for raising achievement and reducing disparity

The TIMSS and NEMP analyses in the first five sections of this chapter have outlined some of the major issues to emerge in studies of New Zealand students' recent science achievement. These analyses clearly indicate issues that require further attention. However, as suggested by Knight (2001) and implied in the sections above, there are also some significant limitations in the depth of analysis that have been undertaken with the TIMSS data in New Zealand. We suggest that additional dimensions of analysis are required. These dimensions would involve unpacking, *in detail*, what New Zealand students' responses to TIMSS and NEMP tasks reveal about:

- students' specific strengths and weaknesses in decoding, comprehending, and responding correctly to science test questions, particularly for those students who are achieving at the bottom end of the scale; and
- how these strengths and weaknesses might be addressed through changes to New Zealand science education policy and practice.

This section reviews research that considers how the data from international comparison studies such as TIMSS might be re-analysed to address the two points above. Two local studies reviewed below, one investigating students' responses to NEMP tasks (Eley and Caygill, in press) and one investigating New Zealand students' responses to TIMSS test items (Harlow, 2000) indicate that a great deal of value would be gained from such analysis.

3.6.1 Analysing international achievement data for localised contexts

There is little argument that from a technical perspective, the TIMSS written achievement tests provide reliable information about educational achievement but many science education researchers (see Gipps, 1994; Goldstein, 1996; Atkin and Black, 1997; Noack, 1999; Harlen, 1999b) have questioned the validity of these studies. Jenkins (2000) suggests that:

> No international comparison of student achievement sheds much light on how well students within a given educational system understand the science or mathematics taught to them within their own educational system (Jenkins 2000 p. 138).

In other words, any meaningful evaluation of student achievement needs to involve an analysis of student performance in relation to a nation's or a culture's own mission and goals and international differences are much less important than a detailed understanding of what lies behind them. Literature from other countries which have sought to improve their science achievement performance in the wake of international comparative studies such as TIMSS indicates that:

- there is a lack of international consensus about what constitutes achievement in science;
- standardized goals and prescriptive curricula do not result in higher achievement; and
- many countries are redeveloping curricula and involving teachers in the development of science education goals.

The lack of international consensus about what constitutes achievement in science

In a study that investigated the consistency of findings between TIMSS and another international survey, the Second International Assessment of Educational Progress (IAEP2), O'Leary, Kellaghan, Madaus, & Beaton (2000) proposed a number of hypotheses in an attempt to explain why the average science achievement for Irish 13 year-olds was reported at the low end of the distribution representing the 20 participating countries in IAEP2, while it was around the middle in TIMSS. As the achievement pattern was more consistent in the two studies in mathematics they suggest that at the international level there is greater consensus about what constitutes achievement in mathematics than there is in science. This position is supported by Hamilton, Nussbaum, Kupermintz, Kerhoven, & Snow (1995) whose analysis of a large scale national test suggested that "achievement patterns in science were much more heterogeneous than in math" and that "in science, a far greater number of factors was required to account for student performance differences" (Hamilton *et al.,* p. 577, cited in O'Leary *et al.* 2000).

Standardized goals and prescriptive curricula do not result in higher achievement

In an attempt to promote student achievement a number of countries have developed relatively prescriptive curricula. However, Atkin and Black (1997) found no evidence to support the idea that a country with nationally prescribed standards fared better in the international arena than one with no such guidelines. Further, they argue that while some have ascribed mediocre student performance to the lack of standardisation of the goals of science education, the TIMSS results indicate that "it is by no means clear from experience in other countries that the vision need be a 'single' one or national in scope" (Atkin and Black, 1997, p. 27).

Redeveloping curricula and involving teachers in the development of science education goals

In seeking strategies to improve achievement it is important to be mindful of the fact that no country is satisfied with the condition of its existing programmes of science education, even those who score near the top in the comparisons of educational achievement (Atkin and Black, 1997). For example, Japan and Germany, as well as a number of other countries, are concerned about social and community-based issues and have developed new curricula designed to educate students about the importance of protecting natural resources. Similarly some countries, including Japan, have viewed their students as lacking in creativity. Their reforms call for schools and teachers to encourage problem solving and original investigations. Atkin and Black maintain that "virtually everywhere, the curriculum is becoming more practical. Topics are chosen that have an impact on the daily lives of the students and the communities in which they live" (Atkin and Black, 1997, p. 23) They suggest that an emphasis on practical work and applications has led several countries to pursue innovations that utilise cross-disciplinary approaches, often called *integrated science*.

Atkin and Black (1997) identify one common element across nations in successful educational improvement: "teachers are deeply involved in figuring out what high quality science education actually looks like at the classroom and school levels if significant change is to take root" (p. 28). They cite both Japan and Germany where teachers are expected to, and do, take the opportunity to meet with other teachers to deliberate about the kind of science education they believe is best for the students.

The major message from these commentaries is that data from international comparison studies are of most benefit when they are examined in relation to a country's own mission and goals for science education, and matched to the needs and abilities of students and communities of that country. Furthermore, research and analysis is required to identify the factors contributing to achievement so that specific strategies can be designed and implemented to support students' learning in science. Examples of studies already undertaken in New Zealand include one that investigated students' responses to NEMP tasks and another that reviewed responses to TIMSS test items. These are described below.

3.6.2 New Zealand students' responses to NEMP tasks

Eley and Caygill (2001; in press) conducted a study to investigate the appropriateness and effectiveness of different assessment formats used in NEMP. The researchers constructed parallel versions of NEMP science and math assessment tasks so that the same tasks could be assessed using more than one format. The formats used were: multiple choice, short written answer, written answer with supporting resources (stations), and one-on-one interviews. A sample of 258 Year 8 students from five schools participated in the probe study and student performance on the different formats were explored on a task-by-task basis. Eley and Caygill found that there were substantial differences in student performance in each format. Table 3.14 shows the number of questions for each format in which more students answered correctly in that format (numerator) compared to the total number of questions asked in that format (denominator).

Table 3.14 Number of questions per format where students performed better (Source: Eley and Caygill, in press)

Task format	One-to-one	Stations	Short answer	Multiple Choice
Student performance	31/51	5/45	2/22	8/16

As shown in the table, Eley and Caygill's study indicated that:

- **More students were scored as answering questions correctly in the one-on-one format than in any other format.** Students were generally given higher scores for the quality of their explanations in this format. Eley and Caygill note that in this format, teachers read the task to students, compared to all other formats where students had to read the tasks themselves, thus eliminating reading ability as a factor in the one-on-one format. Eley and Caygill also suggest that students' better performance in this format was due to teacher clarification of students' unexpected responses and probing of incomplete answers, and the use of non-verbal cueing which encouraged students to extend their answers.

- **Students did worst in the short answer format.** This format gave students the least support, compared to other formats in which either the teacher, or the presence of equipment, pictures, or the availability of fixed choices, provided students with a form of scaffolding to answer questions.

- **Students did second best in the multiple choice format.** Interviews with students indicated that for any particular questions, up to one quarter of students said they had used the given multiple choice answers to work out or guess the correct answer.

In order to examine what type of questions suited specific task formats, Eley and Caygill developed a method for categorising the questions used in the study according to the science and math processes and skills they were examining, and examined student performance in each category against task format. They found that students generally performed better on *Experiment/Investigate* questions when they were administered in the one-on-one format. A similar finding was made with

Compare/Justify/Explain questions and *Compare/Contrast* questions. However, the one-to-one format was not always the best for every question. Questions which required students to recall knowledge were answered best in multiple-choice format, unless answers required extended written answers or complex explanations, (in which case students did perform better in the on-on-one format). These findings suggest that questions which require students to produce an explanation or evidence for their choices are most successfully completed in the presence of immediate feedback from the teacher/interviewer.

Eley and Caygill conclude that, in determining which assessment format to use, a consideration of the type and purpose of the information to be gathered is necessary, and that:

> …the greater the complexity of information we wish to gain from assessment, the greater the investment required to gather that information adequately. (Eley and Caygill, in press)

3.6.3 New Zealand students' responses to TIMSS test items

Harlow (2000) undertook a study to investigate the processes underlying New Zealand students responses to TIMSS test items. The study involved a sample of 181 Year 8 students who completed paper-and-pencil TIMSS science assessment tasks. The written test was followed by an interview of 38 students with the aim of testing the validity of using written test items to explore the students' scientific understanding, and to find out the prior knowledge students were bringing to the assessment situation.

Harlow reports that the TIMSS items are not, on their own, a valid test of students' science knowledge. This study demonstrated that valuable insights can be gained about students' ways of thinking by analysing the verbal explanations of their written test answers, and provided evidence that the test items were not always eliciting the knowledge held by the students. Overall it was found that the additional information elicited from the interviews resulted in students' scores increasing in three content areas (*Earth Science*, *Life Science* and *Physics*), remaining the same in one area (*Chemistry*), and going down in another area (*Science and Environment*). The two areas where scores remained the same or decreased were areas where the items contained information which was generally unfamiliar to the students and may not have been taught at this level. A breakdown of these results indicated that of the 24 items tested, the average percent correct scores went up for 14 items, remained the same for 3, and went down for 7 items. This means that:

- for 58 percent of the items in the test, students had more knowledge than they wrote in their written responses;
- for 29 percent of the items, students who had the "correct" written response did not have a complete understanding of the concept being assessed; and
- only 13 percent of the items actually elicited the knowledge held by the students in the middle school interview sample.

The study found that a correct written response did not always mean complete understanding of a concept. It has long been acknowledged that there is always a chance for the process of elimination or simple guesswork to be used in the answering of multiple-choice items (Black, 1998). Some studies have shown that up to a third of pupils who choose a correct response in a multiple-choice question may do so for the wrong reason (Tamir, 1990). Harlow's study also highlights that incorrect responses were not necessarily an indication of a lack of knowledge of a concept. Sometimes incorrect responses were due to misinterpretation of a question, a word, a phrase or a diagram and at other times they were an indication of poor reading skills or lack of English vocabulary.

Harlow found, for example, that in one of the free-response questions, which asked students to select one of three options, thirteen of the thirty-six students had misinterpreted the question. Free-response items are more flexible than multiple-choice items and are used as they allow for assessment of knowledge, reasoning and skills at various levels of complexity but as Black (1998, p. 84) argues, "the need for clear guidance and sharply focused questions remains, and ambiguity in the demand can still destroy the value of the questions." Harlow found that there were indeed cases where the students' interpretation of the language in a test question led them to think in unintended directions. Box 3.1 illustrates an example from Harlow's study.

Box 3.1 Student responses to a TIMSS test item. Source: (Harlow, 2000)

The TIMSS question:
What could be the unwanted consequences of introducing a new species to a certain area? Give an example.

Students responses*:*
What could be the unwanted consequences was correctly understood as meaning something unpleasant or not desirable that happens as a result of an action. But students were confused about the notion *of introducing a* ***new species*** *to a* ***certain area.*** They understood the term *introducing* to mean bringing into or placing in, but *new species* was misinterpreted in the following ways to mean:

- a man-made or genetically modified living thing;
- an alien;
- a living thing that had not previously lived in this place;
- an Asian boy thought the word *species* was *spices*.

Likewise *a certain area* had different meanings for different students:

- an enclosed space like a zoo, cage or an aquarium;
- a certain area or place within a larger area.

At the end of this question came the instruction: *Give an example*. This instruction did not provide a clear direction for the students who went in many and varied directions depending on their interpretation of the question combined with their interpretation of this statement.

This question was one of several which utilised a partial credit-scoring scheme. For this question in the study, 59 percent of year 8 students were given a "correct" or "partially correct" response, but only 19 percent were given the fully correct response code. The "fully correct" scores on this item for those in the interview sample rose from 24 percent in the test to 58 percent in the interview, again indicating that the written responses did not reflect the true level of knowledge held by the students.

In the case of this question, the students had often misinterpreted the question/instructions and some had not read the item as a whole and so did not realise that the statement *give an example* also needed to be answered. Others had difficulty with interpreting the meaning of the written words in the question but when the question was read out in the interview situation they realised the correct answer immediately.

Harlow's study provides evidence that word knowledge is important when considering achievement on free-response items. If the students do not understand the words used in the test item they are unlikely to be able to construct a correct answer. This finding coincides with those of other studies (Wang, 1998; Lokan, Adams and Doig, 1999). Chapter Seven of this report reviews a large body of research that has resulted, over the last three decades, in progressively richer description of a range of reasons why school students experience difficulties in relation to word-knowledge. This research, when combined with findings such as those reported by Harlow, strongly suggests that language issues are deeply implicated in the achievement patterns that emerge from national and international assessment programmes such as NEMP and TIMSS (see section 3.5.5)

In Harlow's interviews there were several instances where a student's interpretation of the demand of the question had a strong influence on the overall outcome. Black (1995) also gives several examples of this in his discussion of the limitations of national surveys of pupils' performance, and warns that one question on a key science concept or process, such as ability to design an investigation, cannot give a reliable result. One such question used in Harlow's study asked the students to design an investigation into how the human heart rate changes with changes in activity. Some students answering this item thought it was about a medical procedure. Harlow discovered during the interviews that the students had actually conducted an investigation similar to the one intended in class but were thrown by the phrase "human heart rate" and their conceptualisation of the problem.

Harlow's study also matched findings reported by Harlen (1996) that written words and diagrams may not recall to the child the same real events as those intended. One question, for example, showed a diagram of a farm on a plain which some students thought was a narrow valley, and another showed plants in an aquarium which some students thought would be made of plastic (Harlow, 2000).

Word-knowledge or recognition is likewise important for multiple-choice items. When a student thinks a word says one thing and chooses an answer based on this understanding, the response may be incorrect even though the student has a good understanding of the concept being assessed. An example of this was an item which required the completion of this sentence: "The source of energy for the Earth's water cycle is the…." Answer choices were: a) Wind, b) Sun's radiation, c) Earth's radiation, or d) Earth's gravity. Seven out of thirty eight students read "rotation" for "radiation", and knowing that heat was involved they chose Earth's radiation as the answer because they thought that "Sun's radiation" said "Sun's rotation".

The interview situation also revealed that when students were faced with unfamiliar items they resorted to guessing, although this was usually tempered by a process of elimination and "key-word" thinking. These approaches were evident in the way students gained a correct response in the multiple-choice items without having the understanding of a concept. Students employed a process of elimination by discounting the familiar options that did not fit what the student perceived to be a possible choice, and selecting a remaining unfamiliar option which happened to be correct. Of course, a student who does have an understanding of all of the options may also employ this process as a means of checking accuracy. Similarly, students who recognised a word or a part of a word in the item often linked their response to their understanding of this word. This "key word" approach is illustrated by the student responses to the item that asked: "What is the main function of chloroplasts in a plant cell?" Few students on interviewing could recall having learnt about chloroplasts, yet 66 percent of the students being interviewed had chosen the correct answer. Of these, five students had linked the word "chlorophyll" or the "chloro" part of that word with the unfamiliar word "chloroplasts" as in this example:

> I think I've heard "chloro" in another word, but I've forgotten. That was about "chlorosynthesis" or something like that. It's when in the Fall the leaves don't make as much food or whatever to feed the leaves because of the Sun not being out as much and that's why the leaves fall (Harlow 2000, p. 119)

Harlen (1996) also noted that children would link new and previous experiences by finding a connection between words, a property of the objects, or by a scientific link. In this case the student had made a scientific link. Although she did not recall the words "chlorophyll" or "photosynthesis" correctly, she showed an understanding of part of the photosynthetic process.

Thus a number of aspects of Harlow's TIMSS study provide support for previous international literature that has reported on the key role that language plays in analysing student achievement in science. Similarly, the difference between reading and verbal communication in an assessment task is indicated as a major factor in Eley and Caygill's NEMP study. Students' better performance in a one-on-one format was attributable in part to teacher clarification of students' unexpected responses, teacher probing of incomplete answers, and the use of non-verbal cueing which encouraged students to extend their answers.

3.6.4 Examining the TIMSS test items to inform effective pedagogy: indications of areas for improvement

All the international and New Zealand studies of students' responses to science assessment tasks reviewed above indicate that local, contextualised re-analyses of data from studies such as TIMSS and NEMP can provide powerful indicators of specific areas where New Zealand students may encounter difficulties in these tests of their science knowledge and skills. Further studies such as these may be useful to examine the precise nature of the difficulties encountered by particular sectors of the student population.

One potentially informative way of re-analysing the TIMSS data would be to re-categorise the test items in ways other than using the reporting and content category codes employed by the TIMSS test designers. For example, students' performance on test items could be analysed according to the main kind of knowledge, skills or relevant background experiences that students would be most likely to draw on to answer the questions. For example, our preliminary analysis of released TIMSS test items suggested the following typology could be used to classify the questions:

In order to answer this question, students are most likely to need:

1. the ability to interpret information (e.g. from a graph, table, diagram) or to use simple reasoning[5]; or
2. relevant background knowledge and/or experiences, that are just as likely to have been acquired outside the science classroom as inside[6]; or

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[5] An example is given in appendix D

3. to know specific science facts or concepts and be able to apply them to a given question[7]

One feature of this method of categorisation is that it cuts across the content reporting categories (e.g. Earth Science, Physical Science, Life Science) used for the analyses described in the first four sections of this chapter.

Using the categories to classify the released items used in TIMMS-94 and TIMSS-98 with Year 5 students, we judged that:

- approximately 20 percent of the items fell into the first category;
- approximately 50 percent of the items fell into the second category; and
- approximately 30 percent of the items fell into the third category.

The high proportion of questions in category two suggest that at this level, TIMSS is often a test of children's general knowledge and experience of their natural and physical environments. This finding may provide some explanation for why students in countries such as the Netherlands do relatively well in TIMSS at Year 5, when science is not included in the curriculum at this level.

Of the released items used in TIMSS-98 with Year 9 students:

- approximately 15 percent of the items fell into the first category;
- approximately 30 percent of the items fell into the second category; and
- approximately 55 percent of the items fell into the third category.

At this level the proportion of questions that draw on knowledge more likely to have come from studies of science at school has increased. Also noted at year 9 level was a high number of test items related to concepts of energy and energy transfer. An international analysis of TIMSS (Cogan *et al.*, 2001) report that the topics of "energy handling" and "energy types, sources and conversions" are the two most covered topics across the participating TIMSS nations[8]. However, Chapter Four of this review describes a large body of New Zealand classroom research which revealed many difficulties learners encountered when learning about concepts related to "energy".

The TIMSS test items appeared to include several multiple choice questions in which more than one answer could be argued as correct, particularly if a student knows more or is more practised in doing science. An example is given in box 3.2.

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[6] An example is given in appendix E

[7] An example is given in appendix F

[8] 92% of participating countries included these two topics in their curricula.

Box 3.2 Example of a test item in which more than one answer could be validly argued as correct

TIMSS test item P07, Used in TIMMS-R 1998 with Year 9 students

Content category: Scientific Inquiry and the Nature of Science

Q. The primary reason scientists repeat the measurements they take during experiments is so that they can

a) check that the equipment is working
b) list all the results in a table
c) estimate experimental error
d) change the experimental conditions

In this case, the question also rests on students' interpretation of the word "primary". Only 29 percent of New Zealand students answered this question correctly[9].

There are many different ways that the TIMSS data could be re-cut to provide more information on students' difficulties in science. This is a strategy that is being exploited with the NEMP probe studies and there is the potential to undertake similar work with TIMSS.

3.7 Summary of Chapter Three

TIMSS and NEMP in the context of the review

The overall analysis of TIMSS and NEMP given in this chapter suggest some key areas that should be explored in an effort to provide more effective and equitable pedagogy and policy for raising achievement and reducing disparity in New Zealand science education. These key areas need to be set within the context of the intended curriculum as described by *SNZC* (see Chapter Two, section 2.6). These curriculum specifications, and the findings of these national and international assessment studies, provide a frame for Parts II and III – Chapters Five to Nine – as it is these chapters that provide the research evidence of effective practice. A third factor that has been used to frame Parts II and III are the findings of the Learning in Science Projects (LISP). LISP is the only New Zealand example of a large scale, longitudinal research study into the learning and teaching of science. It provided fundamental insights into the complexities of learning science and it identified and investigated a number of pedagogies that were designed to promote the learning of science. Further, the findings were influential in the construction of *SNZC*. The Learning in Science Projects are described in Chapter Four.

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[9] The answer listed as correct is C.

Chapter Four: The Learning in Science Projects and Associated Thesis Research

4.0 Introduction

It is a commonly held view that there was a single Learning in Science Project. But this first project was the first of a series of five projects. These five Learning in Science Projects (LISP), at the University of Waikato, have spanned twenty years. The five projects are listed in table 4.1:

Table 4.1 The Learning in Science Projects

Project	Time period	Focus of research
1. Learning in Science Project (Forms 1-4)	1979–1981	Science learners aged 11-14
2. Learning in Science Project (Primary)	1982–1984	Science learners aged 7-10 and their teachers
3. Learning in Science Project (Energy)	1985–1988	Science learners aged 11-17 and their teachers
4. Learning in Science Project (Teacher development)	1990–1993	Teachers of science learners aged 11-14
5. Learning in Science Project (Assessment)	1995–1996	Teachers and science learners aged 11-14

One of the major themes that dominated these research projects was the goal of researching, developing, and evaluating effective pedagogies to improve learning in science. As all projects were funded by the Department (later Ministry) of Education, this programme represents a considerable investment in research into effective pedagogies in science education in New Zealand science classrooms. Indeed, the Learning in Science Projects research programme is the only New Zealand example of a substantial sustained research programme on effective pedagogies and student achievement. Internationally, the research programme is also unique.

This chapter will describe each of the LISP projects (and related masters and doctoral research) including the major research findings that form a background to the discussions of research in these areas done in the 1990s onwards.

The five Learning in Science Projects, and associated thesis research, have contributed in two ways to our knowledge of what constitutes effective pedagogy in science education. Firstly, the projects have described what these pedagogies are. These descriptive research findings have been an integral part of the research findings as they make explicit, the tacit knowledge of teachers of science. The descriptions have also been written in such a way as to help pre- and in-service teachers put the research findings into practice in the classroom. The second contribution is that of the learning outcome research findings, which are the evaluations of the effectiveness of the pedagogies. This second contribution is less well known. Both of these aspects of the LISP work on effective pedagogy are included in this chapter.

4.1 The Learning in Science Project (F1-4): (1979-1981)

This project was funded by the Department of Education to research science education in Forms 1-4 (Years 7 to 10). The project began shortly after the 1978 Draft Science Syllabus and Guide for students in Years 7 to 10 (Department of Education, 1978) was released to schools. The Department was keen to obtain research information on "what to teach when" in response to the prevailing views of learning at the time, notably learning hierarchies and the Piagetian notion of developmental stages. In other words, the project began by assuming that effective pedagogy in science education was based on the notion of "readiness" for learning science content. This notion was challenged by the findings of the project. The international research context against which the LISP projects were set will be further detailed in later chapters. There were three main phases to the research conducted in the first project description, analysis, and action (Osborne, Freyberg, Tasker, and Stead, 1981).

4.1.1 The First Phase: Perceived problems and difficulties with science education in New Zealand (1979)

The findings of the first (exploratory) phase were documented in a series of thirteen working papers which focused on problems and difficulties associated with experiments, knowledge, topics, the teacher, the learner, process skills, the syllabus, attitudes, classrooms, written resources, and equipment (Freyberg, Osborne and Tasker, 1979). The findings, summarised in the project's Final Report (Freyberg and Osborne, 1982) were:

- Children do find scientific ideas and theories difficult to understand.
- Children have strongly held views about how and why things behave as they do.
- Teachers and students use both science language and everyday language in the science classroom.
- There were problems with the notions of evidence and experiments in promoting conceptual development in science classrooms.
- There were problems in the way the syllabus and associated written resources were formatted and interpreted by teachers.

These findings had a number of important implications for science teachers' pedagogical practice. Because learning science was not something that students could easily do by themselves, some form of input and/or mediation from the teacher was required. Particular aspects which needed to be addressed included: student diversity, progression of science content, teachers' pedagogical content knowledge, learners' knowledge, and science learning activities. The findings about the kinds of language used in the science classroom suggested that the classroom discourse was an aspect of pedagogical practice requiring specific consideration by the teacher. Other questions that were raised related to views of mind, the nature of knowledge, science curriculum aims and purposes, and the teachers' professional knowledge.

4.1.2 The Second Phase: Looking at the problems (1980)

Some of the problems that children encountered in science learning, identified in the first phase of the project, were addressed in more depth in the second phase, namely:

- the existing knowledge students bring to the classroom – "children's science"
- a personal constructivist view of learning.
- the importance of context
- children's classroom experiences and
- children's outlooks on science.

The newly identified theme of children's existing ideas in science was the major aspect of the second phase of the project (Osborne and Freyberg, 1985a). A total of thirteen working papers (Osborne, Freyberg, and Tasker, 1980) and subsequent theses and published articles documented the "alternative" conceptions (meaning alternative to the accepted "scientific" view) held by students on topics such as living, animal, plants, force, energy, particles, friction, gravity, weather, light, electric current, physical change, chemical change, soils, mountains, glaciers, rocks and minerals, and photosynthesis. This research paralleled work on alternative conceptions, for example at Leeds, Surrey and Monash Universities, and soon mushroomed into an international trend in science education research as evidenced by the 5,000 or more entries in Pfundt and Duit's (Pfundt and Duit, 2000) bibliography of research on science learners' alternative conceptions. This research led to discussions about "children's science" (Bell 1993b) `in comparison to "scientists' science"; a view of the "learner as scientist" (Driver, 1983); the differences in the views generated by children and those of scientists (Gilbert, Osborne and Fensham, 1982); the parallels between the ideas of students and historical scientific ideas (Barker 1986, Driver, Guesné and Tiberghien, 1985) and the name given to the existing knowledge that students bring to the classroom - misconceptions, alternative conceptions, alternative frameworks, preconceptions, intuitive ideas or untutored beliefs (Bell 1993b). The recognition that students brought these alternative conceptions to their learning and that these ideas were strongly held on to led to theorising about what pedagogical practices might be required if students' thinking was to be taken into account (e.g. Stead 1980, Osborne, 1982a, Happs 1984). The main focus of this theorising was that students' existing ideas interacted with the taught curriculum to possibly lead to unexpected learning outcomes and that these ideas needed to be addressed in science teaching.

Another significant contribution to science pedagogy was the development of the personal constructivist view of mind (e.g. Osborne and Wittrock, 1985). This view of mind challenged the hierarchical view of learning, in terms of the validity of the notion of prerequisite ideas; behaviourist views of learning, in that the mind could not be treated as a black box and needed to be taken into account when addressing conceptual learning; and the information processing model of learning, in that the mind could influence the cognitive processing and that the mind could not be treated solely as a rational, technicist machine.

The importance of *context* was also raised by the development of a constructivist view of learning and mind. According to the constructivist view, in constructing an understanding the learner must make links between their existing knowledge and the new knowledge being taught in the science classroom (Bell, 1984; Osborne and Wittrock, 1985). Hence, context was important not just for motivational purposes but also it was an important part of the learning process (Jones, 1982; Schollum and Osborne, 1985). This and later research suggested that teaching science in contexts that enabled students to make links between the familiar (everyday) and the unfamiliar (science), resulted in higher science learning outcomes (Jones, 1988; Gribble, 1993; Rodrigues, 1993; Wood, 1996).

The second phase of the research also explored in depth the problems perceived with *practical work* in science lessons (Tasker and Osborne, 1983; Tasker and Freyberg, 1985; Schollum, 1986). More than 40 classroom lessons were examined in detail. The main finding to come from this research was that teachers' and students' perceptions of the same classroom experiences could greatly differ, for example in terms of: the scientific context, purpose, and design of an investigatory activity; in terms of doing the activity; getting the results; thinking about what was done and what happened; and the impact of the practical experience on children's views and the relationship to the teacher's predetermined outcomes (Tasker and Freyberg, 1985).

This aspect of the research addressed many key aspects of science pedagogy, in which the need for and the role of practical work was an unchallenged given. Tasker's work highlighted the need for teachers and students to consider practical work as a thinking activity in which each participant constructed understandings, rather than solely the domain of the manipulative work of the hands. This was in sharp contrast to the predominant view of process skills promoted in the draft F1-4 Science Syllabus (Department of Education, 1978) and the developing Primary Science Syllabus (Department of Education, 1979). This outcome of the in-depth phase was discussed further in the seminal article by Millar and Driver (Millar and Driver, 1987) in which they critiqued the process approach to science education, argued that content and process cannot be separated, and promoted the development of thinking skills as a valuable curriculum and pedagogical aim.

Another strand of the research investigated students' outlooks on their science studies. This related not only to the students' motivation but also to their desire to study science beyond the years of compulsory education. In particular, girls' and Maori and Polynesian students' outlooks on science and their science studies were explored (Stead, 1985). The classroom findings indicated that children can have difficulty relating what they are doing in the world in which they live and the way they think about the world. Also investigated were affective, linguistic, cultural, and sociological influences beyond the classroom on children's outlooks on science, including parental support, cultural background, the image children have of science, the usefulness of studying science, and the status of science.

4.1.3 The Third Phase: Toward action research (1981)

The third and final phase of the first LISP project used an action-research model of research to develop and research new pedagogies that took into account students' thinking and supported a constructivist view of learning. The research covered four areas: biology, chemistry, physics, and classroom activities. The action-research model included involving teachers in the development of viable solutions to the identified problems, and new teaching strategies were suggested which were designed to take into account students' thinking:

- teaching which will help children exchange, evolve, or extend their existing ideas with respect to a particular topic;
- teaching which will present new ideas so that they appear intelligible, plausible, and useful to the learner; and
- teaching which will order the topics of the curriculum better to take into account the learner's intuitive and/or developing ideas (Osborne, 1985a, p. 41)

The focus of the action-research phase was on changing and developing children’s alternative conceptions towards the accepted scientific concepts. A variety of teaching activities were developed and the main debates arising from these activities, and which paralleled research in the international literature of the time, were:

- Did students' alternative conceptions need to be addressed?
- When and how are the accepted scientific ideas best introduced to learners?
- Is there a role for conflict in promoting conceptual change and development?
- What was the role of discrepant events in promoting conceptual change?
- How did the nature and the sequence of the learning task affect student learning?

The roles for the teacher were also documented and were seen to be wider than merely transmitting scientific knowledge to students, and added the roles of the teacher as motivator, diagnostician, guide, innovator, experimenter, and researcher (Osborne and Freyberg, 1985b).

One suggested teaching model, the “generative teaching model” (Cosgrove and Osborne, 1985a; Cosgrove and Osborne, 1985b), was developed. The effectiveness of the teaching strategies in promoting conceptual change was researched in the first LISP project and in related thesis research. For example, Bell and Barker (1982) documented a research exercise in which a class of twenty-six 13-year-old students was taught, as was usual, about the biological term “consumer”, in conjunction with the term “producer”. No teaching was done on the biological term “animal”. In contrast, another class of twenty-four 13-year-old students, had the same teaching about consumer and “producer” but were taught the biological concept “animal” first. The results showed that more students in the second class learnt the scientifically correct concept of “consumer”. Teaching which addressed students' alternative conceptions (about what was, or was not, an “animal”), resulted in better learning of other related scientific concepts. In another example, Bell (1984), in a study involving 227 Year 9 students reading a text to learn the scientifically accepted concept of “animal”, found that a written text challenging the everyday meaning of “animal” was more successful in promoting the required learning than one focusing on the dual meanings (the everyday and the scientific) of the word “animal”.

The action-research, related thesis research, and accompanying teachers’ guides which came out of the first LISP project specifically gave teachers information about the children's science or existing ideas that students brought to the lesson. Two examples of this are the teachers’ guides on burning (Biddulph, 1991) and photosynthesis (Barker, 1985).

4.1.4 Curriculum implications of the LISP (F1-4) research findings

As stated previously, the first Learning in Science project was funded partly in response to the draft 1978 Years 7-10 Science Syllabus and Guide. The LISP findings had implications for curriculum, which paralleled international research findings, and these implications were much debated in the F1-5 Science Curriculum Review (Bell, 1990). These were:

- **science curriculum aims, purposes, and desired outcomes:** these included the need for broad learning objectives and the inclusion of thinking skills as learning outcomes;
- **the format of the curriculum:** for example, the inclusion of suggested teaching activities and prescribing of less content to be “covered”;
- **the nature and role of classroom discourse**: these included using a range of classroom activities that enabled differing types of talking and communication in the classroom;
- **the types of activities suggested by teachers' guides**: for example, the inclusion of pedagogical knowledge of learners’ existing thinking and learning activities that were not the traditional “practical work”; and
- **the teaching of science in meaningful contexts**: for example, the draft syllabus (Ministry of Education, 1990a) organised suggested contexts into the contexts of science and myself, the world, leisure, and work.

Many of these implications for the curriculum were addressed in the draft F1-5 Science Syllabus (Ministry of Education, 1990a), related teacher guides (Ministry of Education, 1990b) and resources (Ministry of Education, 1992a) and the 1993 Science curriculum (Ministry of Education, 1993a). Moreover, the prevailing view of “curriculum” in the early 1990's, and the perceptions of accountability movement in New Zealand education, made it extremely difficult to action these notions in the official curriculum or the classroom curriculum (Bell and Cowie, 2001). It has been difficult for even experienced teachers/writers to write curriculum materials that took into account students' prior ideas. The themes listed in the bullet points above also laid the foundation for further classroom studies and thesis work done during subsequent LISP projects. These studies will be described in later sections.

And finally, the findings changed the views of what constitutes effective pedagogies in science education. Firstly, the rich descriptions of science teaching and learning in the research findings gave science educators many insights into the *kind* of thinking required of both teachers and students for the intended learning outcomes to be achieved. Secondly, the learning outcomes research findings, and in particular those of the associated thesis research, indicated the *extent* of the learning outcomes obtained when these pedagogies were used. These learning outcomes went beyond what was seen as possible given previous theorising on learning. Thirdly, the theorising of learning from a constructivist point of view opened the way for the development of new pedagogies in following projects.

4.2 The Learning in Science Project (Primary): (1982-1984)

The second Learning in Science project began in 1982 straight after the Forms 1-4 project and arose out of a concern that the problems and difficulties faced by middle-school students of science might be fruitfully addressed earlier, that is, in the primary school. There was also concern about the professional development for teachers to use the research findings in their teaching.

The LISP (Primary) project initially had two main purposes (Osborne, 1982b):

- to investigate the problems and difficulties that primary school children have in learning science, and to find ways of overcoming such difficulties, and
- the “training” of primary school teachers to teach science.

However, the main focus of LISP (Primary) developed into the teacher, teaching and pedagogy. The pedagogical aspects of science education were seen as arising from the research on the learner. The learner and learning were given attention and value, given the lack of research findings about learning primary science, but not for their own value. Instead they were valued for their input into teaching. The importance of the teacher and teaching was soon evident in the discussions and focuses of the research (Osborne and Biddulph, 1985a).

The development of solutions to the problems and difficulties of learning primary science were seen as requiring the input of the existing pedagogical knowledge and expertise of teachers and there was a commitment to involving teachers

> "in clarifying problems and seeking solutions to these problems at the earliest possible stage" (Osborne and Biddulph, 1985a, p. 5).

The main issues addressed in the project (Osborne and Biddulph, 1985b) were:

- The reality of primary science teaching and learning.
- Children's questions, ideas, and investigations.
- Exploring alternative teaching strategies.
- Evaluation of the teaching strategies.

The early findings of the project relating to the status of teaching and learning primary science in New Zealand were centred around the dilemmas facing teachers of primary science. The researchers developed the view that the key problem of teaching and learning science in the primary school was related to teacher perceptions and teacher confidence in teaching science (Osborne and Biddulph, 1985a). The pivotal place of the teacher and her or his pedagogical knowledges, outlook, and practices in improving the learning outcomes in primary science was recognised.

Sub-studies investigated the questions and associated ideas that children had in specific areas of content. The content areas chosen were not the big conceptual ideas of the 1960s and 70s science curricula, such as "energy", but topics such as rocks, spiders, metals, floating and sinking, flowering plants, and hot and cold, that were meaningful to children and would enable children to link their existing ideas with new scientific ideas. The researching and documentation of the children's ideas and explanations (Osborne, 1985b) was primarily for the pedagogical purpose of informing teachers' pedagogical knowledge of students, and for the purpose of structuring the classroom curriculum. This simultaneously gave researchers and teachers an insight into the existing ideas and thinking that primary pupils of science were bringing to the lesson, a pedagogical strategy for teaching the content, and a theoretical framework for choosing the content (Biddulph, 1989).

The work on a perspective of primary science and the initial investigations of children's questions led to the development of the "interactive teaching model" (Biddulph and Osborne, 1984). The first LISP project had identified classroom communication as important in promoting conceptual development. The "interactive" teaching approach developed in the second project promoted classroom discussion and dialogue that differed from the normal pattern of "teacher question"-"student answer"-"teacher response". The approach was based on a constructivist view of learning which took into account students' thinking, and, in particular, their questions and explanations. It was also based on a humanist view of learning as children were being encouraged to take ownership of their learning – to have a sense of control over it and feel that the learning was making sense to them (Biddulph, 1989). The key parts were: preparation; exploratory activities; children's questions; children's investigations; and reflection (Biddulph, 1990).

The main evaluation of the interactive teaching approach was through self-report data from 20 primary teachers, 2 science advisors and 61 pupils who had used the approach (Biddulph, 1989). In this and several smaller evaluations teachers reported:

- increased interest by students;
- increased happiness, busyness, co-operation, and engagement of students;
- increased student involvement in the investigations;
- increased student curiosity, willingness to communicate their ideas, open-mindness;
- increased development of process skills, for example, observation; and
- increased development of intellectual skills.

The students reported that they preferred learning science from their own questions as it was more interesting, more challenging, and because they learnt more (Osborne and Biddulph, 1985a).

While the evaluation did not provide evidence of students' increased learning outcomes per se, the self-report data did provide evidence of "better learning conditions" (Bell and Pearson, 1992). These "better learning conditions" were pedagogical signs to the teachers in the classroom that better learning outcomes were more likely to be obtained. This view paralleled the prevailing one at the time that an important role of the teacher is to structure the learning environment. The self-report data from the teachers (Biddulph, 1985; Biddulph, 1990) indicated that using the interactive teaching approach had:

- increased their confidence in teaching science;
- provided them with strategies to listen to and work closely with their children so that they became far more aware of what it was the children were bringing to the lesson, and gaining from a particular lesson;
- made the children's real abilities evident;
- helped develop a sense of "community" in the classroom; and
- enabled them to cater for children of varying ability.

These gains contributed to the teachers feeling better about themselves as teachers and they reported that they used the approach in other curriculum areas. The self-report data also indicated that the teachers also encountered difficulties, including:

- dealing with the superficiality of the children's initial questions;
- thinking of investigations for some questions;
- the diversity of children's questions;

- the change in the teacher's role;
- the intensive nature of the teaching;
- finding suitable resources;
- assessment of learning; and
- the children's lack of investigatory and meta-cognitive skills (Biddulph, 1985).

Biddulph (1989) suggested that teachers who did not already operate within the constructivist/humanistic theoretical framework that the interactive teaching model was based in could not take the written materials and implement them as intended. These teachers needed considerable inservice or preservice support to develop their views of learning, before they could successfully use the approach.

Curriculum implications of the LISP (Primary) research findings

The findings of the LISP (Primary) project had limited impact on the official primary science curriculum. The 1985-1989 revisions of the 1979 primary science curriculum (Department of Education, 1979) included a supplement to the official curriculum, containing the key findings of the LISP(Primary) project. But the primary syllabus continued to give prominence to the process skills and the 'big ideas' of characteristics of living things, properties of matter, some forms of energy and time and space (p 2); the scientific method (p 14). Mention was made of children's existing ideas and their questions, as were the new roles for the teacher, and resources were made available for the professional development of teachers of science to use the teaching approach, for example, a video on floating and sinking (Department of Education, 1988). However, few of the findings of the LISP (Primary) project were taken into account in the 1990's science curriculum development (Ministry of Education, 1993a & 1993b). The focus on planning for levels of achievement and the achievement objectives made it difficult for many primary teachers of science to include the interactive teaching approach in their science classroom curriculum (Bell, 1993a).

An on-going pedagogical concern of the research team was the place of science in the interactive teaching approach as well as in the primary curriculum (Osborne, 1984). For some teachers using the interactive approach, the "science" became lost in the sea of language activities in the context of a topic such as spiders, rocks, metals. The increased teacher confidence in teaching science using this interactive approach may have been due to their not having to know and use scientific ideas, but instead to rely on other resources, such as books or visiting "experts". This debate on the role of the teachers' pedagogical content knowledge was ongoing. For example, to what extent did teachers need to know the scientific ideas about rocks to help a child investigate their question on "rocks"? How could a teacher assess the science learning outcomes of the students if they did not have the scientific ideas themselves? How could children's questions structure the classroom curriculum in relation to the official curriculum? These questions continued to be addressed in later LISP projects.

4.3 Learning in Science Project (Energy): (1985-1988)

The Learning in Science Project (Energy) was a three year project spread over the years 1985-1988 and funded by the Department of Education (Kirkwood and Carr, 1988; Kirkwood and Carr, 1989). Whereas the first LISP project had investigated teaching and learning science by 11-14-year-olds, and the second project explored science for 7-10-year-olds, the third project investigated the teaching and learning of science across the broad age range of primary and secondary schooling. One concept that spanned the official primary and secondary science curricula of the time was *energy* (Department of Education, 1978, 1979). The brief for this third project was to investigate the teaching and learning of the concept of "energy" to 5-17-year-olds (Kirkwood, Carr, Bell, McChesney, Osborne and Symington, 1985; Kirkwood and Carr, 1988). However the research focused on learners aged 11 to 17. It was also hoped that the science content be given a focus during the researching of the teaching. Hence, the project arose out of concerns regarding:

- the ways in which "energy", as a fundamental science concept, is a difficult concept
- for primary and secondary students to learn;
- a need for effective pedagogies to help these students learn the concept of "energy";
- the use of the interactive teaching approach in the secondary school, where there
- were concerns about "covering the exam prescriptions"; and
- the role of the teachers' knowledge of science in the teaching and learning process.

Themes that emerged from the research on teaching and learning science, started in the first two LISP projects were continued in the third project, namely:

- an investigation into problems and difficulties with teaching and learning energy.
- the existing ideas that students and teachers bring to the science lesson,
- the influence that these existing ideas have on the learning outcomes,
- teaching that takes into account students' thinking,
- pedagogical and curriculum implications of the research findings, and
- the professional development of teachers of science to use the research findings.

This project continued to challenge the theoretical assumptions on which pedagogies in science education were based and to provide rich descriptive findings, as well as learning outcome findings, for teachers wanting to change their practice.

A review of literature and research with teachers suggested there was a general consensus that science educators and students felt the concept of "energy" to be abstract and difficult to teach and learn. The scientists' view of "energy" was felt to be vaguely defined and prescribed in the curricula and so the research team developed guiding principles (Kirkwood, 1988) which were intended to assist teachers at all levels and in all disciplines in their consideration of energy topics. These guidelines were not intended as a definition of energy to be taught to students, but were in essence an aspect of pedagogical content knowledge and an attempt to structure the content for ease of use by teachers to address the difficulties faced by students in learning about energy (Kirkwood *et al.*, 1985). However, a key finding of the project was that both students *and* teachers had differing views of energy, some of which were alternative ones to the accepted scientific ones. It was reported that the alternative conceptions of energy held by students of all ages were that energy was:

- a general kind of fuel that does much work for us;
- associated with living things;
- associated with moving things, e.g. fire, car;
- able to take on different forms as it travels through wires or chains on bicycles;
- a source of force or activity stored in objects, e.g. water has energy in it so it can turn a water wheel;
- a storehouse used to make things work such as a battery;
- able to be obtained from food, the body, sun and soil, it is an ingredient stored in them;
- a fluid-like material that flows from one body to another, as an electric current or stream; and
- given off like a waste product, for example, chemicals give off heat (Kirkwood and Carr,1988).

The most notable feature of these alternative conceptions was that energy was viewed as a substance by many students of all ages. It was also reported that students had difficulty understanding the concept of energy conservation but not those of energy transfer and energy flow. Students also demonstrated considerable confusion between the word “energy” and other terms such as “force”, “power”, and “work” (Kirkwood and Carr, 1988).

It was also reported that science teachers differed in their views of energy. Biologists tend to view energy as what is required by living things for the maintenance of life and which flows through the ecosystem. Chemistry specialists tend to hold a view associated with the re-arrangement of bonds in matter and the physics specialists' view is that energy is the ability to do work (Kirkwood *et a*l., 1985; Kirkwood, 1988). This was said to have caused considerable confusion for students in their junior secondary schooling who had science teachers of different specialities.

As indicated above, students aged 11-17 held views of energy that are alternative to the views of scientists. In other words, school teaching on energy in primary and secondary science lessons had not resulted in the students developing their concepts of energy into the accepted scientists' views. The LISP (Energy) project detailed some of the difficulties in teaching and learning energy at the junior secondary level (Carr, Kirkwood, Newman and Birdwhistell, 1987; Carr and Kirkwood, 1988). These were:

- "confusion in the classroom as to what constitutes energy and its different forms;
- conceptual and semantic difficulties with potential energy;
- confusion between energy forms and energy resources;
- energy seen in static situations/objects with what happens next implicit;
- the use of energy as a signal;
- difficulties between the everyday use of the phrase "conservation of energy" and the scientist's "conservation of energy";
- confusion about energy conservation and energy degradation;
- unhelpful and confusing use of extra words, e.g. direct/indirect; renewable/non-renewable;
- inconsistent view of energy portrayed in teacher resource material;
- implicit and inconsistent use of systems by teachers; and
- unawareness of students' ideas and few links made to their ideas about energy. (Kirkwood and Carr, 1988, p. 18).

These findings are of importance, given the predominance of energy related questions in the TIMMS test items (see section 3.6.4).

The researchers felt that these difficulties were characterised by a lack of teaching that took into account students' thinking and a lack of classroom discussion, dialogue and interaction on the meanings and understandings being constructed in the classroom by teachers and students. Therefore, a teaching package was developed and trialled by the researchers (Kirkwood, Carr and Newman, 1988) evaluated in an action-research mode. A teachers' guide, based on this package (Kirkwood, 1989) was also produced and distributed to every secondary school in the country. These alternative teaching approaches were demonstrated to be effective for students' learning about the concept "energy" as illustrated by the students' and teachers' self-report data and pre/post survey results (Kirkwood, 1988). The pre/post survey results for the three classes (n=28; n=34; n=25) showed more development of the students' energy concepts than one might expect given the results of the cross-age studies of children's concepts of energy.

Curriculum implications of the LISP (Energy) research findings

The recommendations in the Final Report (Kirkwood and Carr, 1988) include suggestions for future curriculum development:

- that the actual concept of energy should not be the focus in primary education (years 1-8). Rather, students should be provided with many experiences of heat, light, sound, electricity, and movement set in familiar contexts;

- that the concept of energy be taught in contexts meaningful to students;
- that in years 9-11, the energy concept be introduced as a useful and powerful abstraction or model, or as a constructed, invented idea for understanding changes to a wide variety of systems; and
- that the concept of energy be taught in the context of defined systems undergoing defined changes.

Only the first two of these recommendations were apparent in the 1993 science curriculum and teacher guides. The Learning in Science Project (Energy) continued the themes that emerged from the previous two projects. In addition to the ideas students bring to the lesson, the views that teachers bring to their teaching were highlighted, and a teaching approach that took into account students' prior ideas and their understandings constructed during the lesson, was shown to be more effective than traditional teaching approaches. The degree of professional development required by teachers to teach the new approach was considerable. Under-researched were the details of the classroom interaction that resulted in student conceptual development and the details of the teacher development process. These were researched more fully in the fourth and fifth LISP projects.

4.4 Learning in Science Project (Teacher Development): (1990-1993)

A thread running through the first three Learning in Science Projects was that of the teacher development to enable teachers to use the research findings to inform their pedagogical practice. Both the descriptive and learning outcome research findings of the previous projects had been intentional, so as to provide the kind of research data or evidence to support and promote change in classroom practice. Teacher development to implement teaching approaches based on a constructivist view of learning was a key element of this research of the first three projects. It was paralleled by an interest in teacher development internationally (Hargreaves and Fullan, 1992, Gilbert 1993, Bell, 1998). With respect to the LISP research findings, there was a perceived difficulty experienced by teachers in using the research findings to inform their teaching and the perceived lack of change in the pedagogies commonly used by teachers of science.

From 1989-1992, the Ministry of Education funded a three-year research project to investigate ways to promote teacher development in science education (Bell, Kirkwood and Pearson, 1990; Bell and Pearson, 1991). In particular, the research investigated the teacher development required to help teachers take into account the findings of the three previous Learning in Science Projects, into students' learning in science, and the related international research on children's science, conceptual change and constructivist views of learning (Bell, 1993a). Many teachers, on their own initiative, wanted to take this research into account in their teaching but had found it difficult to do so (Gilbert, Jane, 1993). In addition, the contract specifications for the new science curriculum (Ministry of Education, 1993a) required that the curriculum be written to take into account current research on teaching and learning science (Haigh, 1995). The fourth LISP project explored the teacher development required for the implementation of new teaching activities for the teachers.

Over the three years, the research addressed these questions: (Bell 1993a)

1. To what extent did the teachers on the programmes change their ideas and beliefs about:
    - teaching activities and the roles of the teacher
    - learners and the process of learning, learning-to-learn and teachers as learners
    - the nature of science and scientific knowledge
    - science in the school curriculum?
2. To what extent and in what ways did the teachers change their behaviour in the classroom?
3. What factors helped or hindered this development?
4. What resource materials were needed to support teacher development?
5. What were the strengths and weaknesses of the school-based and regionally-based programmes?
6. What model of the teacher development can be recommended to policy makers, school managers, teacher educators and teachers as a template for developing programmes?
7. What are appropriate criteria for the evaluation of teacher development courses?

Four teacher development programmes were run for a total of thirty-four teachers of science in the Waikato region in 1989-92. Two of the programmes were school-based and two regionally-based. The teachers in the programmes were primary and secondary; beginning and experienced teachers; and assistant teachers and Heads of Departments. The programmes consisted of after-school sessions over one or two school terms and a small number of classroom visits. As part of the programme, some teaching approaches, strategies, and activities were developed based on a constructivist view of learning, including, for example, brainstorming, concept-mapping, post-box techniques, and classroom discussions, which encouraged teachers to change from being primarily a transmitter of knowledge to being a facilitator and mediator of students' learning.

The pedagogies used in the programme sessions were sharing sessions, in which the teachers talked with each other about the new activities they had tried in their classrooms, and workshop sessions in which the facilitator ran activities to help the teachers reflect on their practice (Bell, 1993a). Initially, the teachers wanted to talk about what they were doing in the classroom and about themselves as teachers, and how they felt about the changes they were making in their classrooms. This initial focus on teaching (and indirectly on learning and students) was a factor that helped the teacher development. The teachers commented that using the new teaching activities had helped them to "feel better about themselves as teachers or to be more like the kind of teacher I would like to be". This was felt to be a pay-off to continue to change and grow professionally despite the difficulties that the change process involved. The teachers' sense of self as a teacher was an aspect involved in the teacher development process. For some teachers, the new classroom activities enabled their actions to match their beliefs about what it means to be a teacher of science. For others, the programme helped them develop their beliefs about being a teacher. For example, many of the teachers changed their view of noisy classrooms. A noisier classroom may not necessarily indicate a lack of control – it could mean more discussion between students and improved learning.

When talking about the classroom feedback they had received on the new teaching activities from students, the teachers initially talked about "better" learning (Bell and Pearson, 1992), meaning better learning conditions (enjoyment, social co-operation, ownership, student confidence, motivation) and "better" learning outcomes (responses to teacher questioning, debates and written work, the development of students' ideas and the transfer of learning). The teachers were comparing their perception of the learning occurring with former teaching to that occurring with the new teaching.

Later in the programmes, the emphasis changed from commenting on the "better" learning occurring with the new teaching activities to comments on indicators of learning, such as learning-to-learn skills, transfer and linking of ideas, retention of ideas, and better test and examination results.

Thus, the four factors that helped teacher development were:

- a perception that better learning occurred with the new teaching activities compared to that with former teaching;
- being more aware of and seeking more information in the classroom on learning;
- focusing more on learning outcomes than learning conditions; and
- support, feedback, and reflection.

The main finding was that teacher development has three overlapping aspects: professional, personal, and social (Bell and Gilbert, 1994). The professional development involved the development of the teachers' conceptions of science education and the development of the teachers' activities and roles in the classroom. The personal development involved the teachers attending to their feelings associated with being a teacher, and with changing. The social development was the development of collaborative ways in which the teachers related to, and worked with, other teachers and students and the development of the socially constructed knowledge of what it means to be a teacher of science. The researchers took the view that teacher development programmes needed to address all three aspects. In particular, it was believed that the personal development strongly influenced the nature and pace of the changes. These key findings are closely connected with pedagogy, in that to effect change or to develop classroom teaching requires more than merely changing the teaching activity in the classroom. The fruitfulness of the teacher development model in informing the ongoing curriculum development process has also been explored (Bell and Baker, 1997).

The research indicated that the teachers developed their teaching in two ways. Firstly, the teachers used different activities in the classroom, such as concept mapping, brainstorming, the post-box technique, eliciting students' questions as in the interactive teaching approach, small group discussions, interviewing, open-ended investigations, and card-sorting activities, which created the opportunities for the teachers to take into account students' thinking. Once the teachers were able to use these activities in a way that felt comfortable from a classroom management perspective and in a way that did not conflict with school restraints (Bell and Gilbert, 1994) they were able to develop, at another level of detail and skill, the way they took into account and interacted with the students' thinking.

In the final year of the project, the nature and extent of the changes made by the staff of one high school science department to their pedagogy was researched (Pearson and Bell, 1993). The data was mainly quantitative data (frequency counts) collected by surveys and classroom observations. The post-programme observations found:

- all teachers had changed in their classroom practice.
- the teachers were using more of those activities suggested and modelled in the programme and which created the opportunity for the teacher to interact with the students' thinking.
- in junior classes especially, there was much more open-endedness in the teaching activities and students had a much greater chance to explore their own questions about the various content areas that were in the school scheme.
- there was a much greater emphasis on cooperative learning – groups were organised to promote sharing of ideas either by the teacher or within common interest groups.
- “sharing” sessions with the whole class through groups or individuals reporting back were more common
- in senior classes, the teachers talked more about meta-cognitive learning techniques and again emphasised in their practice finding out the prior views of the students.

The findings of the teacher development project indicated ways in which teacher development needs to be undertaken in order to promote the teacher development of teachers to use effective pedagogies in their classrooms. The extent to which the Ministry of Education, Colleges of Education and other providers have implemented the findings has yet to be researched.

The Learning in Science Project (Teacher Development) concluded at a time when the constructivist view of mind and learning was being strongly critiqued. A main criticism of teaching based on a constructivist view of learning was that the teacher was portrayed as a “facilitator” and not a “teacher”. The role of teacher as a provider of information was erroneously seen as teachers not telling and explaining the science to students. But teachers do tell and explain the science to students and in many different ways other than lecturing (Oxenham, 1995). The interaction between teacher and student is not a simple monologue nor is it characterised by a simple teacher comment and student reply. This complex interaction is at the heart of pedagogy and was given more attention in the fifth Learning in Science Project.

4.5 Learning in Science Project (Assessment): (1995-1996)

The teachers in the previous Learning in Science Project on teacher development had indicated that an area of professional development they would welcome is the pedagogical practice of interacting with students to discuss and explain science concepts. In taking into account students' thinking in their teaching, these teachers were responding to and interacting with the students' thinking that they had elicited in the classroom. A central part of this teaching is dialogue with students to clarify their existing ideas and to help them construct the scientifically accepted ideas. Therefore, giving feedback to students about how their existing conceptions relate to the scientifically accepted ones, and helping them to modify their thinking accordingly, is a part of teaching for conceptual development. This process of appraising, judging, or evaluating students' work or performance and using this to modify teachers’ and pupils’ work in order to make for more effective teaching and learning is otherwise known as formative interaction or formative assessment (Gipps, 1994; Black, 1995; Harlen and James, 1996; Cowie, 1997).

Formative assessment improves student achievement (Black and Wiliam, 1998). The seminal review of the literature on the impact of formative assessment on learning outcomes (Black and Wiliam, 1998) shows conclusive evidence that formative assessment does improve learning and has led to achievement gains amongst the largest ever reported for educational interventions However, there had been little research on the process of formative assessment itself and the professional development required for its use in classrooms. These descriptive research findings were the focus of the fifth Learning in Science Project. Student achievement can only be raised if teachers actually use it as a pedagogical and assessment tool in the classroom.

By the mid-1990s in New Zealand, there was an increasing interest in assessment in education, due to the accountability movement in education policy. In particular, formative assessment was increasingly becoming a focus in policy documents on educational assessment and in the professional development of teachers due to its effects in improving learning outcomes. However, alongside “formative” assessment was a focus on “summative” assessment and assessment for “accountability” purposes. While formative assessment is a process used by teachers and students during learning, summative assessment is used for the purposes of describing learning achieved at different times for the purposes of reporting to parents, other teachers, the students themselves, and in a summary form to other interested parties such as school governors, school boards, or accreditors of national qualifications (Harlen and James, 1996). Assessment for accountability purposes is used to evaluate and report on the effectiveness of education systems (National (USA) Research Council, 1999).

The three cornerstones of assessment for accountability are: a prescribed set of standards or learning objectives (for example, Ministry of Education, 1993a); an auditing and monitoring process to ascertain if standards have been attained (for example, Crooks and Flockton, 2000b); and a way of raising standards if low standards have been indicated in the audits. In this climate of accountability to improve learning outcomes, the fifth Learning in Science Project, LISP (Assessment) was funded by the Ministry of Education in 1995-96. It was to investigate assessment in Year 7-10 science classrooms and in particular, formative assessment (Bell and Cowie, 2001). Formative assessment was being seen as both an effective pedagogy and as a purpose for assessment. The research, funded by the Ministry of Education, was based around eight case studies of ten teachers and their students and the assessment they undertook in the classroom. In addition, the ten teachers and the researchers met on eleven teacher development days for professional development on classroom-based assessment and to reflect on the data analysis. This enabled a collaborative research method which intentionally combined research and development (Bell and Cowie, 1999).

The five research aims were:

1. to investigate the nature and purpose of the assessment activities in some science classrooms.
2. to investigate the use of the assessment information by the teacher and the students to improve the students' learning in science.
3. to investigate the professional development of teachers with respect to classroom based assessment, including formative assessment.
4. to investigate the use of assessment information in reporting to parents or others,
5. to develop a model to describe and explain the nature of formative assessment process in science.

The research indicated that the ten teachers assessed three aspects of student learning in science classrooms: the students' personal, social, and science learning. The students' personal development related to their learning about themselves as learners and about learning-to-learn. The students' social development related to their interacting with others in the classroom, for example, group work, and discussion skills. The students' science learning related to their learning of science content, science processes, and contextual information (Cowie, Boulter and Bell, 1996).

The teachers indicated that they undertook formative assessment to promote the students’ learning: to give feedback as to whether the students had scientifically acceptable ideas and skills; to give legitimacy to the students' scientifically acceptable ideas; to monitor whether the learning activities were working; to monitor students' progress in learning; to give feedback on what is valued as learning outcome in the classroom; and to give feedback on the students' social and personal learning (Bell and Cowie, 2001). The ten teachers also indicated that they did formative assessment to inform their own teaching: to plan the following lessons; to find out if the learning activities were working; to find out if the students were learning the intended learning outcomes; to monitor the progress of the students' learning; to know when to input new ideas into the lesson; to know when to introduce an activity or idea to maintain interest and motivation; to know when to move on to another topic or activity; to evaluate the unit of work for future classes; to obtain qualitative assessment information to complement the grades on reports; and to plan for future units of work with these students.

The research findings suggested that the ten teachers used two kinds of formative assessment: “planned” and “interactive”. “Planned” formative assessment was that which the teacher had planned in advance to undertake in the lesson and it tended to be at the beginning of the unit of work, for example a brainstorm to find out the students' existing ideas on the topic of the new unit, or at the beginning of a lesson, for example a question-and-answer session to ascertain what the students had learnt from the previous lesson. Planned formative assessment tended to be done with the whole class and involved the teacher eliciting, interpreting, and acting on the formative assessment information.

“Interactive” formative assessment occurred during the interactions between the teacher and the students and so had the potential to occur any time the teachers and students interacted, for example, during practical work. Interactive formative assessment involved the teacher in noticing, recognising, and responding to assessment information and tended to be done with small groups or individual students. Interactive formative assessment was not able to be planned in detail. Although it was planned for in the sense that the teachers prepared in advance to have the students do learning activities that enabled them to interact with the students, they could not plan for or predict exactly what they and the students would be doing.

The formative assessment done by these teachers was a highly skilled and complex task, which relied on the following knowledge bases (Shulman, 1987) of:

- content knowledge, e.g., knowing the scientific understanding of the concepts being taught;
- general pedagogical knowledge, e.g., of classroom management;
- curriculum knowledge, e.g., of the learning objectives in the curriculum being taught;

- pedagogical content knowledge, e.g., knowing how best to teach atomic theory to a class of 14-year-olds;
- a knowledge about learners in general and the students in the class;
- knowledge of educational contexts, e.g., the assessment practices in the school; and
- a knowledge of educational aims and purposes, e.g., a possible "science-for-all" emphasis in a national curriculum.

The teachers felt the use of both forms of formative assessment and the switching between them was the hallmark of a competent teacher.

The research findings (Bell and Cowie, 2001) suggested, to the teachers and researchers (Bell and Cowie, 1999), a model for formative assessment which had the following six key features:

1. Teachers used two kinds of formative assessment: *planned and interactive.*
2. Formative assessment was described as a complex, skilled task.
3. The teachers perceived that the purposes for planned and interactive formative assessment were different.
    - The purpose of planned formative assessment was perceived as obtaining information from the whole class about progress in learning the science as specified in the curriculum to inform the teaching.
    - The purpose of interactive formative assessment was perceived as mediating in the learning of individual students with respect to science, personal, and social learning.
4. Formative assessment was seen as an integral part of teaching, and the teachers in the research claimed that they did not think they could promote learning in science unless they were doing formative assessment.
5. Teachers were doing formative assessment but they were not always aware of exactly what they were doing that could be called "formative assessment".
6. Students played an active part in their disclosure of what they know.

The teachers commented at various times during the project, that they perceived constraints to their doing more formative assessment in their classrooms (Bell and Cowie, 1997). These included perceived national and school policy on assessment; the demands by others outside of the classroom for assessment information for summative and accountability purposes; the demands of a curriculum which contains much content to cover and the need for more teacher development to increase their professional skills of interacting with students in the classroom.

4.6 Outcomes of the Learning in Science Projects and associated thesis research

4.6.1 Taking into account students' thinking

One key theme running through all five LISP projects has been the pedagogies that take into account students' thinking and, in particular, their prior ideas, their existing ideas, and their tentative constructed understandings during the lesson. This pedagogical skill is a highly complex skill and requires the teacher to plan and undertake different actions in the classroom. The teacher needs to plan for activities that allow her or him to engage in discussion with the students – to find out what they are thinking – and to respond to that thinking (Bell and Cowie, 2001). It also depends on the students being comfortable and trusting enough to disclose their thinking (Cowie, 2000). These activities are further discussed in sections 4.7 and 4.8.

A sub-theme highlighted in the research has been the taking into account of the students' cultural values, experiences, and knowledge in the pedagogical practices in the classroom. The taking into account of the students' cultural values as a part of their existing cognition, was theorized as a way of linking the students' existing knowledge to the newly learnt scientific knowledge of the classroom. The cultural knowledge was not seen as being replaced by but as co-existing with the scientific knowledge. It was advocated in the development of the 1993 *Te Tauākī Marautanga Pūtaiao: He Tauira* curriculum document (McKinley, 1995); in the use of Maori contexts in the teaching of science (Gribble, 1993); and in the research undertaken by international students at the University of Waikato, which has relevance for the New Zealand situation, given the high number of Pacific Nation and Asian students in New Zealand classrooms (e.g. Chu, 1997; Evening, 1999; Cheng, 2000).

4.6.2 Communication for conceptual development

Another theme emerging from the LISP research programme was the promotion of classroom communication as a worthwhile pedagogy in science education. The five Learning in Science Projects and related theses (1979-2001) researched effective communication in classrooms. The main focus of this research was on pedagogies to promote teacher-student and student-student classroom interactions, dialogue, and communication (both oral and written) in promoting conceptual development.

Lessening the mismatches

In the first Learning in Science Project, the role of language was discussed in the context of the mismatch between the students', teachers', and accepted scientific concepts. The problems in communication were viewed as different meanings being constructed by participants in the classroom either in teacher-student or student-student communications. This was not only due to some of the technical words of science being unfamiliar to students (and some teachers) but also because even simple words can have different meanings in differing contexts. For example, the word “animal” is an everyday word that is used differently in an everyday context (a four-legged furry creature), and a scientific context (a consumer). Calling a person an animal in an everyday context has a different meaning to their being called an animal in a scientific context.

To help students differentiate these differences in meanings, small discussion groups were used to enable student-student discussions as well as teacher-student discussions. For example, the card game based on students sorting interview-about-instances cards was trialled. The students had to reach a consensus about the categorisation of an instance before it was placed on one of two piles: the animal pile and the not-animal pile. Other language-based activities trialled crosswords and dice games.

Mindful that teachers have a responsibility to teach the scientific concepts, as legislated in the national curriculum, the caution was made that these discussions do not always result in the scientifically accepted concept being constructed by students. The scientists' concept may have to be provided by the teacher or a student. But this does not have to be done by the giving of a lecture. Oxenham (1995) documented the twenty-nine ways (including telling the students) four secondary teachers introduced the scientists’ ideas into the classroom dialogue.

Reading texts as a pedagogy to learn science

In recent years, there has not been a focus on researching reading-to-learn in the science education literature, despite considerable interest and development work in this area in the 1970s and 1980s. A New Zealand study that has researched reading as a pedagogy for conceptual development in science education, linked the conceptual development research with that of reading comprehension. Bell (1984) investigated the role of students' existing knowledge (of "animal") in reading to learn science, that is, in both the reading comprehension and learning processes. Three different methodologies were used – one in each of the three phases of the research. These were the qualitative interview techniques ("spot-the-mistake interviews", n=6 Year 9 students and the "reading-to learn-interviews", n=21 Year 9 students) and quantitative survey measures before and after a class reading task, n=227 Year 9 students.

The findings indicated that the students' existing knowledge not only contributed to the meanings constructed whilst a student was reading a text to learn science, but it also influenced what constructions were made. The existing knowledge was also used to evaluate the constructed meaning, in terms of whether to accept or reject the construction. Hence, the careful explication of the scientists' meaning in a text by the author does not guarantee that the reader will construct and accept the intended meaning nor learn it.

The role of discussions in improving learning

Discussions by small groups of students and discussions by the whole class have been a feature of all five Learning in Science Projects and related thesis research at the University of Waikato. Their use as a pedagogical strategy to promote conceptual learning is argued on the ground that specific focused discussions avoid the typical patterns of teacher-student and enable the students to use skills and competencies that promote conceptual development. The small-group and/or whole-class discussions provide the opportunity for the students to clarify and share their own understandings; to compare their own conceptions with those of others; to test out their understandings; to ask questions and to challenge the views of other students and the teacher; and to reconstruct their understandings and to use the new ideas with confidence.

The discussions usually emerged during a specific and planned activity such as card-sorting, crosswords, task sheets, practical work, rock sorting. It was not the activity per se that promoted the learning but the language and thinking involved in completing the activity. This widening of the notion of small-group discussion work beyond that involved in doing practical work, was a feature of the 1993 Science Curriculum development (Ministry of Education, 1993a).

The role of meaningful contexts to promote effective discussions was investigated. Rodrigues and Bell (1995) analysed the interaction of some discussions by a whole class and in small groups, as part of a larger study (Rodrigues, 1993). The discussions took place within a programme of work based on contexts that were meaningful for Year 12 chemistry students in a unit of work on oxidation and reduction. The contexts included:

- Thiobaccillus bacteria and the New Zealand farmer. These bacteria found in New Zealand soils convert sulphur to sulphates at ambient temperatures and pressures. A class discussion involving a comparison between this scenario and the "Contact" process was proposed.
- Hair today ... gone tomorrow. This unit investigated the chemistry of hair-perming and colouring, starting with a newspaper article about "Madonna".
- I can Al Right: a role play in which 5 groups of people (environmentalists, local people, scientists, company personnel and the local council) consider the development of an aluminium smelter in their town.
- Driving teenagers to drink. This unit asked whether there should be a zero breath alcohol level for teenagers. The students were ten asked to design a breathalyser.

The units were used over a period of 10 lessons in a class of 20 Year 12 female students. There was some measure of gain in the students' redox conceptual understanding as elicited before and after the teaching using pre- and post-questionnaires, concept mapping, and formal school tests. In addition to their declarative knowledge, the students also developed a variety of cognitive skills including:

- constructing questions, proposing new questions, setting up hypotheses in the form of questions;
- volunteering evidence drawn from other sources, therefore making links to other experiences;
- communicating through recreated experiences;
- being reflective; and
- challenging each other and the teacher. There was a notable shift in expertise from the teacher to expertise shared with the student.

Social and affective aspects of learning

Rodrigues (1993) gives many instances of when the teaching and learning activities promoted the sharing of anecdotes. In the unit of work "Driving teenagers to drink", the students shared experiences of themselves and others having been breathalysed by Police in random breath-checks. They also shared experiences of hair-perming, and farm activities. The anecdoting was a way of linking prior experiences to the science being learnt to enhance conceptual development. In other words, the anecdoting was a part of the discussion that resulted in conceptual development.

A focus on the social, rather than the cognitive, aspects of classroom interactions was a feature of a study by Wigglesworth (1999). The stimulus for this research was to investigate the "barriers to learning and achievement". Of special concern were the social "barriers to learning" for the "at risk" students and students with low self-esteem, the main research question being "what aspects of the classroom social environment significantly influenced the construction of scientific understandings?"

The research involved a five-week teaching module on photosynthesis, taught to a class of 14-year-old (Year 10) students. The students were asked directly to name their understanding of what events/situations working with others within their class helped or hindered their learning of science concepts. Their personal reactions to some of these social interactions were also obtained. Self-report data were obtained by student and teacher/researcher observational and interpretive daily journals and also by way of interviews and open-ended class discussions between the teacher/researcher and the students.

The classroom aspects that the students said helped their learning were:
- practical activities;
- class and small discussion group discussions;
- teacher and student question/answer sessions;
- teacher explanation of the science concepts; and
- written work, in that it offered an opportunity for students to review and reflect on their work, particularly their homework time (Wigglesworth, 1999).

The classroom aspects, which were viewed as hindering learning, and which were consistently listed by students, included:
- affect – largely negative feelings triggered within the learner as a result of some social event/situation that generally occurred within the classroom;
- noise –if there was more than a low level of "working" sounds within the classroom; and
- a rushed pace – if the speed at which the teacher moved through the concepts involved in the topic being taught was perceived by the students as "too fast" for them to "grasp" the conceptual understandings (Wigglesworth, 1999).

Affect was seen to play a role in learning in the science classroom.

> Within this class the majority of feelings experienced by the students were listed as positive. ...negative feelings were perceived as having a more powerful impact and were shown to interfere with the students' ability to concentrate on their learning of the science concepts, so hindering learning. Negative effect particularly came into play when students felt their learning goals were being thwarted by some event/situation within the classroom or when an interpersonal relationship became somewhat "dysfunctional" (Wigglesworth, 1999, p. 206).

Students' questions

The pedagogical role of questions in the classroom was addressed in the Learning in Science Project (Primary). However, the questions were not seen as teachers' asking questions to which they already knew the answer, but as student-initiated questions to facilitate their learning. The argument or thesis was that primary school children's own questions about natural and technological phenomena can have considerable significance for their learning in science (see section 4.2).

4.6.3 Meaningful contexts and effective pedagogies

Several thesis studies associated with the LISP research programme researched the use of contexts that have meaning for the students, as a pedagogical strategy for science education. The theory was that students would find these learning contexts interesting and relevant, and would be able to relate to, ask questions about, develop, and explore their own ideas and make sense of their world. Such contexts would enable the students to make links between their existing ideas, experiences, values, and cultural experiences to the science to be learnt. Other contexts could be used to help students use their newly learnt science with confidence.

Jones (1988) studied Year 13 physics students as they learned about capacitance and the Doppler Effect. These science ideas were taught in the context of technological applications, such as: the camera flash; the microphone; the Apnoea mattress; altitude measurement; the thickness measurer; a humidity sensor; and the early detection of volcanic eruptions. Rodrigues (1993) used these contexts to teach about redox reactions to Year 12 chemistry students: Thiobaccillus bacteria and the New Zealand farmer; hair-perming; the development of an aluminium smelter in a town; alcohol and teenage drivers. Both Jones and Rodrigues found that the achievement of the middle quartiles of students was raised through this use of "teaching in context".

Wood (1996) suggested the contexts of Supertoms, AIDS, making babies and fingerprinting, and Darwin today to teach genetics to students between Years 8 and 13.

Gribble (1993) used the contexts of Maori myths and legends, and specifically the two legends of "The Warrior Mountain" by Katerina Mataira and the Legend of Whakaruamoko, during the teaching of a unit on volcanoes and earthquakes to two Year 9 classes. The findings indicated that the Mäori students from the intervention class made no significant improvement in cognitive learning from the teaching of the earth science unit, which included the two Mäori legends, than students from the comparison class. A similar trend was found for the non-Mäori students. In the post-survey findings, the Mäori students in the intervention class had a positive attitude towards the inclusion of aspects of Mäori culture in science lessons and the value that was placed on their cultural knowledge by a Päkehä teacher. This improved the rapport between the Mäori students and the teacher (who was also the researcher). In the post-survey findings, a significant number of non-Mäori students in the intervention class changed their views to believing that myths and legends did have a place in the science classroom. Given the small sample size and the short span of the teaching, any test of significance must be interpreted cautiously. These findings parallel studies on taha Mäori (see Bishop and Glynn, 1999), which indicate that while non-Mäori gain knowledge and acceptance of Mäori cultural knowledge, the achievement of Mäori is not increased.

This research raises the question about whether the contexts felt by students and teachers to be meaningful and useful today, will still be so in a few years' time. A mechanism within a curriculum format for the revision of specified contexts is required, as in the Year 13 biology curriculum and exam prescriptions' "current issues" section.

4.6.4 The relationship between content and pedagogy

Another key finding of the LISP research programme has been the importance of the content in a debate on pedagogy and learning (for example, see Kirkwood and Carr, 1988). The research on the role of students' existing ideas has indicated not only how the science content in part shapes the teaching and learning processes as in traditional curriculum planning, but also how the pedagogy and learning processes shape the content learnt. The teachers', students', and scientists' existing views of a concept (for example, of energy, or animal, or boiling) interact in the communication during teaching and learning to strongly influence the learning outcomes. The content to be learnt is not unproblematic nor is it a generic, neutral aspect of pedagogy. The scientists' concept of "energy", for example, is not transmitted from sender to receiver unchanged. As the sender and the receiver both construct understandings, during the communication process and negotiate shared understandings there is much room for mis-communication and unexpected learning outcomes. For example, a teacher may say that water is made of hydrogen and oxygen and understand it to mean it to be a molecule comprised of hydrogen gas and oxygen chemically bonded together. But the students who say that the bubbles in boiling water are bubbles of hydrogen and bubbles of oxygen gas, may or may not have the notion of them being chemically bonded. The content (water is made of hydrogen and oxygen) is not unproblematic.

4.6.5 Formative interactions and effective pedagogies

The fifth Learning in Science Project (Assessment) researched the important and effective pedagogical activity in the giving of feedback and feed-forward to the students whilst they are learning (Black and Wiliam, 1998; Bell and Cowie, 2001). This activity is called formative assessment or formative interaction. The term “formative interaction” is useful here as it emphasises the role of dialogue (not a monologue) and communication (not just talking) in promoting conceptual development. The teacher and student must negotiate a shared understanding if the feedback and feed-forward is to be given and understood (Cowie, 2000).

4.7 Concluding comments on the Learning in Science Projects and associated theses

The theoretical frameworks underpinning the views of learning, language and cognition during the five Learning in Science Projects shifted from a personal constructivist view (Osborne and Wittrock, 1985) towards more socio-cultural (Bell and Gilbert, 1996) and discursive views (Bell and Cowie, 2001). In summary, the descriptive and learning outcome findings of the LISP research programme indicated that effective pedagogy in science education, included the following:

- **Taking into account students' existing thinking:** Pedagogy in science education is effective when learners’ existing ideas and beliefs, which they bring to a lesson, are elicited, addressed, and linked to their classroom experiences at the beginning of a teaching programme. Knowing the possible alternative conceptions (alternative to those of scientists) that students may bring to the science lesson and the specific ones that students in her or his class do actually hold, is part of a teacher's effective science pedagogy. The prior ideas of the students determine subsequent curriculum planning, choice of teaching and learning activities, and the interaction the teacher has with the students.
- **Taking into account students' experiences, world-views, culture and values:** Pedagogy in science education is effective when the teacher takes into account and builds on the experiences, worldviews, culture, and values of the students. In this way, science education can become more inclusive for students from diverse cultures, girls and boys, special-needs students, students with special abilities, and students with learning difficulties.
- **Learning activities that promote thinking:** Pedagogy in science education is effective when the students are engaged in thinking about the science during the learning tasks. Learning activities such as brainstorming, surveys, concept mapping, students' questions, post-box activity, card sorting games, crosswords, role play, drama, reading stories and articles, group presentations, class discussions, problem solving, and investigations can provide opportunities for the students to be engaged in thinking about the science.
- **Teaching in relevant contexts:** Effective pedagogical practice in science education includes the teaching and learning of science in contexts in which the student can make links between their existing knowledge, the classroom experiences, and the science to be learnt.

- **Giving feedback:** Pedagogy in science education is effective when students are given feedback on their learning during the learning process. To give feedback, teachers need to understand the science, the appropriate level of understanding in the curriculum, the student's understanding and the appropriate progression of the science ideas to be learnt. This formative interaction or assessment does raise learning outcomes.
- **Questioning content:** Effective pedagogy in science education acknowledges that the science content in part shapes the teaching and learning processes. The teachers', students' and scientists' views of a concept (for example, energy) interact in the communication during teaching and learning to strongly influence the learning outcomes.
- **Classroom discussion and communication**: Effective pedagogy in science education involves effective classroom discussion as a part of the overall communication. This may be a discussion by the whole class, discussion within small groups or dialogue between a teacher and student or student and student. The key aspect of discussions is that the students are talking science, and sharing their thinking with others, including the teacher.

The first three LISP projects preceded the development of the 1993 Science in the New Zealand Curriculum. Several of the recommendations which emerged from the LISP findings were reflected in the official curriculum document “suggested contexts”, “possible learning experiences”; the broad achievement objectives; the titles of the strands as “making sense ...”; the inclusion of thinking skills as part of the strand of “developing scientific skills and attitudes”; and the use of terms relating to constructivist views of learning in the introductory and policy statements at the front of the document. However, other aspects of the curriculum format, especially the notion of the “levels of achievement” do not reflect the research nor the associated theories of learning which developed during the LISP projects.

The degree to which the LISP findings are reflected in the teachers' pedagogical practices and the students' received curriculum is less clear. Despite the pre-service programmes that include the LISP findings, and the in-service programmes run in some parts of the country as part of the 1993 science curriculum implementation work, the actual uptake and use of the LISP findings in classroom pedagogies and supporting resources is thought to be varied and has yet to be widely researched. In addition, the use of recent theorising on learning and mind (Bell, 2000) to develop and evaluate additional effective pedagogies has yet to occur as has the researching of the use of the pedagogies developed in the LISP programmes, without the perceived constraints of national and school curriculum and assessment policies.

Timeline Overview

Time period for the review (1991-2001)

While the time period for the review has been specified for the general curriculum policy context of 1991-2001, as requested by the Ministry we have included literature dated prior to this period as necessary to show major developments in science education and the state-of-the-art position at the outset of the decade both nationally and internationally. In particular, we have considered the contribution to New Zealand science education made by the Learning in Science Projects 1979-1996 in relation to effective science pedagogy in practice.

Timeline overview

A diagrammatic timeline overview was developed as an organising device and a point of reference for the remaining review chapters. The overview is intended to assist readers who are unfamiliar with recent science education literature to identify the significance of trends and developments in research, curriculum and policy development, teaching practice, and student outcomes.

The timeline is divided into several strands and depicts some of the major factors related to New Zealand science education research, practice, and policy including: predominant learning theories and international research trends in science education; the five Learning in Science Projects; past and current equity debates in science education; curriculum and policy developments affecting New Zealand science education; and measures of New Zealand students' achievement in science during the last decade.

The overview also shows some of the temporal relationships between the depicted strands. We emphasise that the figure is intended as a conceptual aid only, and is designed to give a thumbnail sketch of some of the important events and ideas relevant to New Zealand science education that are discussed in following chapters. It is by no means a comprehensive picture. In many cases the vertical lines delineating the time periods for particular theories, debates, or research lines are approximations only. Furthermore, we add a reminder that the figure is intended to indicate *temporal*, not causal, or contributory relationships.

With these cautions in mind, the overview, and the relationships it illustrates, will be referred to again at certain points in later chapters.

Figure 4.1: Timeline overview for science education research in New Zealand prior to and during the review period 1991-2001

<table>
<tr><td rowspan="2"></td><td>1960s</td><td colspan="10">1970s</td><td colspan="10">1980s</td><td colspan="10">1990s</td><td colspan="2">2000</td></tr>
<tr><td></td><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>0</td><td>1</td></tr>
<tr><td rowspan="4">Predominant Learning Theories</td><td colspan="3">Behaviourist views</td><td colspan="9">Developmental theories</td><td colspan="15"></td><td colspan="6">Neurocognitive theories</td></tr>
<tr><td colspan="9"></td><td colspan="9">Personal constructivist theories</td><td colspan="1"></td><td colspan="14">Social constructivist views of learning</td></tr>
<tr><td colspan="19"></td><td colspan="14">Situated cognition and socio-cultural views of learning</td></tr>
<tr><td colspan="13"></td><td colspan="20">Theories of conceptual change and conceptual development</td></tr>
<tr><td rowspan="6">Research Trends in International Science Education</td><td colspan="12">Discovery learning , “process” approaches to science learning</td><td colspan="11"></td><td colspan="10">Models and modelling in science education</td></tr>
<tr><td colspan="6"></td><td colspan="8">Learners’ alternative conceptions</td><td colspan="19">Teaching for conceptual development, teaching for metacognitive thinking</td></tr>
<tr><td colspan="11"></td><td colspan="22">Developing learners’ own questions, encouraging discussion and argumentation in the classroom</td></tr>
<tr><td colspan="11"></td><td colspan="10">Developing language and reading-to-learn in science</td><td colspan="12">Teaching for scientific literacy and probing the nature of science, teaching with narrative pedagogies</td></tr>
<tr><td colspan="18"></td><td colspan="15">Setting science teaching in authentic contexts</td></tr>
<tr><td colspan="21"></td><td colspan="12"></td></tr>
<tr><td>LISP Projects</td><td colspan="9"></td><td colspan="4">LISP Form 1-4</td><td colspan="3">LISP Primary</td><td colspan="4">LISP Energy</td><td colspan="1"></td><td colspan="4">LISP Teacher development</td><td colspan="1"></td><td colspan="3">LISP Assess-ment</td><td colspan="4"></td></tr>
<tr><td>NZ Curriculum Developments</td><td colspan="8"></td><td colspan="3">1978 Draft science syllabus yrs 7-10</td><td colspan="7"></td><td colspan="4">1989 Draft Forms 1-5 science syllabus</td><td colspan="1"></td><td colspan="3">1993 NZCF & SiNZC</td><td colspan="2">1996 Putaiao</td><td colspan="4">1999 Guidelines for environmental education</td><td colspan="1"></td></tr>
<tr><td rowspan="3">Equity Debates (Gender & Culture)</td><td colspan="11"></td><td colspan="10">Deficit model of girls</td><td colspan="6">Gender inclusiveness and equal opportunities</td><td colspan="6" rowspan="2">Post-modern deconstruction and anthropological views of gender and culture</td></tr>
<tr><td colspan="27"></td></tr>
<tr><td colspan="23"></td><td colspan="5">Multicultural debates</td><td colspan="5">Science education as cultural “border crossing”</td></tr>
<tr><td rowspan="3">National Measures Of Student Achievement In Science</td><td colspan="24"></td><td colspan="3">1994 TIMSS</td><td colspan="1"></td><td colspan="3">1998 TIMSS-R</td><td colspan="2"></td></tr>
<tr><td colspan="25"></td><td colspan="3">1995 NEMP cycle 1</td><td colspan="1"></td><td colspan="3">1999 NEMP cycle 2</td><td colspan="1"></td></tr>
<tr><td colspan="30"></td><td colspan="3">2000 PISA</td></tr>
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PART II: EVIDENCE FROM CLASSROOM RESEARCH IN SCIENCE EDUCATION

Chapter Five: Pedagogy to Support the Achievement of "Content" Learning Outcomes

5.0 Introduction

This chapter focuses on pedagogy that could help raise students' achievement in science through better learning of science content. As noted in Chapter Two, the achievement of student learning outcomes related to science content knowledge is given strong emphasis in *Science in the New Zealand Curriculum (SNZC)*, via four contextual strands that specify broad achievement aims and achievement objectives for content learning at all eight levels of the curriculum. Students' science content knowledge also appears to be the main focus of comparative measures of international (TIMSS) and national (NEMP) student achievement as outlined in Chapter Three.

However section 2.6 also outlined the diversity of ways that teachers could interpret the achievement objectives specified in the contextual strands of *SNZC* and suggested that such interpretations may depend on a wide range of factors. These factors include the teacher's view, often implicitly held, of the purpose(s) for learning science at school, and their practical decision making about what content to include and how it should be sequenced, paced, and related (or not) to real world contexts. Such interpretive flexibility is a deliberate feature of *SNZC*, and is related to the equity focus on "science for all". This makes the specification of universally appropriate content learning outcomes a far from straightforward task.

Chapter Four noted the impact of the research findings of the earliest Learning in Science Projects (LISP). These world-renowned projects clearly demonstrated that, notwithstanding their classroom learning experiences, students frequently continue to hold their "everyday" understandings of key science concepts, especially where the scientific understanding is counterintuitive (Osborne and Freyberg, 1985a). The insights of LISP and similar projects that have continued to be carried out around the world since the 1980s (Pfundt and Duit, 2000) have challenged science educators to think deeply about effective pedagogy. As outlined in Chapter Four, the second of the LISP projects explicitly researched new possibilities for teaching that might succeed in taking account of children's ideas and helping them towards the development of understandings that are more scientifically appropriate. Such learning implies a process of conceptual change or conceptual development[10] that is considerably more challenging to both teachers and learners than the more traditional learning activities of assimilation and recall. The timeline overview given at the end of Part I shows the close temporal alignment between the first three LISP projects and the development of *SNZC*. As noted in Chapters Two and Four, the curriculum development team captured the essence of this conceptually-focused research in the philosophy of "personal constructivism".

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[10] While the term "conceptual change" is widely used, it should be noted that some authors prefer the term "conceptual development" which alludes to the more gradual nature of concept learning, rather than abrupt change.

Against this background of change and transition in New Zealand's science education policy and practice during the late-1980s/early-1990s, Chapter Five introduces international and New Zealand research that has sought to evaluate the learning outcomes that are actually achieved by students when their teachers implement pedagogy based in conceptual development views of learning. Section 5.1 begins with a brief overview of conceptual change models of learning. Following that, sections 5.2, 5.3 and 5.4 report on key features of pedagogies that have been demonstrated to be effective in meeting the challenges sketched in Section 5.1. Section 5.5 then explores three internationally significant longitudinal research projects that have sought to combine aspects of these various pedagogies into "learning programmes", contrasting the results of these projects with the research already outlined in the earlier parts of the chapter.

5.1 Conceptual change pedagogies: meeting the challenge of working with students' own ideas

As a consequence of the constructivist approaches developed during the 1980s and early 1990s, much recent research into effective learning and teaching in science has focused on understanding the processes involved in learners' conceptual change and how this understanding might be used to promote more effective science pedagogies. There has also been a strong research emphasis on the elicitation of children's prior ideas in science, taking these ideas into account, and the development of teaching strategies designed to move them towards science ideas (for example, see the first three Learning in Science Projects described in Chapter Four). The term "conceptual change research" describes the broad range of research projects that have been carried out with these aims in mind (for comprehensive summaries see Tyson, Venville, Harrison and Treagust, 1997; Duit and Treagust, 1998; Georghiades, 2000).

5.1.1 The nature of conceptual change

The basic foundation of conceptual change research is that learning of science concepts and principles involves restructuring, rather than replacement, of students' already existing pre-instructional conceptions (Duit and Treagust, 1998). The influential model for conceptual change proposed by Posner, Strike, Hewson and Gertzog (1982) suggests that four conditions foster conceptual change: there must be dissatisfaction with current conceptions, and any new conceptions must be intelligible, initially plausible, and fruitful to the learner. Central to this model is the notion that different ideas and conceptions hold different degrees of "status" in a person's mind (Posner *et al.*, 1982). "Status" is defined as the degree to which the person holding an idea knows this, accepts the idea and finds it intelligible, fruitful and plausible. According to this conceptual change model, to learn something means that the learner has raised its status within the context of his or her "conceptual ecology" – that is, all the knowledge that the person has. This model locates knowledge primarily within the mind of the individual, thus conferring on the individual the power and the responsibility to take control of his or her own learning (Hewson, Beeth and Thorley, 1998).

5.1.2 Teaching for conceptual change

The requirement that students take responsibility for their own learning clearly carries profound pedagogical implications. Within this model of learning, students may not merely sit and absorb content that has been "delivered" by the teacher. Rather they are required to be active co-participants in the learning process. Consequently, the conceptual change model of learning has led to the development of teaching approaches which place students' science conceptions, and their ability to reflect on their own conceptions, at the centre of science pedagogy.

Teaching approaches that have been developed from constructivist and conceptual change views of learning thus require teachers to engage with and respond to students' ideas. In a review of research, Scott, Asoko and Driver (1992) describe various conceptual change teaching strategies reported in the research literature as falling into two main types:

1. those which use teaching strategies designed to elicit students' ideas and to contrast these with scientists' ideas at the outset - sometimes called the "cognitive conflict" model; and
2. those which begin from students' ideas and leading towards gradual change – sometimes called "conceptual development".

Key features of pedagogy that have been designed to take one or both of these two broad approaches are explored in sections 5.2 – 5.4 below. First, however, several longitudinal research studies are outlined to illustrate the complexities that teachers must face when they use conceptual development pedagogies to help individual students achieve pre-specified knowledge outcomes.

5.1.3 Conceptual change research and the individual child: insights from longitudinal studies

Many studies of children's conceptual change in science take place over relatively short periods of time, and rely on cross-age studies to draw conclusions about what happens to learners' conceptions over time. Although there have been many calls in the literature for more longitudinal studies of learners' conceptual change, the time and difficulty they involve means that few such studies have been conducted. However, a small number of studies do suggest challenges to views of learning represented in mainstream conceptual change literature. Johnson's (1998) three-year study of children's conceptions of particle theory was born from earlier research into alternative conceptions that seemed to suggest a widespread failure by children to grasp particle ideas. The results of Johnson's longitudinal study suggest that children's alternative conceptions can form part of a progression, over time, towards scientifically acceptable ideas, but that teaching practices that take account of students' ideas may inadvertently promote "alternative" ideas as endpoints in themselves (Johnson, 1998).

Other longitudinal studies highlight the personal characteristics of individual learners and learning pathways. Peterson and Tytler (2001) studied 14 Australian Primary school children's views of evaporation over three years, from age 5 to age 8. Hellden (2001) studied 23 Swedish students' conceptualisations of ecological processes over a ten-year period, from age 9 to age 19. At age 15 and

19, the students listened to audiotapes of themselves at age 11 and 15 respectively, and were asked to comment on what they heard and to describe how they thought their understanding had developed over the years. While the learners in both of these studies generally moved towards more sophisticated views of evaporation and ecological processes, respectively, their learning pathways were complex. At different points, each student's learning pathway was determined by a unique combination of:

- their exposure to science ideas in the classroom;
- their beliefs about the nature of science knowledge; and
- their own conceptions of themselves as individuals and as learners.

Many of the latter two aspects were evident from the beginning of their school life. The students wove their understandings of the science ideas into narratives which revealed their individual subjectivities, including their views of themselves as learners, their commitments and orientations to schooling, and their social relationships with friends and family members (Peterson and Tytler, 2001). These and other longitudinal studies (Holgersson, 2001; Nieswandt, 2001) indicate several common themes:

- The process of conceptual learning does not appear to be one where old conceptions are exchanged for new ones.
- Rather, as learners develop conceptual understandings, they add concepts to their conceptual repertoire, and learn to use these in appropriate contexts.
- Learners' conceptions are interwoven with personal biographies, and personal contexts and continuity are evident in students' thinking across time.
- Specific, often social incidents, involving friends, neighbours or family members, appear to be critical in the formation of children's science conceptions.
- Reflective learners are often able to explain the way they developed their understandings, and can identify important precursors to their understandings years later.

5.2 Developing students' metacognitive awareness

The classroom teacher who wishes to follow the intentions of *SNZC* and develop personal constructivist approaches to classroom pedagogy is faced with a difficult dilemma. The longitudinal studies reported in section 5.1.3 suggest that the overall conceptual development of each child is idiosyncratic and related to a complex mix of contextual factors that include, but are by no means limited to, their organised learning experiences at school. Is it feasible that all students working in one class can be expected to confront and challenge their own diverse ideas, and to move these significantly in the direction of scientists' ideas, as specified in the "Achievement Objectives" of the curriculum? Section 5.2 begins to address this critical question by examining evidence concerning students' willingness to engage with the learning challenges they might face in a classroom where teaching seeks to work from and develop students' own ideas.

The large body of "alternative conceptions" research that has been comprehensively collated by Pfundt and Duit (2000) underscores the very real pedagogical challenges that teachers and students face when working with conceptual change models of learning. Beginning with the early LISP projects, it has become clear that "understanding scientifically" is a very demanding type of learning outcome. Science ideas are often counterintuitive and this impedes students' ability to "fruitfully" and "plausibly" reconstruct their views in the manner outlined by Posner *et al.* (1982). This section explores evidence for the proposition that assisting students to become more metacognitive will also assist them to develop their understanding of scientific concepts and ideas. Metacognition broadly refers to a learner's awareness of, and power to control, their own cognitive functions – that is, to think about their own thinking and to act on the insights thus gained. The remainder of this section reviews research from science classrooms in which metacognitive teaching strategies have been used and considers the evidence for whether these strategies can improve students' science content knowledge learning outcomes.

5.2.1 Theoretical links between conceptual development and metacognition

Because conceptual development approaches require students to become more aware of their own personal theorising about science ideas, there is considerable overlap between research on conceptual development and research on metacognition in the science education literature. While research into learners' conceptual development provides an in-depth view of many of the problems and difficulties learners face in developing understanding in and about science, metacognition is seen as a potential mediator of improvement (Georghiades, 2000). A survey of research on the effectiveness of metacognition as a classroom strategy in science education is thus highly germane to the question of how student achievement in science might be raised.

Many studies involving metacognition are based on theories of conceptual change similar to that described by Posner *et al.* (1982). Hewson *et al.* (1998) further developed the conceptual change model into a pedagogical model that encourages students to discuss and reflect on their ideas in science as they are engaged in developing science concepts. The guiding principles for Hewson *et al.*'s "teaching for conceptual change" model are as follows:

- both students' and teachers' ideas in science should be an explicit part of classroom discourse;
- the discourse of the classroom should be explicitly metacognitive;
- the status of ideas should be discussed and negotiated in classroom discourse;
- students should be able to make decisions about the status of certain ideas and be able to explicitly justify their decisions; and
- the justification process should be a part of the curriculum of the classroom.

(Hewson *et al.*, 1998)

5.2.2 Linking metacognition and conceptual development in the classroom

The studies outlined in this section explore situations where teachers embedded metacognitive strategies within the overall learning experience they had planned for their students. Thus both metacognitive and conceptual development learning outcomes were evaluated and reported on in the research.

In a small study by Beeth (1998), sixteen 10 and 11 year old US elementary school students learned to use the "status" of ideas as a metacognitive tool to speak about their conceptions while studying the physical science concepts of force and motion. Under the guidance of their teacher, students in this classroom first developed their own clear definitions of the words "intelligible" and "plausible", and then applied these constructs when speaking about their ideas related to force and motion. The students were able to successfully apply status constructs to their developing notions of force and motion and to determine at each stage whether their ideas and explanations were intelligible and plausible according to their newly-developed understanding of these words.

The teacher used comments from the students during the lessons to evaluate their progress and help her to plan instruction based on the students' progress. For example, at the early stage of the unit on force and motion, the teacher elicited students' own descriptions of force and motion and asked them to categorise these according to what made sense to them. It became clear to the teacher during this exercise that students were placing *descriptions* of motion and *causes* of motion in the same category. She thus asked the students to separate these two notions and initially to focus only on describing the motion of objects. The concept of force as something that could change the motion of an object was finally introduced when the teacher felt that the students could "go no further" (Beeth, 1998, p. 351) with their ideas about the motion of objects. While Beeth's study does not provide quantitative evidence of enhanced student learning outcomes, detailed dialogue between students, and between students and the teacher, does provide qualitative evidence of the achievement of conceptual development goals.

The teacher in this study believed that changes in students' abilities to comment on the status of a conception were just as important as their changes in science content knowledge. She valued the deep insights these students provided into their developing conceptions of force and motion when using the status constructs. However she also had a clear knowledge outcome in mind: for students to understand that there is a relationship between the motion of an object and forces that caused motion, an understanding necessary for developing a contemporary understanding of Newtonian physics. Thus metacognitive and cognitive learning outcomes were developed in tandem and each was an essential part of the total learning experience for these students.

While the students in Beeth's study were taught to use the ideas of "intelligibility" and "plausibility" to evaluate their own developing ideas about force and motion, Georghiades (2000) suggests that the long periods required to familiarize students with metacognitive terminology are not necessary in order for primary school pupils to be able to reflect on their own thinking in science. In trials with 68 year 5 pupils in Cyprus, short “metacognitive instances”, comprising brief discussions, thinking and writing tasks, and group activities, were introduced at selected points of a teaching unit on electricity. These instances encouraged pupils to reflect on their own thinking using their own language, so that rather than being made explicit, metacognitive strategies were mediated through careful lesson planning and teacher management of activities during the lessons. Georghiades argues that positive outcomes can be achieved when metacognitive feedback is given at a level that is appropriate for the pupil, for example (citing Adey, Shayer and Yates 1991): “How did you solve that problem? What were you thinking of when you reached that conclusion? You seem to have an interesting answer; go and explain it to Bob over there”. Pupils who received the intervention engaged more fully in classroom discussions and performed measurably better in a subsequent test of their understanding of electricity than pupils who did not.

5.2.3 Direct teaching of metacognitive thinking skills

Research by Hogan (1999a) focuses on practices that students themselves can use to regulate their own co-construction of knowledge in the context of group work. This study describes the use of an intervention called “Thinking Aloud Together” which was embedded within a 12-week science unit on building mental models of the nature of matter. The intervention included a phase of direct metacognitive instruction with the aim of helping students to make their collective thinking processes more visible “so that they could be examined, questioned and shaped as an object of learning” (Hogan, 1999a, p. 1090).

Four classes of American eighth-grade middle-school students (aged 13-14) received the intervention while four classes at the same school acted as a control for quantitative and qualitative analysis. Hogan found that the students who received the intervention gained more metacognitive knowledge about collaborative reasoning and were better able to articulate their collaborative reasoning processes than students in control classrooms (Hogan, 1999a).

Significantly, however, a post-intervention test which required students to apply their conceptual knowledge and to work collaboratively to solve a novel (for them) nature-of-matter problem, showed no difference between treatment and control student groups. Furthermore, students' enhanced metacognitive awareness did not translate into improved collaborative reasoning behaviours following the intervention. In other words, the students did not, or could not, use their declarative knowledge of how to think collaboratively when they encountered a new and different collaborative group task. Students’ ability to perform the new cognitive task appeared to be constrained in part by their lack of conceptual knowledge: groups who reasoned better together were those who “knew more science” (Hogan, 1999a, p. 1103) while groups who reasoned poorly often had difficulty comprehending the objectives of the task.

This study provides an interesting contrast to Beeth's research, reported in section 5.2.2 above. It suggests that thinking skills are not easily transferable to new contexts if content knowledge in the new area is not strong. Hogan notes that the collaborative mental model building task presented students with "extremely high cognitive demands to co-ordinate and synthesise information" (Hogan, 1999a, p. 1103). However,

> …whenever a student introduced a seed of conceptual information to his or her group, perhaps a concept remembered from a prior science class or an explanation needled out of a parent the previous night, the groups took off with the information as they continued to try to meet the explanatory demands of their task. The information that students gained access to on their own seemed to facilitate the continued growth of their thinking. Induction from laboratory experiences and observations alone were not sufficient to move students' thinking along (ibid.).

This supports the finding from Beeth's research that it is important to develop both conceptual and metacognitive knowledge together. The fact that students who did better drew on knowledge beyond what they had gained in the classroom further suggests that some students may be disadvantaged by gaps in conceptual knowledge that other students have the means or opportunity to fill for themselves. Unless these gaps are addressed in the classroom, students who are less able to draw on knowledge gained outside the classroom, may continue to struggle in classroom activities.

5.2.4 Linking metacognition and students' attitudes to learning

Evidence from the classroom-based studies reported above suggest the teacher needs to have clear conceptual goals in mind when attempting to use metacognitive approaches to conceptual development. This section also focuses on student and teacher attributes that might help raise student achievement when students' attitudes to learning are also taken into account. The research outlined in this section suggests that the development of personally meaningful understandings could raise achievement in science for both conceptual and attitudinal reasons.

Chin and Brown (2000) studied six students in the context of hands-on group laboratory activities in a chemistry unit in an eighth grade science class in midwestern United States. Chin and Brown's analysis contrasted "deep" and "surface" approaches taken by these students to their learning. When students used a deep approach, they:

- ventured their ideas more spontaneously;
- gave more elaborate explanations, describing mechanisms and cause–effect relationships or referring to personal experiences;
- asked questions which focused on explanations and causes, predictions, or resolving discrepancies in knowledge; and
- engaged in on-line theorising.

In contrast, students using a surface approach gave explanations that were reformulations of the questions, a "black box" variety which did not refer to a mechanism, or macroscopic descriptions which referred only to what was visible. Their questions also referred to more basic factual or procedural information.

Chin and Brown discuss disagreements in the literature concerning whether "deep" and "surface" approaches, as described above, represent contextual responses to a particular situation, or whether they represent a style-like, stable trait of the learner. One view is that, although students can change their approaches to learning according to the demands of each situation, they may have a predilection to adopt deep or surface approaches. Such a predilection is argued to persist over different situations, and may be linked to the student's personal characteristics including disposition and ability. In their own study, Chin and Brown found that the "deep" strategies were used more consistently by the students typically characterised as "deep approach" learners than by those typically characterised as "surface approach" learners. However, there were occasional instances when "surface" learners used a deep approach, and vice versa. They concluded that individual students' learning approaches are likely to be more differentiated than can be denoted with a simple bipolar deep-surface distinction.

This finding raises questions about what prompts students to switch from deep to surface approaches and vice versa. New Zealand research reported by Burns (1997) suggests some possible answers. Burns investigated relationships between students' conceptions of their personal learning goals and the types of content outcomes that they achieved. She found two different meanings for "understanding" among 6th form chemistry students. Students with a "knowledge" orientation to understanding were concerned with recall of relevant facts, while students with a "coherence" orientation to understanding examined relationships between pieces of information and wanted to know the meaning of terms and why things happen as they do. They were thus more actively involved in the construction of their own understandings. This description suggests similarities between the characteristics of the "deep/coherence" students and the "surface/knowledge" students of the two different studies.

Burns' study of 39 students found that only those with some coherence orientation achieved levels of understanding that progressed beyond factual recall. Burns concludes that students need to know about the nature of "understanding" – that is, they need to learn to be metacognitive - if they are to develop meaningful content learning outcomes in science. However, she warns that simply teaching metacognitive strategies is not enough to encourage the students to use these if the classroom environment is not appropriate. Significantly, less than half the students in her study "said that they would ask the teacher for help, and then only as a last resort or in private" (Burns, 1997, p. 29). While a variety of possible reasons for this type of response are outlined in Burns' analysis, the overall findings suggest that the classroom environment is critical to the achievement of more metacognitive levels of understanding. In such an environment:

- students and teachers would work collaboratively to identify topics of interest;
- opportunities for group work and peer discussion would encourage students to gather information and explore relationships between pieces of information; and
- students would then be encouraged to construct the integrated whole that constitutes understanding (Burns, 1997).

Summary of section 5.2

The research reported in this section suggests that a focus on metacognition may help raise student achievement when:

- a clear focus on cognitive goals is an integral part of the teaching and learning;
- students are supported to share and develop their ideas (which may or may not involve explicit coaching in metacognitive strategies);
- students' ideas are seen to be valued and are used by the teacher to help the students reflect on and move towards the conceptual goals;
- teachers use formative interactions to assess difficulties students may encounter during the development towards conceptual understandings; and
- students' progress in learning activities is carefully monitored so that critical gaps in students' conceptual knowledge can be diagnosed and addressed.

5.3 Using models to integrate cognition and metacognition

This section extends the proposition from section 5.2 that, in order to successfully develop conceptual understandings in science, learners need to be able to reflect on and discuss their understanding of scientific concepts as they are developing them. Section 5.3 explores possibilities for using mental models, conveyed as physical models, metaphors and analogies, to raise achievement of conceptual learning outcomes in science education. The area of models and modelling in science education has received an increasing amount of research attention in recent years (Franco, Barros, Colinvaux, Krapas, Queiroz and Alves, 1999; Gilbert and Boulter, 2000; Greca and Moreira, 2000) and there are several significant New Zealand studies to draw on (Coll, 1999; France, 2000; Taylor, 2000). Research indicates that models, metaphors and analogies are already widely used in science pedagogy. As outlined next, findings from a substantial body of research suggest that more metacognitive approaches to pedagogies which use models, metaphors and analogies could be a practical and manageable way to integrate cognition and metacognition in classrooms at both primary and secondary levels.

5.3.1 Types of models

A model is a representation of an idea, object, event, process or system (Gilbert and Boulter, 2000). "Mental models" are defined as human cognitive constructions (Smit and Finegold, 1995; Ritchie, Tobin and Hook, 1997) which are used to describe and explain phenomena which cannot be experienced directly. Mental modelling is an activity undertaken by individuals, whether alone or within a group. It is an attempt by humans both to understand the world and, when expressed publicly, to articulate their concepts to others (Harrison and Treagust, 1996). Mental models are not to be confused with the expressed models and the analogies that are often used to represent the mental model. The following is a helpful framework for discussing different kinds of models used in science (Gilbert and Boulter, 2000):

- Mental models that are expressed in the public domain through action, speech, writing or other symbolic form are called "expressed models".
- Expressed models which gain social acceptance following testing by the community of professional scientists become "consensus models".
- Consensus models which are currently in use at the frontiers of science may be termed "scientific models", while those produced in specific historical contexts and later superseded may be called "historical models".

Models and modelling play a crucial role in science practice, and one justification for their inclusion in science teaching is that they contribute to an "authentic" science education, in which the education reflects the nature of the parent discipline as much as possible (Gilbert, Boulter and Elmer, 2000). In fact, models and modelling already play an important role in teaching. Teachers commonly use models to explain ideas to pupils (Duit, 1991). Expressed models used in science teaching include: two-dimensional models, such as those found in textbook diagrams; three dimensional models such as scaled miniatures, scaled enlargements and working models; and visual and verbal metaphors and analogies, either in text or presented by teachers. Each of these models represents a mental model in some, but not all, its properties. That is, they are simplified representations of phenomena or ideas in that they take up an intermediate position between reality and a mental model.

5.3.2 Learners' difficulties with models

Notwithstanding their widespread use in traditional science pedagogy, as outlined above, there is a great deal of literature that documents the difficulties that science learners have in using and understanding scientific models. Models are human inventions and are thereby based on an incomplete understanding of how nature works. Models concentrate attention on specific aspects to explain something that is not familiar in terms of something that is familiar. Consequently, most models are "wrong" in some key aspect.

The pragmatic use of models that are known to possess limitations is one of the characteristics that differentiates the expert from the novice (Grosslight, Unger and Jay, 1991). Illustrating this, in a cross-age inquiry of learners' mental models for chemical bonding in Australia and New Zealand, Coll (1999) found that learners across three academic levels (Year 13, undergraduate and postgraduate) preferred simple or realist mental models for chemical bonding. However senior level learners were able to describe their mental models of chemical bonding in greater detail than their younger counterparts and were more critical of these mental models (Coll, 1999). Findings such as these have important consequences for science education. The literature shows that students frequently hold substantially different views on the nature of mental models to those held by their teachers, scientists and other experts (Ogborn & Martins, 1996). Factors that may impede pupils' effective use of models include:

- some learners may learn the model rather than the concept it is meant to illustrate (Thiele and Treagust, 1991; Treagust, 1993);
- pupils may lack awareness of the boundary between the model and the reality the model is representing (Dyche, McClurg, Stepans and Veath, 1993);
- unshared attributes are often a cause of misunderstanding for learners (Thiele and Treagust, 1991; Thagard, 1992);
- given a range of models, pupils often continue to use the least sophisticated one (Gilbert and Osborne, 1980);
- some pupils lack the necessary visual imagery (Treagust, 1993);
- some pupils find it difficult to apply the model in different contexts (Gilbert and Osborne, 1980);
- pupils may mix their models. For example they may have the concept that heat makes molecules expand (Gilbert and Osborne, 1980).

Many researchers argue that confusion in the use of models may have origins in the mode of instruction (Raghavan and Glaser, 1995; Harrison and Treagust, 1996). For example, Smit and

Finegold (1995) found that Southern African biological science teacher-trainees viewed models as necessarily scale models of reality as a result of their exposure to medical models such as models of the human body, insects, skeletons and so forth. Similarly, Barnea, Dori and Finegold (1995) report that Israeli pre- and in-service chemistry teachers failed to distinguish between a mental image and a physical model, believing instead that a model is simply a way to describe a process or phenomenon.

Evidently student (and sometimes teacher) difficulties arise in the absence of awareness of the differences between models and actual events, or of the limitations of various models of the same event. However in order to develop such awareness, students arguably need to learn to think about their thinking processes when using models. Section 5.3.3 describes evidence that does indeed suggest that this could be a useful way of overcoming difficulties that appear to be widespread in current teaching practice.

5.3.3 Learning to think about models and analogies for science concepts

Research on models and modelling suggests that students need to gain experience in the construction, critique, and use of mental models. Specific pedagogical strategies which have been suggested include teachers informing students as to the fundamental basis of mental models; that mental models are just that; they are scientists' constructions that are generated to explain data, model processes and behaviour, provide predictions and so forth (Harrison and Treagust, 1996; Franco *et al.*, 1999; Greca and Moreira, 2000).

Using concrete models with intermediate and primary learners

Taylor (2000) developed and trialled a model-building approach designed to teach astronomy to New Zealand year 7 and 8 students. Although *Science in the New Zealand Curriculum* (Ministry of Education, 1993a) emphasizes the integration between the learning of investigative skills and the learning of astronomy "content", the teaching of astronomy appears to remain fact-based and transmissive in style (Taylor 2000). The difficulties that learners may have in using and understanding mental models for astronomy concepts are well documented in the research literature (Pfundt and Duit, 2000), suggesting that transmissive pedagogy is not likely to be successful in helping many students meet the intended "content" outcomes. With this challenge in mind, Taylor's approach drew on Hesse's (1966) suggestion that the efficacy of a model can be judged by a process of learners (rather than the teacher) repeatedly critiquing the model in terms of its positive, negative and neutral attributes. Positive attributes are those properties which both the model and the mental model share and negative ones are those attributes not common to both the model and the mental model. Neutral attributes are simply those attributes not yet classified as positive or negative (Hesse, 1966).

Taylor's intervention comprised eleven lessons that proceeded according to a four-phase sequential teaching structure:

1. The *Focus on the Mental Model Phase*, (lessons one and two), explored ideas about mental models and actual models. The technique of critiquing models to show that all models have

limitations was introduced during this stage and the pupils' mental models were elicited and shared.

2. The *Model-Building and Critiquing Phase,* (lessons three to seven), focused on the use of scientists' mental models for the solar system to construct an actual model (called an orrery). The class repeatedly critiqued the ability of their orrery to illustrate the scientists' concepts, with the intention of helping them understand the intelligibility and plausibility of the scientists' mental model. Each lesson in this phase included a focus-challenge-review cycle of the concept under investigation in that lesson.
3. The *Using the Scientists' Mental Model to Solve Problems Phase*, (lessons eight and nine) encouraged pupils to utilise the scientists' mental model to solve some problems which were novel to them. Thus the focus of their thinking shifted from intelligibility and plausibility to fruitfulness. Novel (for pupils) problems that were explored included the causes of tides on Earth and what might happen to these tides if Earth had two moons. Each of the problems was resolved by several groups of pupils, thereby ensuring an attentive audience for the final reflective phase. (It is again interesting to note the similarities between the pedagogy used in stages 2 and 3 and the "status" approach taken by Beeth (1998) as outlined in section 5.2.2 above.)
4. The *Reflection Phase*, (lessons ten and eleven) focused on reporting and debating solutions of the different groups to each of the problems posed. This was intended to help the pupils further consolidate the scientists' mental model.

The pupils' astronomy knowledge was assessed in a pre-test, and the results were compared with tests of astronomy knowledge immediately following, and four weeks after, the intervention. The results showed that pupils learned many astronomy concepts as a result of the intervention and that this knowledge was retained for over four weeks. Taylor interviewed pupils and found that they responded positively to the learning-teaching approach adopted in the astronomy intervention, showing a clear affinity with the idea that they could attempt, as a group, to resolve problems in their own way within an overall supportive environment. They appeared to find the co-operative problem-solving and reporting-back phases to be interesting, challenging and informative, particularly when they realised there were conflicting views that needed to be resolved.

Penner, Giles, Lehrer and Schauble (1997) gave American grade 1 and 2 children the task of building a model that works like a human elbow. The teaching approach used in the study was very similar to that used by Taylor in New Zealand but included a more detailed evaluation of student learning outcomes. Through discussion, model building, evaluation and revision, children came to understand that not only motion, but also constraints on motion, were important qualities to include in their elbow models. After the model-based teaching, samples of students from the class were interviewed and asked to rate the functional quality of four elbow models: a picture of an arm with an arrow pointed at the elbow, a model made of two popsicle sticks joined by a lump of clay, a flexible straw, and a simple cardboard-and-string pulley model. The children's explanations for why each model was a good model for how the elbow works were examined and compared against non-modelling grade 2 and grade 4-5 classes. In comparison to a non-modelling peer group, modellers were largely able to ignore perceptual qualities when asked to judge the functional qualities of models and showed an understanding of the modelling process similar to that of children 3-4 years older.

Abell and Roth (1995) found that fifth grade American students misunderstood a pyramid model of trophic levels in a terrarium community as representing the space needs of the organism rather than energy relationships. However, when the teachers abandoned the scientific model and allowed students to construct their own, it was found that students did in fact have reasonable ideas about number relationships in the terrarium community.

Together, these three studies suggest that:

- enabling students to construct and critique their own models effectively supports the achievement of conceptual development outcomes during their learning;
- linking of conceptual and metacognitive learning when working with physical models can promote positive attitudes to learning science; and
- in addition to the achievement of science content learning outcomes, model-based teaching approaches can also result in students learning about the uses and limitations of models and the modelling process.

Using analogies for scientists' mental models

Analogies in particular, are used by scientists to help build more complex mental models and are used by scientists and exemplary teachers to explain abstract science conceptions (Ault, 1998). Therefore students need to be made aware of the value and use of particular types of mental models such as analogies (BouJaoude and Tamim, 2000).

Research on analogy use has centred on two conceptual themes: the prevalence of analogy in curriculum materials such as textbooks and in classroom practice; and learners' use of analogy or analog models. Dagher's (1995b) review of studies on the effectiveness of analogies in science education classified studies into one of two main categories according to whether the analogies were included in text or presented/facilitated by a teacher or researcher. She stated that the literature indicates that the level of guidance provided to readers, the degree of interaction permitted and the way the analogy is presented in the textbook are the main factors that determine the effectiveness of learning via textbooks.

Investigations into analogy use in the classroom have focused on the teacher's use of analogy during instruction, where it is frequently idiosyncratic (Thiele and Treagust, 1994). Dagher (1995a) found analogy use covers diverse source domains such as actual life experience, observed life experience, science fiction, personalised stories, and common objects. Thiele and Treagust's (1994) classroom study of Australian secondary school chemistry teachers' use of analogies is consistent with the work of Dagher (1995a) and revealed that teachers mainly used analogies for the purposes of explanation when learners were struggling to cope with the concepts. Similarly, according to Jarman (1996) the greater proportion of the analogies used in the science classrooms were generated spontaneously, although some were adapted from prior exposure to instruction.

Since analogies are clearly already in widespread use in science teaching, research on the effectiveness of approaches intended to allow students to reflect on their status as models for scientific ways of thinking is germane to the overall findings of this section of the review. Such research has indeed shown that even young students can use metaphors (Christidou, Kouladis and Christidis, 1997), and that the direct comparison of mental models and analogies can aid understanding (Newton and Newton, 1995). It has been suggested that teachers should encourage students to generate their own analogies (Pittman, 1999) whilst encouraging them to examine their mental models and analogies critically to see where they break down with respect to the scientists" mental models (Duit, 1991; Venville, Bryer and Treagust, 1994). These approaches appear to be applicable across a wide range of ages.

Given the widespread traditional use of models - especially analogies - in science teaching, and the evident promise shown by the research in their more explicitly metacognitive use, it seems timely to next explore research concerning the likely efficacy of professional development in the types of approaches described in section 5.3.3.

5.3.4 Learning how to teach science using models

France (2000) researched and developed a model-based professional development programme for New Zealand teachers teaching biotechnology. The professional development model for the program proposed that the teacher's role is one of mediation between the community of the classroom and the community of biotechnological practice (France, 1997). In order to fulfill this role, nineteen teachers in the programme developed teaching models to help students to understand some of the biological processes and concepts upon which biotechnology is based. However, following an analysis of the way the teaching models were actually implemented in classrooms from year 7 to year 12, France (2000) found several problems were encountered with model use. These included:

- Teachers often had insufficient pedagogical content knowledge to use these models effectively.
- Although familiar with the biological concepts, these teachers were new to biotechnology education and were unfamiliar with the knowledge base that this technology utilised.
- Generally, these teaching models were used to tell or direct students rather than providing a framework for personal discovery.

- In some cases students gave imaginary characteristics to the model.

For example, in one teaching model designed to teach aseptic techniques for microbial transfer, using red dye in place of bacteria (which are not visible), year 11 students mistook the red colour of the bacterial loop as it was flamed for sterilisation to indicate the presence of red bacteria. In another case, a teaching model designed to teach about the industrial fermentation process used the same microbes and substrates as the industrial process but had few features which could be extrapolated to understanding the wider dimensions of industrial bio-processes such as organism selection and culturing, and disposal of effluent.

France (2000) concluded that students and teachers need to discuss the purposes for model development in classrooms, and that teachers need pedagogical content knowledge of model use in order to be able to critique the models in terms of their classroom effectiveness. France also suggested that teaching models in classroom programmes will only be effective when teachers are aware of the role of models in the community of experts that use them (in this case, the community of the biotechnologists). This point is developed further in Section 5.3.5 below.

It has also been suggested that investigating learners' mental models can provide science education researchers and teachers with valuable information about the learners' conceptual framework, that is, the underlying knowledge structures (Vosniadou, 1994). However, discovering what a person's mental model is like is not easily accomplished, and learners' mental models may behave quite inconsistently (Hesse, 1966; Glynn and Duit, 1995; Harrison and Treagust, 1996; Greca and Moreira, 2000). Notwithstanding this complexity, it does seem that teachers need a broad understanding of the types of mental models that children might hold, and the ways in which these are likely to differ from scientists' mental models, thereby impacting on what is actually learnt. Such understandings could well be used as part of a process for strengthening teachers' pedagogical content knowledge where necessary. There are clear implications here for policy development and we return to these in Chapter Ten of the review.

5.3.5 Using models to develop other types of learning outcomes

Section 2.6 in Chapter Two described a range of possible outcomes for science education and outlined the manner in which *SNZC* specifies that students should develop outcomes related to understanding the nature of science at the same time as they are developing content learning outcomes. As outlined next, the pedagogies described in Section 5.3 lend themselves to this type of integration.

Models play an essential role in the practice of science (Ogborn and Martins, 1996). Accounts of the work of professional scientists are dominated by the building and testing of mental models (Penner *et al.*, 1997). Well known historical examples include Rutherford's solar system mental model of the atom and Volta and Ampere's representations of electricity in terms of the pressure and flows of liquids (Stavy, 1991). In fact, science cannot proceed without recourse to mental models and expressed models because of their necessary and central role both in research and in the communication of knowledge (Treagust, 1993; Dagher, 1994).

Gilbert *et al.* (2000) argue that learning about the origin and purpose of historical models for key science concepts is an important aspect of knowing *about* science. They also suggest that students need to learn about how expressed models are debated and tested until a consensus decision about their status is reached within the community of scientists. This is an aspect of the *sociology* of science, as described by Ryder (2001) and outlined in Section 2.6. (Chapter Two). If learning outcomes related to understanding the nature of science (NOS) are valued and are to be developed in tandem with strong conceptual outcomes, as suggested by the integrated structure of *SNZC*, then the rich body of research introduced in this section suggests that the explicitly metacognitive use of models and analogies may be an appropriate choice of pedagogy.

Summary of section 5.3

- The research reviewed in section 5.3 indicates that helping students to understand key mental models of science as part of their conceptual development will be most effective when:
- the teaching approach used emphasises the place of models, modelling, metaphor and analogies in both science and science education, so that students learn science, learn to *do* science and learn *about* science;
- students are helped to understand the role that mental models play in the construction of scientific models, and to be aware of the strengths and limitations of models in describing and explaining scientific concepts;
- students are able to construct and critique both their own models and scientists' models of scientific phenomena; and
- teachers have a good pedagogical content knowledge about the nature of science, in particular, the role of models, metaphor and analogy in scientific communities of practice, and they are also aware of the range of possible mental models of scientific phenomena that their students may hold.

5.4 Socio-cultural approaches to teaching and learning science for conceptual development

Recent literature in science education includes a line of critique against mainstream "conceptual change" approaches that address the tendency to overemphasise the individual's learning and neglect some of the wider social aspects involved in learning science (Duit and Treagust, 1998). There has also been criticism of a narrow focus on student conceptual and procedural knowledge development as if these are the only possible outcomes for science education.

> The fundamental question for understanding the rationality and objectivity of conceptual change involves what the basic unit of analysis is. Do we focus on individuals or communities of practice? Is the focus on the development of procedures of reasoning or on a conceptual understanding of scientific knowledge? Is conceptual change facilitated by directly impacting the cognition of individual learners or is it affected by the kind of social interactions which individuals have in a community of practice that promotes the development of scientific reasoning process?" (Duschl and Hamilton, 1998, p. 1061).

Questions such as these have direct relevance to pedagogical practice in science education because, as Duschl and Hamilton suggest:

> Shifting the focus from knowing and reasoning by individual scientists or learners of science, to communities of scientists or learners of science, requires fundamental changes of both our images of science learning environments and of what we want students and teachers to do in those environments (ibid., p. 1054).

Social constructivist and socio-cultural views of learning are becoming increasingly important in international science education research. These views suggest that the cognitive activities of individuals can be understood by examining the social and cultural contexts from which they are derived. Socio-cultural views of learning endorse the view that knowledge is socially constructed and context dependent, and that human mental processes are situated within their historical, cultural and institutional setting (Wertsch, 1991). This view of learning is related to the idea of "situated cognition" (Hennessey, 1993), meaning that cognitive processes differ according to the domain of thinking and the specifics of the task context (Brown, Collins and Duguid, 1989; Rogoff, 1990) From a socio-cultural perspective, learning means changing from one socio-cultural context to another as a process of enculturation by participation in shared activities (Lave and Wenger, 1991).

Typically, such social-cultural views of science learning promote the *community* aspect of the classroom and the role of peer discussion in assisting students to learn science. In this view, discussion with peers has the potential to provide students with alternative models of scientific phenomena and to introduce criteria as well as evidence to help learners to distinguish among scientific models. Classroom-based research into "cooperative learning" as a means to achieve these aims in science education extends back at least to the 1970s. Many earlier studies sought to investigate the efficiency of this pedagogy in classrooms, for example by using standardised achievement test scores or students' affective gains as indicators. The general conclusion of this research is that cooperative learning can positively enhance achievement and attitudes towards science (Lumpe, 1995; Lazarowitz and Hertz-Lazarowitz, 1998; Lowe and Fisher, 2001). However, recent literature shows research has moved towards a deeper examination of group work in science along several interrelated dimensions. These dimensions include:

- the embeddedness of group work in socio-cultural or social constructivist theories of learning (Lumpe, 1995; Woodruff and Meyer, 1997; Hogan, 1999b; Smeh and Fawns, 2000);
- the role of group work in facilitating deep learning and collaborative knowledge-building in science (Woodruff and Meyer, 1997; Tao, 1999; Hogan, 1999b);
- the use of group work to establish classroom conditions which emulate those of scientific discourse communities (Woodruff and Meyer, 1997; Newton, Driver and Osborne, 1999);
- the relationship between group work and the use of argument and discussion in science classrooms (Sprod, 1998; Newton *et al.*, 1999; Osborne, Erduran, Simon and Monk, 2001);
- students' roles in groups (Smeh and Fawns, 2000; Nuthall, 2001);
- the use of group work and peer discussion to achieve equity and excellence in classrooms of diverse students (Bianchini, 1997); and
- the intervening role of teacher beliefs and knowledge in facilitating group work which can achieve all these things (Lumpe, Haney and Czerniak, 1998; Ritchie and Tobin, 2001).

These are very diverse issues and concerns, signaling that the intended outcomes of group work may need more careful consideration in cases where broad claims are made for the efficacy of group work as a general type of pedagogy. Supporting this, Nuthall (in press) suggests that it is necessary to evaluate the practicality and effectiveness of "social constructivist" teaching approaches through a critical appraisal of the learning outcomes actually achieved via these group work approaches in classrooms. That is the aim of this section of the review.

5.4.1 Emulating scientific discourse communities: structuring productive student discussions

Much research on group work embodies the notion that students' knowledge building in science classrooms should have some relationship to the way that science knowledge is developed in the scientific community. In recent years thinking about what it means to be "doing science like a real scientist" has shifted from a focus on the individual to a focus on social context and the nature of interactions between scientists (or learners) [11] as the vehicle for knowledge change (Duschl and Hamilton, 1998). Inquiry/discovery approaches, which had been popular since the 1960s (see the timeline overview at the end of Part I), promoted the idea that students "doing science like real scientists" would be focused on academic, essentially cognitive outcomes, using a combination of rational thinking and "discovery" events. However, it has been widely suggested that "discovery learning" approaches neglected social, cultural, affective dimensions of science and were only partially suited to the complex and diverse context of school classrooms where these dimensions play

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[11] An important difference is that outcomes for scientists include *adding to* the existing stock of knowledge, whereas outcomes for students focus on conceptual development – that is coming to a more coherent *understanding* of concepts from the existing stock of knowledge.

an important role (Lazarowitz and Hertz-Lazarowitz, 1998). Such complexities are evident in the research that is reported in the rest of this section.

The whole class as a site of discussion

Nuthall (in press) suggests that in order to critically appraise the claims made about the effectiveness of social constructivist teaching approaches, it is worth investigating how these are experienced by students. He cites episodes from a series of New Zealand classroom studies (Nuthall, 2001) which examine how the actions of teachers in setting up and managing classroom activities interact with students' peer relationships and personal knowledge and beliefs to shape the ways in which students experience and learn from those activities. The studies were set in the context of students aged 9-12 engaged in units on science, social studies and technology. Students were fitted with wireless microphones and ceiling-mounted cameras recorded classroom activity.

The studies illustrated how the private conversations and social interactions between students impacted on the way they carried out and experienced classroom activities. Excerpts from these studies show that when students become actively involved in a whole-class discussion problem posed by the teacher, many alternative private discussions erupt in parallel with the public discussion. Nuthall concluded that:

- whole class discussion works best in the context of an activity in which the focus of discussion is on experiences that the students have shared with each other; and
- the aims of social constructivist teaching are more achievable in small groups than with a whole class.

Arguably, then, there should be a balance between whole class and small group work. Research that focuses on such a balance is outlined next.

Alternating between small-group and whole-class discussion

Taking a social constructivist perspective, Woodruff and Meyer (1997) propose a model for the construction of science knowledge in classrooms which emulates the way that science knowledge is developed in scientific communities. They suggest that scientists work in two types of communities using two different types of discourse. Within the scientist's laboratory, scientists discuss ideas that are not fully worked out, among peers, without high risk to their ego or career. Scientists also participate in a wider, inter-laboratory community. This more public forum sets and applies standards and benchmarks to scientific knowledge claims and supports the arbitration that lets the discipline advance. Woodruff and Meyer contend that classroom conditions can support these two forms of discourse when students build knowledge using a combination of small-group and whole-class work. Small group discourse supports students as they generate explanations and build on each other's ideas, while large-group discourse places a high demand for clarity and explanatory power on the working products of the groups, and challenges the acceptability of the ideas students generate. Such deliberation could be used to develop students' learning about the nature of science outcomes, if students were made aware of the differing purposes of these two types of discourse in a real community of scientists.

Woodruff and Meyer implemented this approach in grade 5 and grade 7 Canadian classes using topics such as shadows and images, and floating and sinking. Their study provides qualitative evidence to suggest that it effectively promoted students' ability to develop shared, coherent understandings of these phenomena. Taylor's New Zealand-based research with solar system models, outlined in section 5.3, also followed the pattern of alternating small-group and whole-class discussion at some stages. However Taylor attributed the success of his intervention to the systematic use of models (Taylor, 2000). Clearly within the complexity of real classroom settings it is difficult to make conclusive judgments about the effectiveness of individual components such as "discussion" per se.

Conditions for effective small group discussion

Jane Gilbert (1990) investigated ways to structure talk in secondary school science classes as a means of motivating a wider range of students to see science as interesting and personally relevant, as well as a means of achieving conceptual change through exploratory talk. She worked with three small groups of students from two Level Six modular science classes in an inner city New Zealand secondary school. The students discussed issues related to the concepts they were exploring, via a series of tasks that were designed to draw on their personal experiences.

Analysis of these discussions led Gilbert to emphasise the key role of the teacher, even when the intended focus of the communication is between small groups of students. She found that it was indeed possible to "engineer" rich exploratory talk if the small group tasks were well designed. Effective design features were those that required the students to:

- operate at higher levels than recall of cognitive information – that is, the task involved some aspect of cognitive development;
- produce an outcome as a result of the discussion;
- use carefully selected input material as a focus for discussion and decision making; and
- provide opportunities for everyone in the group to speak.

Gilbert found that the last of the above points was influenced by group dynamics, especially gender composition – something that is also evident in other literature reviews of classroom based research (Alton-Lee and Praat, 2000). She recommended that discussion groups be as homogeneous as possible (single sex, same or similar culture, same or similar ability) if full participation by all students is to be achieved.

Role allocation in group discussion

Teachers often structure group tasks via role allocation. Richmond and Striley (1996) analysed student talk in six groups of four students working in groups during laboratory investigations in a 10th-grade interdisciplinary science class. They found that specific social roles and leadership styles developed within groups and that these roles and styles greatly influenced the ease with which students developed scientific understanding. Smeh and Fawns (2000) examined patterns of communication within Australian year 8 science students engaged in problem solving. Groups were assigned one of two experimental treatments: a low-role structure, in which one role was rotated among members; and a high-role structure, in which each member was assigned an unchanging role. Control groups were not assigned specific roles. Analysis of student conversations found that no one strategy consistently resulted in the production of the highest levels of conceptualisation communication. However, the low-role strategy appeared to result in slightly more conceptual communication in all-male or all-female groups, while the high-role structure led to slightly more conceptual communication in mixed-gender groups. Smeh and Fawns suggested that mixed gender groups may be more socially difficult for middle school aged students and may require more management support, specifically for the teacher to impose role structures. The finding of difficulty in mixed-gender groups is consistent with Gilbert's (1990) findings but the proposed solution is quite different. Clearly there is no single answer to the pedagogical challenges that arise when teachers strive for meaningful engagement with conceptual ideas, for all students in small group discussions.

Using group discussion to promote positive attitudes to learning science

Feedback from Gilbert's participating students was almost universally positive and two selected verbatim responses show that these students were aware of, and able to comment on, the range of ways in which the exploratory talk of these activities assisted their learning:

> I enjoyed this method better than the standard methods used by most schools. I enjoyed this method because I remembered more about the subjects we learned. I remembered more because I had a clear exercise to think back to. I think that I was more interested because I became more involved in the topics. I found some of the topics weren't extensive enough so it did make me want to learn more (Gilbert, 1990, p. 183)

> …you think more about what you're discussing – in other words it goes into your brain and you analyse it. When you just write about it and copy it from a book it goes straight through your brain. …the way we had been doing the last module (discussing etc.) has helped me think about it more. …I think organised discussions would be very beneficial if they were a regular part of our classes. They've helped me learn heaps and I think other people like me (who don't learn much from copying notes and listening to the teacher) would really benefit from talking about different topics. And how and why things work. (ibid., p.184)

Other New Zealand studies involving younger students have also demonstrated their metacognitive awareness of how classroom episodes contribute to the retrieval and deduction strategies they call on when learning is being assessed (Nuthall and Alton-Lee, 1995; Nuthall, 2000) and clearly exploratory talk was very effective in this regard. Given the NEMP and TIMSS findings of a decline in attitudes towards science learning across the transition years from primary to secondary school, the students' comments on interest and engagement suggest both cognitive and motivational benefits of pedagogy that actively involves students in challenging and carefully structured exploratory talk.

Lowe and Fisher (2001) report on a New Zealand study designed around using group work for assessment as well as during learning. They hypothesised that positive attitudes towards science may be eroded when students first encounter secondary science classrooms where learning and assessment activities are generally focused on individual work. Lowe and Fisher designed an intervention in which year 9 and 10 science students were encouraged to work cooperatively in all aspects of class work including assignments, practical work, fieldwork *and* assessment exercises.

The intervention was trialled in 13 classes at four co-educational rural schools in New Zealand. Lowe and Fisher hypothesized that improving students' attitudes to learning science was an important first step towards raising student achievement in science, hence their study investigated changes in student's attitudes to science and did not report data on students' content learning outcomes. Surveys of students' attitudes towards science before and after the intervention showed no significant changes. However, Lowe and Fisher suggest that the fact that students' attitudes did not decline over this period was an improvement on the "norm" (in which students are perceived as showing declining attitudes towards the study of science across the early secondary school years).

5.4.2 Promoting student argumentation as a specific type of pedagogy

The role of argument in science education has become a much-debated topic in recent literature, further supporting the socio-cultural view that structured discussion, and the conditions which facilitate it, are a central dimension of both science and science education. (Solomon, 1998; Newton *et al.*, 1999; Osborne *et al.*, 2001). A distinguishing feature of argumentation is that students are expected to draw on *evidence* for their assertions (Osborne et. al, 2001) and this expectation necessitates that the materials that students work with are structured in ways that make the evidence for science theories apparent. In this manner students could well be developing understandings about how science theories are justified and validated against empirical data, as well as strengthening their understanding of the actual science concepts (Ratcliffe *et al.*, 2001).

Not all historical models for scientific argument are appropriate for the science classroom. Solomon (1998) cautions against the "strictly logical" style of argument favoured by Aristotle and other scientists of the Enlightenment, which can be confrontational and destructive. She favours a more "humanistic" kind of argument in which all students feel comfortable to listen to the ideas of others, to question these without angry rebuttal, and to introduce their own ideas, modifications and opinions in order to build towards shared understanding. Explicit reference to evidence to support such arguments is intended to ensure that such discussions are focused towards clear conceptual outcomes.

Using concept cartoons to promote argumentation

Concept cartoons appear to be a promising way of encouraging argumentation and learning in science classrooms (Naylor, Keogh and Downing, 2001). These simple cartoons show characters expressing different viewpoints about the science involved in an everyday situation. For example, one cartoon shows three people expressing different views about whether putting a coat on a snowman will either melt him or stop the snowman from melting, or make no difference. Concept cartoons were created to address constructivist views on learning in science, and in particular to incorporate the extensive research into children's alternative conceptions in science. They could be seen as a refinement of the "interview about instances" materials used in the early LISP projects. Because they present alternative ideas as a means of challenging and developing the learner's thinking, concept cartoons avoid the expectation that all groups of students will be able to draw a range of salient ideas from their joint personal experiences in any particular context. This helps avoid the problem of debate going in directions that are not helpful to the teacher's conceptual purpose. The provision of various pieces of evidence (that could be claimed to support one or more of the cartoon views) can further sharpen both the conceptual and the metacognitive focus for the group's argumentation processes.

Early trials with the cartoons found an extremely positive response from students and teachers (Keogh and Naylor, 1999). A particularly positive response was found amongst teachers who were committed to constructivist ideas, such as taking into account learners' existing ideas, but felt this to be unmanageable under normal circumstances. Current research on concept cartoons aims to explore in greater detail the nature of discussion and argumentation in primary science classes using the cartoons as a stimulus. Initial findings from pupils aged 7-9 in the UK show that discussion is focused, purposeful, and self-sustaining and results in high levels of pupil involvement, sometimes from pupils otherwise reluctant to express their personal views (Keogh and Naylor, 1999; Naylor *et al.*, 2001).

Clearly, this simple strategy holds considerable pedagogical promise, but we have found no research that investigates its use in New Zealand classrooms. Nor, to our knowledge, have any of the existing cartoons, which visually reflect the English social and environmental context, been adapted so that they show obviously New Zealand contexts and students.

5.4.3 Teacher behaviours which can help or hinder student discussions for conceptual development

Extending a piece of research discussed in section 5.2.3 (Hogan, 1999a), Hogan (1999b) looked at the depth of cognitive processing which occurred among five groups of eighth-grade American students, working in triads, as they collaboratively built science knowledge during a three-month investigative unit on building conceptual models of matter. The students' sense-making discussions during the unit were analysed for depth. Hogan found that two groups tended to process information on a surface level, while the other three tended to engage in deeper processing. Interestingly, the relationship between depth of processing and scientific "correctness" of students' ideas was not straightforward. Some groups engaged in deep processing yet expressed misconceptions about the nature of matter, albeit with high internal consistency. Other groups generated accurate explanations that were readily accepted by all members of the group, but then subsequently engaged in more surface-level processing. Again, these findings suggest that teachers need to have very clear conceptual goals in mind and that the design of the task will be critical to the successful realisation of these goals as focused conceptual development.

Task design may also require teachers to give attention to the type of interactions they have with students so that the need to reach conceptual learning goals does not supersede the specific needs and abilities of students. The ASSEN research project (Accessing Science for Special Educational Needs) recently carried out in Britain, explored features of student/teacher dialogue that kept science-related conversation flowing. The researchers analysed 812 interactions between experienced special-needs teachers and their primary school students. They identified patterns of teachers' responses that kept conversations open and those that stalled progress. They found that questions that elicited factual recall were very likely to bring the dialogue to a halt. For these special-needs students, very open-ended questions were also likely to stall dialogue. On the other hand questions that: gave clues; sequenced the conversation; changed the focus; built up steps for problem solving; and encouraged the child to "have a go" were all more likely to be successful (Bell, 1999). The ASSEN research confirmed that special-needs students do hold identifiable personal ideas about science concepts, similar in range to the "everyday" views of their peers. When talk is structured to their particular needs, these ideas can be productively explored and thus these students can experience meaningful learning in science (Bell, 1999).

Given findings such as these, the question arises whether, from a teaching perspective, it is more important for students to reach the "correct" answers or for students to engage in deeper discussion and cognitive processing at the expense of "getting it right" right away (Osborne *et al.*, 2001). The consensus view in the literature on group work in science from a socio-cultural or social constructivist research perspective appears to suggest that sometimes it is necessary to ease up on expecting students to construct understandings that are scientifically accurate. In this view it is important, at least initially, to allow them to experience what it is like to build original models, theories and explanations in the way that scientists do (Hogan 1999b).

However, such metacognitive outcomes may be extremely difficult for teachers to achieve. During in-depth investigation of group discussions in an 8th grade middle-school science class, Ritchie and Tobin (2001) found that students' discussions were dominated by statements which reproduced information from textbook or teacher. They rarely engaged in truly dialogic discussion - that is, building on the ideas generated during discussions between themselves and questioning or challenging their ideas or the information coming from the textbook or the teacher. The teacher in Ritchie and Tobin's study used and saw the value of group work activities. However, they reported that the teacher's referent for learning science was one of "exposure"- that learning required students to be exposed to science for themselves (i.e. through investigative work) in order to understand – a position more akin to "discovery learning". During both group and whole-class dialogue, the teacher rewarded reproductive talk and cued students towards the correct predictions. Consequently, the teacher's authority as dispenser of scientific facts was never challenged. Ritchie and Tobin suggest this was a barrier to the development of dialogic discussion in the class:

> Students need to be shown how to represent their knowledge in the form of evidence-based arguments. When students are able to challenge each other's arguments from an empirical position as well as one based on the authority of textbook propositions, small group discussions will move towards the discourse characteristic of a scientific discourse community (Ritchie and Tobin, 2001, p. 297)

Newton *et al.*(1999) investigated the extent to which teachers provided opportunities for pupils in Years 7-11 to contribute to the co-construction of knowledge through discussion and argumentation in seven London schools. They found classroom discourse to be largely teacher-dominated and opportunities for the social construction of knowledge, or the use of argument-based pedagogical techniques, were few. Discussions with teachers suggested two major barriers:

1. There were limitations in teachers' pedagogical repertoires: they felt they didn't know how to manage group discussion effectively.
2. External pressures such as lack of time, demands to "cover" curriculum, and the demands of the assessment system were seen to mitigate against using such pedagogy.

While there is evidence that the teaching approaches described in this section can result in various combinations of conceptual, attitudinal and "nature of science" learning outcomes, there are tensions in the research reported in this section between what researchers may see as "ideal" and what teachers are prepared or are able to do in practice. Clear thinking about the intended content knowledge, attitudinal and "nature of science" learning outcomes would appear to be a necessary first step to designing learning tasks to promote argumentation as an approach to structured discussion.

Summary of section 5.4

- Classroom research indicates that pedagogies involving whole-class and/or small-group discussion activities can promote conceptual learning, metacognitive learning, nature-of-science learning and/or positive student attitudes in science classrooms
- The structure of groups can impact on the participation rates and types of outcomes achieved by individual students.
- Role allocation may increase participation of some students, especially in mixed-gender groups.
- Pedagogy that encourages students to develop their discussion skills through structured argumentation has been a focus of a range of recent research projects.
- Students may achieve different types of outcomes through argumentation, depending on the design of the task and their degree of engagement with it.
- Skillful task design and teacher clarity about intended outcomes impact directly on the outcomes actually achieved.
- "Content" learning outcomes are achieved when students think deeply about the manner in which evidence does or does not support their personal theories about science concepts.
- "Nature of science" learning outcomes are achieved when students recognise that science theories are similarly tested against evidence that has been systematically collected from the natural world.
- In some studies, students have shown reluctance to challenge the authority of teachers, textbooks and other traditional sources of information during group discussion, despite the fact that these sources may not present the evidence for stated theories and concepts.

5.5 Three detailed pedagogical models

This section outlines key features of three well-documented, research-based models for teaching and learning, each with its own combination of specific pedagogical features. These features are compared with those identified in the earlier sections of the chapter and evidence for the effectiveness of each model as a total "package" is outlined.

5.5.1 "Complex Instruction"

Bianchini (1997) argues that greater recognition of group work's complexities and further refinement of its tasks and strategies are needed to improve the depth and breadth of students' scientific discussions in small groups, particularly in classes where students are diverse. She investigated group work in three diverse Californian middle-school science classrooms where initiatives designed to provide greater access to science for traditionally marginalised students were being used. These initiatives were: the *Human Biology* curriculum, which aims to teach science in contexts familiar to diverse students' everyday lives; and the *Complex Instruction* (CI) model of group work. This is a research-based model developed by researchers at Stanford University. CI is intended to enable teachers to teach at a high intellectual level in academically, linguistically, racially, ethnically and socially heterogeneous classrooms. It includes the aim of overturning conventional definitions of "smart" and "dumb" among students, and of disrupting status hierarchy in the classroom. Key features of the Complex Instruction model (Cohen and Lotan, 1997) are:

- organising the classroom for productive group work;
- assigning learning tasks that are true group tasks (in the sense that they are challenging, open-ended, require many different intellectual abilities and resources and are organised around a big idea or central concept of a discipline)' and
- equalising the participation of students of different status in small groups by using the following two strategies:
  1) *The multiple-ability orientation:* teachers make clear to students that the task requires many different kinds of skills and abilities to complete and that no one person in the group will have all of the abilities necessary to complete the task but that everyone will have some of the abilities.
  2) *Assigning competence to low-status students:* teachers carefully observe groups, ask probing questions, and watch for moments when low-status students show how competent they are on some of the abilities previously identified. The teacher then tells the student (and points out to the group) what the student did well and how their contributions are relevant to the group task.

It takes at least one full year for teachers to learn how to manage the classroom successfully using CI. Professional development begins with an intensive two-week summer institute in which teachers learn about the theoretical base and central principles of CI. A year-long follow-up is a non-negotiable component of the CI professional development model. A staff developer visits the teacher's classroom at least nine times, collecting data on the students' activities and the teachers' practices to see how well the CI is working. Together, the teacher and the staff developer use this information to identify problems and potential solutions.

Evaluation of CI and effect on student achievement in science

CI has been used and evaluated across a number of disciplines in a wide range of elementary and middle schools in the United States. An evaluation study of 13 middle-school science classrooms using the CI model was conducted in 1992-1993 and 1993-1994, using tests content-referenced to four of the six *Human Biology* curriculum units that had been taught. The tests were designed to assess students' factual knowledge, conceptual understanding and ability to apply and synthesize scientific information. Three hundred and forty sixth- and eighth-grade students were given pre-tests and post-tests before and after each unit. Although control groups were not used as a reference, post-test scores for the 13 classes were significantly higher than the pre-test scores for all of the five units. The highest of these was a 24.9% gain (Cohen, Bianchini, Cossey, Holthius, Morphew, and Whitcomb 1997).

Although these results suggest that Complex Instruction can be very effective in raising student achievement, three classroom studies reported in detail by Bianchini (1997) provide naturalistic evidence that behind the statistics, attempts to implement CI in the classroom do not always live up to the ideal. Analysis of videotape and audiotape of students during the group activities in these classrooms indicated that "high-status" students (those perceived as more able or intelligent) still had higher rates of on-task talk, and learned more, while "low-status" students were often excluded from participation during group work. Students who had participated more during the discussions also scored higher in pencil-and-paper tests administered after the unit. Overall, students' exploration, discussion and negotiation of scientific ideas during the study lacked intellectual depth. Bianchini points to difficulties in both the task designs, and the implementation of the strategy, as contributing to these results. Students appeared to have difficulty comprehending the purposes of some of the activities, connecting them with the science concepts they were intended to introduce and/or connecting them to the context of their everyday lives, often because they lacked relevant prior knowledge. Students only connected the content of their activities to its context, to other scientific information, or to everyday life when prompted by their teacher. Also, the teacher used the "multiple abilities" strategy, but did not use the "assigning competence" strategy which might have helped the contributions of the low-status students be recognised by their peers.

All of these findings are consistent with the complexities reported in the earlier sections of this chapter. Clearly, students do require assistance to develop the necessary skills for group work and discussion to enhance deep science learning. They do also need direction and advice on the intellectual nature of learning tasks and they do need the social skills to engage in collaborative learning. As also noted in earlier sections of the review, teachers also interpret such models according to their own beliefs about the purposes for learning and their own ideas about "what works". The tight pedagogical specifications of this model appear to add an extra layer of teacher decision-making that may actually impair their focus on the actual "content" thinking that should be happening if conceptual development is an intended outcome for every student.

5.5.2 Cognitive Acceleration in Science Education (CASE)

Cognitive Acceleration in Science Education (CASE) is an intervention programme, targeted at students aged 11-14 years, developed in the UK. CASE was designed to strengthen the academic achievement of the middle 80-90% of learners (Adey and Shayer, 1994; Adey, 1999). The model aims to improve children's thinking processes by accelerating progress towards the higher-order thinking skills deemed necessary to match the demands of the National Science Curriculum - skills which prior research had suggested were lacking in many students even by age 16 (Adey and Shayer, 1994). The CASE intervention is intended to span over two years and is accompanied by a two-year in-service professional development course for teachers.

Once every two weeks in CASE schools, normal science curriculum lessons are replaced with special "Thinking Science" lessons. These are designed to teach patterns of thinking in science (for example, the isolation and control of variables) while attending to metacognitive thinking and transferability of knowledge and strategies to other learning contexts. Thus CASE practice involves children participating in whole-class and small-group discussions. The pedagogical model is carefully sequenced into five steps:

- concrete preparation (establishing the terms of a problem);
- cognitive conflict (thinking develops in response to a cognitive challenge);
- construction (students must construct their own reasoning processes);
- metacognition (reflection on the process of problem solving); and
- bridging (using reasoning patterns developed in the CASE context in other contexts).

Evaluation of CASE and the effect on student achievement in science

In 1984-1987 CASE was trialled in 10 schools representing widely different social and geographical environments in England, using experimental classes (with CASE intervention) and control classes (without CASE intervention). After two years, experimental and control classes were given post-tests of cognitive development and a test of science achievement. Little difference was found in experimental and control group scores. However, two years after the intervention, students took their GCSE (General Certificate of Secondary Education) examinations and a statistically significant difference was found between CASE and non-CASE student achievement. Furthermore, students who had participated in CASE achieved higher results in Science, Mathematics and English than students in control groups. Shayer and Adey consider this to be evidence that the effect on student thinking transfers beyond the science context in which the CASE intervention is delivered (Adey and Shayer, 1994; Adey, 1999). Further trials of CASE continue to show measurable increases in student achievement two years after the interventions (Shayer, 1999)

Despite these promising findings, the literature indicates that there is a lack of qualitative naturalistic classroom evidence to further confirm exactly how and why CASE seems to work (White and Mitchell, 1994; Leo and Galloway, 1996; Jones and Gott, 1998; Shayer, 1999). Further qualitative or descriptive data from CASE classrooms would certainly help to elucidate the crucial features that contribute to the success of CASE in raising student achievement (Shayer, 1999). However, existing descriptions of the CASE methodology seem to point to three particularly important features:

1. Students work in small groups and then participate in whole-class discussions. The teacher's role is to facilitate and manage this process so that "each pupil gets a chance to move a little beyond their present level of understanding" (Shayer 1999, p. 900).
2. The science content of the "Thinking Science" curriculum appears to be integral to the process of developing students' understanding and metacognitive capability.

3. The teachers participate in a two-year development programme and teach the same students for two years:

> During this time, teachers learn a great deal about the learning difficulties of their pupils, they learn more about the hierarchies of difficulty of the science they teach, and learn how to match these to their pupils' abilities (ibid.).

Achieving motivational outcomes through CASE pedagogy

One difficulty with the CASE data is that the way in which individual learners respond to the CASE intervention has not been adequately investigated. Evidence suggests that some children show no improvement in achievement following the CASE intervention (Leo and Galloway, 1996). This raises some interesting questions, particularly in the context of a classroom where students may be diverse in their abilities and backgrounds.

Leo and Galloway (1996) suggest that a theoretical model of motivational style can illuminate CASE findings by considering underlying psychological processes involved in children's learning. The concept of motivational style suggests that children are actively involved in their own learning process and make choices about how they will behave. A motivational style or "thinking disposition" (Perkins and Grotzer, 1997) describes what the thinker is inclined to do, as opposed to "thinking ability", what the thinker is able to do. Thinking dispositions or motivational styles are thought to emanate in part from students' underlying beliefs about learning, or their view of themselves as learners. These may vary according to context (for example a child's motivational style may vary by subject or by teacher) and it has been suggested that these may be learned patterns rather than characteristics of an individual.

Leo and Galloway describe three kinds of motivational style:

- "learned helplessness" where a learner avoids challenges due to a perception that failure is inevitable;
- "self-worth motivation" where a learner perceives their performance as ability related, with subsequent avoidance of difficult tasks; and
- "mastery-oriented" where a learner perceives learning as valuable and intrinsically worthwhile and difficult tasks as challenging rather than threatening.

Motivational styles or thinking dispositions are considered to be independent of actual ability (Leo and Galloway, 1996). However, they may have a powerful influence on thinking ability because without appropriate thinking dispositions, thinking abilities can lie fallow. Leo and Galloway suggest that children who adopt a mastery-oriented approach focus on effort and that the differential effects of the CASE intervention might be explained in terms of motivational style; in other words, that mastery-oriented students are more likely to respond positively to the CASE intervention. They also suggests that CASE techniques, with their emphasis on metacognitive thinking and creating a co-operative classroom environment, could be used to help children who are underachieving or experiencing learning difficulties, by refocusing their thinking about the actual challenges involved in their learning.

Metacognitive strategies and the relationship to science content

Jones and Gott (1998) question whether pedagogical aspects of the CASE intervention might be abstracted to work in other contexts beyond the “Thinking Science” curriculum. They review the evidence from CASE and add further contextual information drawn from the experience of one of the authors (Jones) who trained teachers and provided classroom support in the CASE methodology at five schools in 1992. The authors report that the actual implementation of the CASE programmes varied at each school and suggested that these variations contributed to differences in student achievement. The authors suggest that the CASE technique could be conceptually dismembered into:

- A “content”, consisting of both science content and science procedural knowledge; and
- A “methodology” for teaching that content using the following steps: concrete preparation, the presentation of a situation to stimulate cognitive conflict, and teacher intervention to enable metacognition and bridging of students' understanding to other contexts.

Jones and Gott suggest that this dismemberment would give teachers and schools greater freedom to add CASE methodologies to their range of teaching strategies and to apply these independently of the CASE content for use with different groups of children (including younger children) and in different contexts.

An American analogue to the CASE approach is White and Frederikson’s (1998) computer-based middle-school science curriculum and teaching strategy, “ThinkerTools”, which is designed to develop students’ metacognitive knowledge and skills through a process of scaffolded inquiry, reflection, and generalisation. The students learn, and reflect on, the processes of scientific inquiry as they construct computer-based models of force and motion phenomena. The developers believed that students’ difficulty with science lies in not knowing how to construct conceptual models of scientific phenomena or how to monitor and reflect on their learning progress. In trials in 12 urban classrooms, grade 7, 8 and 9 students’ performance improved significantly on physics and inquiry assessments. A particular finding was that the program was especially beneficial for educationally disadvantaged students and contributed to closing the performance gap between low and high-achieving students, without impeding the high-achieving students.

Findings from classroom studies of CASE and "ThinkerTools" *add* further support to the argument that the metacognitive aspect of the teaching cannot be easily separated from the subject context in which it is taught. This was a clear message all the earlier sections of this chapter - to improve students' ability to reflect on their performance, the performance itself needs to be addressed. Simply put:

> A student's deeper understanding of the significance of these activities comes from actually practicing them and reflecting on them over time. The hypothesis is that one has to be already engaged in a practice in order to develop an understanding of it, because if you are not doing it, you cannot reflect on it (White and Frederikson, 1998)

5.5.3 The Project for Enhancing Effective Learning (PEEL)

There has been much Australian research related to metacognition in science education. Research into individual student learning of science concepts was strongly influenced by the development of research into students' alternative conceptions when the PEEL model was conceived (White, 1991). PEEL began in 1985 with ten teachers in one secondary school, and has spread to over twenty schools in Australia and other countries (White and Mitchell, 1994). Unlike CASE, for example, which was targeted only at science classrooms, PEEL aimed to have teachers across different subjects (including science) use procedures to promote a wide range of learning. However, science learning has been a key focus of PEEL, primarily because of the science education background of its leading figures.

The conceptual basis for the Australian approach to metacognition in the science classroom is described by White and Mitchell (1994). During the 1970s and 1980s, two lines of research in Australia caused concern about the quality of learning of science. One was research measuring students' attitudes to science, which showed students had increasingly poor attitudes as they progressed through their schooling. The other was research probing students' beliefs about natural phenomena and scientific principles (i.e. students' alternative conceptions), and the fact that these seemed to persist in the face of exposure to scientists' explanations. The conclusion was that both of these findings could be attributed to students' lack of control over their learning. Whether learners were unable to direct their own learning because they had not learned how, because they were not allowed to, or because they did not want to, it was believed that training in metacognition may overcome all of these things. This belief resonated with a personal constructivist view: that adequate metacognition empowers the learner to undertake the constructivist process of recognition, evaluation, and revision of personal views. (White and Mitchell, 1994). This learner-focus is evident in studies that have investigated students' views of learning and of themselves as learners of science (Thomas and McRobbie, 1999), and whether collaborative reflection by teachers and secondary (year 8 to year 12) students might enhance teaching and learning of science (Baird, Fensham, Gunstone and White, 1991).

In spite of its goal of enhancing effective learning, studies of the effects on student outcomes from PEEL are rare (White and Mitchell, 1994) and White (2001) suggests that PEEL has been evaluated only lightly with respect to its key goal. There is only limited evidence showing that PEEL students became more purposeful, independent and reflective, and there have been no longitudinal studies, for example, to track subsequent performance of PEEL students as they go into tertiary education. In fact, the major focus of PEEL and related projects has been on teacher professional development. While the evidence of transformation of student learning is scant, there is evidence to suggest that PEEL is an effective model for positive transformation of teaching practice (White, 2001).

A small New Zealand study mirrors the Australian approach to metacognition as a strategy of directly addressing and enhancing students' conscious knowledge of their own learning (Conner and Gunstone, 2001). Metacognitive learning strategies were introduced to a class of sixteen Year 13 biology students by their regular teacher during a four-and-a-half week essay research and writing unit. The unit required students to "investigate contemporary biological issues and make informed judgements on any social, ethical or environmental implications" - in this case, the causes, development and treatments of cancer. The teacher used prompter instructions as part of the everyday learning, and provided the students with written guidelines for planning their research and for writing their essays. Most of the students set their own agendas for planning their individual research, choosing the two types of cancer they wanted to investigate and determining the key words and key questions that would drive their work. They also used notebooks (journals) to record their thinking. The journals included bookmarks that had prompts designed to help them consider the biological, ethical and social issues as well as planning and monitoring their researching and writing. For example:

- What does what I've found out today mean?
- It seems important to note .....
- I disagree with............... because.......
- What I need to do now is........

The teacher encouraged the students to write questions into their notebooks as a guide for their research. The teacher also went through a checklist of features of an essay with the students. The students marked each others' draft copies of the essays, a process that allowed them to share ideas, especially in terms of what could be written and how the ideas could be organised and presented. The essays were marked according to a marking schedule negotiated between the teacher and the students.

Final essay marks provided a measure of student achievement in the unit. The study investigated the link between the use of the suggested learning strategies and the quality of the final essay product. It was found that metacognitive awareness and student control of their own learning was more evident in students who produced "quality" essays (scoring marks of 26/40 or higher). Students who were motivated to achieve good essays were more apt to use the self-monitoring strategies and produced higher quality essays. A link was also found between students' perceptions of their own role in learning and student achievement in essays. Students who produced lesser quality essays (scoring marks of 25/40 or less), or did not submit essays, expected the teacher to monitor their work for them and wondered why the teacher was not "telling" them what they needed to know (Conner, 2000). However, the study does not provide evidence that the introduction of metacognitive strategies increased student achievement. Rather, the findings strongly suggest that students who achieved well were simply more receptive to using the strategies or were already familiar with these ways of thinking, while students who did not achieve well did not find the strategies useful or relevant.

Because of the limited evaluation of student outcomes in the PEEL and PEEL-related studies, it is difficult to draw decisive conclusions about how successful these approaches have been in developing students' conceptual learning in science. However, studies such as Conner and Gunstone's (2000) tend to suggest that an approach which seeks to directly develop students' metacognitive thinking, without also seeking to develop their understanding of the specific content they are learning, is not likely to lead to enhanced content learning outcomes.

5.6 Summary of Chapter Five

The classroom research literature reviewed in this chapter provides a number of clear implications for pedagogy aimed towards raising student achievement in science. Evidence for "raised achievement" has surfaced in studies across this chapter both in terms of improving content knowledge learning outcomes, and in terms of promoting other positive learning outcomes related to students' attitude, motivation, and understandings about the nature of science.

Research reported in sections 5.2 and 5.5 indicated that direct teaching of metacognitive thinking skills, or encouraging learners to reflect on their own learning independent of a subject context does *not* seem to be effective in enhancing students' conceptual learning. Instead, effective metacognitive thinking is best promoted when classroom conditions are structured so that strategies can be learned in conjunction with development of conceptual understandings in science. Several studies indicated that students may successfully learn how to use metacognitive strategies in one science learning context, but may struggle to apply these strategies in a new context if they have gaps in their content knowledge that are not directly addressed. Whether metacognitive thinking strategies are explicitly taught to students, or whether they are built in to the design of a particular learning task, the most successful instances in classrooms involving metacognitive thinking are those in which both cognitive and metacognitive learning outcomes are intended, and teachers engage in formative interactions with students to track their progress and help them towards both kinds of learning outcome.

A common theme to emerge in studies reported in this chapter is that in order to successfully develop conceptual understandings in science, learners need to be able to reflect on and discuss their understandings of scientific concepts as they are developing them. Section 5.3 reviewed a significant body of research relating to the role of mental models, physical models, metaphors and analogies in science teaching. Studies indicate that pedagogies involving various types of modelling are most effective when students are able to construct and critique both their own, and scientists', models of scientific phenomena. The "effectiveness" of these pedagogies has been measured in terms of both conceptual learning and "understanding the nature of science" learning outcomes. That is, students in some studies appear to have learned not only the content of a particular science concept, but also about the uses and limitations of models as a representational tool.

Research reviewed in sections 5.2, 5.3 and 5.4 indicates that group work and peer discussion can be vital components of successful teaching to enhance students' cognitive *and* metacognitive thinking skills. In the studies reviewed in section 5.4, the development of social interaction through group work and discussion was typically not seen as an end in itself, but was a medium for promoting students' deep conceptual development in science.

Finally, section 5.5 reviewed three well documented, research-based models for teaching and learning that have been trialled in science classrooms in New Zealand or in other countries. Several of the features of the smaller studies reviewed in sections 5.2 to 5.4 are reflected in different degrees and in different combinations in the large projects reviewed in section 5.5.

Chapter Six: Learning to "do" science

6.0 Introduction

Chapter Five reviewed recent classroom research for evidence of pedagogies which are effective in promoting the development of students' understandings of scientific concepts. The primary focus of this chapter is to further investigate evidence for pedagogies that are effective in helping students to learn about the "doing" of science.

Section 2.6 (Chapter Two) noted that there are two kinds of learning outcomes, specified in the integrating strands in *SNZC*, which relate to the "doing" of science: process/skills learning outcomes; and outcomes related to learning about the nature of science. These are described below:

1. Process/skills learning outcomes

The achievement objectives related to these outcomes are identified in the *Developing Scientific Skills and Attitudes* integrating strand of *SNZC,* and organised as four sets of skills subdivided into four broad levels of achievement: Focusing and Planning; Information Gathering; Processing and Interpreting; and Reporting. These outcomes focus on students' experiences when learning how to do science in the classroom, i.e. how to become skilled and capable "investigators".

2. Understandings about the nature of science (NOS) learning outcomes

The achievement objectives related to these outcomes are identified in the *Making Sense of the Nature of Science and its Relationship to Technology* strand. They focus on learning about the processes and practices of real scientific inquiry – that is, how the content is produced, validated, and applied within and beyond the community of working scientists. In this chapter they are abbreviated as "NOS understandings" or "NOS learning outcomes".

The purpose of this chapter is to provide a further analysis of evidence for pedagogies that are effective in helping students to achieve these two kinds of learning outcomes. The dedication of a separate chapter to this end should not be taken to imply that learning the *processes and skills* involved in doing science, and learning about the nature and characteristics of scientific inquiry, should or can meaningfully be separated from learning about the content or concepts of science. In fact, the relationship between these three types of learning outcomes in the classroom is complex. Conceptual, procedural and NOS understandings interact to produce a range of student learning outcomes.

During the development of this review, it became evident that there was a paucity of classroom research in which the effectiveness of different types of pedagogy were explicitly reported on in terms of their impact on all three kinds of learning outcome:

- students' conceptual knowledge development; ***and***
- students' development of process/skills understandings in science; ***and***
- students' understandings about the nature and characteristics of science.

Chapter Five also illustrated the complexities of disentangling conceptual/content knowledge learning outcomes from other types of learning outcomes when evaluating the effectiveness of various pedagogical approaches to teaching and learning science. For example, many of the classroom studies described in Chapter Five included instances where students were engaged in various kinds of practical learning activities designed to aid and promote their conceptual learning in science. When building and critiquing a model of an elbow or an orrery, for example, students are not only learning specific science content, but are also engaged in "doing" science. In examples such as these, the "doing" component is integral to the whole learning experience, though the explicit research focus may be on some other aspect of what is occurring in these classrooms (for example, the metacognitive thinking aspect; the models and modelling aspect; or the classroom discussion aspect).

The difficulty in separating the conceptual and procedural aspects of science learning is most evident in the large body of science education literature which deals with the role of "practical work" in the science classroom. This chapter begins with an exploration of three distinct pedagogical approaches to practical work in school science: "recipe practicals"; "open investigations"; and "fair testing". Section 6.1 investigates classroom studies that reported learning outcomes which have resulted from "recipe" practical work. Following that, section 6.2 explores the nature of "open" student investigations and reports on their uptake in one large New Zealand secondary school study. Section 6.3 explores the common conceptualisation of practical science as only being about "fair testing", especially at the primary school level. For each of these pedagogies, both positive and problematic learning outcomes are identified. These learning outcomes variously relate to the development of students' conceptual/content knowledge, their process/skills knowledge, and their understandings about the nature and characteristics of scientific inquiry. Finally, section 6.4 provides a summary of research that has sought to evaluate the effect of different teaching approaches on students' understandings about the nature of science, and section 6.5 provides a summary of this chapter.

6.1 Learning outcomes of "recipe practical" approaches to science teaching

The use of "recipe practicals" in science lessons appears to have been commonplace since at least the 1960s, especially in secondary schools, although we have found no New Zealand research that provides specific data about this. The pedagogical features of such practical work in secondary classrooms follow a general pattern:

- clear instructions are given as to how to proceed through the stages of the investigation (sometimes on worksheets, sometimes on the board);
- materials needed are prepared ahead and are in the classroom in advance;

- students follow the "method" outlined and collect the data specified, recording these as "results" (often, but not always, in a pre-specified format); and
- students "explain" their results (sometimes with clues as to the appropriate theory, for example: "use the idea of "particles" to explain what you see").

6.1.1 Recipe practicals in secondary classrooms

During the first LISP project, Tasker and Freyberg (1985) observed practical work of the "recipe" type in a range of junior secondary science classes. This appears to have been the most comprehensive research of this type of pedagogy that has been carried out in New Zealand. Tasker and Freyberg identified a number of ways in which such practical work was misinterpreted by groups of students, leading to outcomes that were obviously not those intended by the classroom teacher. Such misinterpretations included:

- **Mistaking the purpose of the experiment by attending to aspects other than those that the teacher intended.** For example, in one classroom students were following instructions for an experiment designed to show that it is easier to judge distance with two eyes (binocular vision) than with one (monocular vision). However, students variously misinterpreted the experiment to be about reaction times, cross-eyedness, or the time it took the eye to focus after it was opened.
- **Failing to recognise the significance of particular aspects of the investigation, even though the correct terminology was being used**. For example, students in another class talked about the "control tube" they had used in a recent experiment but could not explain why it was called a "control" or what purpose it served.
- **Making procedural blunders that obviated against the production of meaningful results, yet failing to recognise this.** For example, students who had difficulty fitting the stopper on a flask in one experiment simply proceeded without the stopper, without recognising that the experiment would not "work" properly without it.

Commenting on the last of these episodes, the researchers drew clear conclusions about the pitfalls of this type of pedagogy:

> This is a clear example of how important design features of an experiment can remain obscure to at least some of the pupils in a class to the extent that the experiments they are engaged in become meaningless (Tasker and Freyberg, 1985, p. 71).

More recent Australian research has also found that students had difficulty understanding the aims and purposes of laboratory work (Berry, Mulhall, Gunstone and Loughran, 1999).

6.1.2 Missing the point of practical work in the primary classroom

Bourke (2000) examined the variations of meaning given to learning and self-assessment by Year 7 and Year 8 students in relation to learning activities in both school and out-of-school settings. She collected data through observations, interviews with teachers, and interviews with seven target students. In Bourke's study, as in Tasker and Freyberg's study, the students missed the point of practical activities. During one science lesson students were given circular pieces of paper and bowls of water. They cut the circle into a flower pattern, turned the petals into the centre of the circle, and then placed the closed flower onto the water and observed what happened. They then experimented with possible variables. By the end of the activity, none of the target children knew what the purpose of the lesson was, or what they had learned. Bourke concludes that, although the students enjoyed the activity and found it a fun way to spend an afternoon, they showed little understanding of the principles behind the experiment.

6.1.3 Links between "recipe practicals" and content knowledge learning

With the key "process" decisions made for them in advance, it is difficult to see how students working through a pre-specified "recipe" practical activity could be achieving many of the investigative skills learning outcomes intended by *SNZC*. The findings from these two classroom-based research projects resonate with international commentary that sees much traditional school science practical work as being ineffective in developing students' understandings of science (Wellington, 1998). That being the case, it seems problematic that this pedagogy appears still to be so pervasive, especially in secondary classrooms.

It may be that in many cases the teacher's intended focus during practical work activities is not actually on students' "skills" learning outcomes. Millar (1998) highlights the traditionally close association between practical work and teaching that aims to develop "content" understandings in science:

> Given its subject matter, it is natural that communicating scientific knowledge will involve acts of "showing" as well as of "telling". The subject matter is all around us; it is obvious we will want to use it in the task of communicating information and ideas about it (Millar, 1998, p. 16).

In this view, practical work serves to illustrate important conceptual understandings about the natural world by demonstrating them as directly observable phenomena. In analysis of research about the role of practical work in UK schools, Watson (2000) reports that teachers in a 1998 survey rated "finding facts and arriving at new principles" more highly than had teachers in an equivalent 1982 survey (Watson, 2000, p. 58). This suggests that teachers' views of this purpose for doing practical work in the UK had further consolidated in the intervening years. However, one American researcher reports teacher confusion about whether their intention is actually to promote student enquiry and allow student investigations, or to illustrate, demonstrate, and verify known concepts (Tobin, 1990).

While there is a lack of equivalent research in New Zealand on teachers' understandings of the purposes of practical work, TIMSS-98/99 data does provide some degree of circumstantial evidence. According to the TIMSS data, 52 percent of New Zealand students were taught in classes where there was a high level of emphasis given to conducting experiments (Martin *et al.*, 2000, p. 232). An index was created to determine the value Year 9 teachers placed on scientific reasoning and problem solving (see section 3.4.4 in Chapter Three). Among the measures used to create this index were teachers' reports about how often they asked students to explain the reasoning behind an idea, or to work on problems for which there is no immediately obvious method of solution. The TIMSS rating for New Zealand teachers on this index was only 4 percent (Martin *et al.*, 2000, p. 222).

Millar (1998) suggests that practical work of the pre-planned type needs to be clearly understood as serving "pedagogic" rather than "epistemic" purposes. He does not advocate that teachers should stop carrying out familiar and well-tried practical events to support conceptual learning outcomes. As he points out, such practical events can be memorable and this in itself aids interest and learning. Rather, he suggests that there is more need to "change what we say than what we do" (Millar, 1998, p. 30). As a result of analysing a range of practical activities typically used at differing levels in schools, he proposes rethinking their intended outcomes so that they are seen as augmenting the theoretical accounts by either:

- demonstrating complex systems as simplified physical models that can be observed and manipulated;
- enacting mental models as direct physical models, so that students can practise talking about the relevant science ideas as they manipulate the model;
- producing the phenomenon to display the "power" of science ideas that generate unexpected phenomena, especially if students can produce the phenomenon for themselves;
- using a predict-observe-explain pedagogy to repeatedly produce the phenomenon that is predicted by the relevant theoretical model; or
- showing what an event is really like when words will not suffice (for example "gas evolved", "vigorous reaction", "less vigorous reaction" (Millar, 1998, p. 29).

Millar's suggestions thus propose a rethinking of purposes for using practical work in the classroom with associated adjustments to familiar and well-tried pedagogy. Section 5.3 in Chapter Five suggests one possibility for the closer alignment of practical work and conceptual development pedagogy when the practical event *models* a new idea. This would involve the teacher and students in discussing and drawing out an explicit awareness of the status of the model, especially of its strengths and weaknesses as an accurate representation of the mental model it expresses. As noted in Chapter Five, there is an explicitly metacognitive element to such a process. Evidence suggests that students need to think about their thinking in relation to the practical activity, and teachers need to know strategies to help them to do that.

This finding is not new – as reported in Chapter Four, the recommendation for teachers and students to consider practical work as a thinking activity, was made as a result of the LISP research (see section 4.1.2 in Chapter Four). In spite of this, few New Zealand studies provide indications that teachers have been led to rethink the ways in which they use this popular pedagogy, and there has been little widespread research to assess whether there have been significant changes in the way practical work is carried out in New Zealand classrooms since the 1980s LISP projects.

Summary of section 6.1

- The interaction between students' conceptual and procedural understandings in science has been underestimated. Pedagogical approaches to practical work must be underlined by an awareness of this interaction.
- "Recipe practical" pedagogy is familiar, relatively straightforward to prepare for, and seemingly clear for students to follow.
- Classroom studies have shown that students frequently misinterpret the teacher's intended purpose(s) for the practical work when this pedagogy is used. In these cases, the intended learning outcomes are often not achieved by students.
- Students need opportunities to reflect on their own thinking about the purposes for, and meanings gained from, practical activities.
- There is limited evidence to indicate on a wide scale how practical work is carried out in New Zealand classrooms.
- There has been little research which explores New Zealand teachers' views on the purposes for carrying out practical work, but TIMSS data suggests that scientific reasoning and problem solving are not rated highly in teachers' practice.
- Rather than changing their whole pedagogical approach, it has been suggested that teachers could more effectively achieve the intended outcomes if they rethought their purposes for using such practical events, and guided the students' learning towards more specifically focused outcomes.

6.2 Learning outcomes of “student investigations” pedagogy

As already noted, *SNZC* specifies four sets of investigative skills to be developed when carrying out practical inquiry work in science. There is considerable debate about how this strand of the curriculum should be read. Through the 1970s, “process” approaches, in which the acquisition of particular conceptual knowledge was considered less important than understanding and developing the skills and processes of scientific inquiry, became prominent in both the United Kingdom and the United States science curricula (Hodson, 1996; Osborne and Simon, 1996). During the 1980s, the separation of science into the distinct strands of “content” (a body of knowledge to be learned), and “process” (the methods through which scientific knowledge is developed), was widely criticised as being artificial (Millar and Driver, 1987), and damaging to the goals of science education (Hodson, 1996). Science educators began to argue that students need to experience investigations in their entirety if they are to develop a true sense of what it means to “do” science. From this perspective practical work is not just about acquiring skills but also involves appropriate application of these skills within the context of, and in relation to the concepts that underpin, an investigation.

While “recipe practicals” specify a sequential and structured approach, “open” investigations hold considerably more uncertainty for both students and teachers. At their most open, these investigations require students to design an appropriate inquiry to address a question of their own choice. A slightly more supportive version presents students with a problem to be solved and then challenges them to design their own way of doing so (Haigh, 1998). Open investigations may not proceed in a linear sequential order, but may require a number of recursive problem-solving loops. In this respect an open investigation is more akin to authentic science inquiry, although students are unlikely to be building genuinely new knowledge, unless in exceptional circumstances.

6.2.1 Learning to carry out open investigations

Haigh (1998) worked with four classes of Year 12 Biology students and their teachers, all at the same New Zealand secondary school. The study began with a negotiated intervention to introduce open investigative tasks to the practical work programme. Classroom observation, pre- and post-intervention questionnaires of students’ confidence to do investigations, teacher questionnaires, interviews, and document analysis were used to gather data related to the outcomes of the intervention. The findings of this stage were used to develop a teaching pack containing classroom material and teachers’ guides for investigative practical work in senior biology, which was subsequently trialled by teachers from 22 schools around New Zealand.

Data collected over two years identified difficulties associated with open investigation as a pedagogical approach. Pre-test and post-test measures of students’ confidence to carry out investigations indicated that while students’ overall confidence at carrying out investigations grew during the year, certain aspects related to the processes of scientific inquiry showed a drop in confidence. Haigh suggests that this drop in confidence was paradoxically related to a growing awareness of complexities such as:

- knowing how to select appropriate equipment to carry out experiments;
- knowing how many times to repeat an experiment; and
- knowing how to present data in an appropriate form.

While these students were challenged by their awareness of the gaps in their skills at Year 12, Haigh reports that when interviewed at Year 13, all of the students reported enjoyment and confidence in researching the internally assessed "Plant or Animal Study" component of their Bursary course (Haigh, personal communication, February 2002).

Haigh found that unless the students were prepared beforehand, a sudden shift from carefully structured experimental work to the relative freedom of partially open investigations caused confusion. The synthesis of all the data collected from the study led Haigh to identify the following teaching strategies as valuable for assisting students engaged in science investigations. These include helping students to understand the nature of scientific investigations, through:

- discussion on the nature of scientific inquiry;
- acknowledging that failure to reach expected outcomes can be a part of the process of science;
- whole-class discussion and planning of an approach to solving a particular problem; and
- analysis of "recipe"-style investigation from texts, with discussion as to why the planner may have chosen to carry out the investigation in that particular manner.

Other strategies involve providing assistance during the course of planning and conducting the investigation, such as:

- "refresher" courses for students on all aspects of designing, carrying out, and reporting on the findings of practical investigations;
- the breaking down of an investigation into its particular phases and concentrating discussion on one aspect only;
- having students plan an investigation and then comparing their plans to a "given" method (supplied by text or teacher);
- asking many cueing questions of students while they carried out their investigations;
- encouraging the explicit formation of linkages between students' prior knowledge and present situations;
- asking students to plan their investigations individually and then sharing their ideas in small groups to argue for, and agree upon, a group plan; and
- having students critically analyse each others' plans and evaluate their own work on completion of the investigation.

With carefully structured support, the students in this study achieved a wider range of outcomes than appears to be the case from more conventional practical work.

By requiring the students to draw on their own ideas as they carried out tasks at the various stages of the investigation, this pedagogy made student thinking a visible component of the classroom discussion. Thus, it seems that a key factor of effective pedagogy identified in Chapter Five – that is, enabling students to be aware of and reflect on their own ideas while they are dealing with the specific conceptual demands of a particular learning task – is equally important in the practical work setting.

6.2.2 Links between open investigation and students' attitudes to learning science

Haigh's study showed that the adoption of open investigation pedagogies could affect students' attitudes and confidence both positively and negatively. A study by Bowmar (1997) investigated the relationships between teachers' and students' attitudes towards science and the way science was being taught in one New Zealand intermediate school. The way science was taught in the school was illuminated by document analysis, researcher observation, interviews, and questionnaires with teachers and students. Two of the key features of the school's science programme were:

- **a predominantly traditional view of science**, manifested through teacher-directed prepared lessons, which were not set in a student context, with little opportunity for students to conduct their own investigations; and
- **strong leadership,** evident in the systems that the school had established to support science teaching. Most of the teachers had limited educational backgrounds in science, although the teacher with responsibility for science had high science content knowledge. The problem of many teachers' perceived "weak" area of teaching, *Making Sense of the Physical World*, had been addressed by the preparation of lesson units by this teacher for the other teachers to use.

Teachers' attitudes towards teaching science were evaluated using interviews and questionnaires. Responses indicated that teachers had generally positive attitudes to teaching science and, as a result of the science support within the school, teachers felt more confident in areas of science for which they had low content knowledge. However, many teachers also said they would feel more confident in their science teaching if they had more content knowledge, and felt that this related to students' enthusiasm for the subject. Students' attitudes to science were measured using attitude questionnaires (n=518) and focus group interviews with six groups of 3-4 students each. The questionnaires indicated that students had a generally positive attitude towards science, although attitudes did appear to drop between form one and form two students. Students also felt they had few opportunities to pursue investigations of their own during science lessons. Interview data indicated that:

- Students' positive attitudes were related to their sense of understanding the subject.
- Students expressed positive attitudes when teachers had some background knowledge and could explain "why".
- Students liked open-ended, hands-on activities. These activities were perceived as challenging. Activities which had no challenge were deemed "boring".
- For some students there was a negative link between the science support offered and positive attitudes to science. These students felt that the prepared lessons were too teacher-directed and not open-ended enough.

It is interesting that these students identified more open investigation as one of the factors that would help improve their attitudes to science learning. However, the findings of both Haigh's and Bowmar's studies also indicate that if teachers:

- lack the appropriate science content knowledge; or
- have limited understandings of the nature of scientific inquiry; or
- do not know how to help students productively engage in this kind of inquiry;

then students' attitudes and confidence in learning science may also be eroded by the shift to more open investigations.

Some students with a special interest or ability in science may be particularly in need of the opportunity to engage in more open investigation. International and New Zealand literature concerning students with special abilities in science suggests that adjustments to the educational programmes for gifted students must consist of qualitative rather than quantitative changes and that these adjustments should incorporate well-thought-out, meaningful learning experiences that capitalise on students' strengths and interests. Francis (1998) surveyed 143 New Zealand students considered to be gifted in physics. Little evidence was found of intentional, systematic addressing of the needs of students with special abilities in any of the respondent schools. Twelve students (all male) were subsequently interviewed. They expressed the feeling that they were constrained by the schooling system and that they would have liked to engage in wider studies; to be able to take university courses or engage in extra research and practical investigations; and to work with other students of similar ability.

6.2.3 Open investigations beyond the classroom: CREST

The CREST (Creativity in Science and Technology) programme, which is open to all students from Year 7 and above, provides opportunities for New Zealand students to be extended in contexts beyond the formal school curriculum. A recent evaluative study of the effectiveness and uptake of CREST included questionnaires and interviews with 53 teachers in 34 schools, and 46 past and present student participants (Davies and France, 2001a). The study found that CREST (and the "Science Olympiads" which were included in the research focus) had significant benefits for both teachers and students. In particular, it confirmed interests and extended the ability of exceptional students for whom there is a dearth of appropriate learning contexts (Davies and France, 2001b).

Students who participated in CREST developed understanding of the complexity of real-world problem solving through consultation with professional scientists; developed investigative ability and scientific knowledge beyond that otherwise developed through the school curriculum; and were encouraged to go on to further study in science. Teachers involved in CREST developed significant personal contacts with professional scientists; were stimulated to extend their knowledge in science; and developed their ability to teach “investigation”.

These findings support those of Haigh (1998) in suggesting that more open investigative work challenges students to achieve multiple outcomes as a result of their learning experiences. However, Davies and France (2001a) also found:

- low participation by low-decile schools in both of these programmes;
- poor promotion of CREST in schools where CREST is not integrated into the curriculum and teachers have heavy workloads; and
- low participation by male students in CREST and low participation by female students in the Olympiads.

The study concluded that both programmes have a role to play in supporting science learning but are in need of secure funding and further publicity to allow wider uptake.

Summary of section 6.2

- Investigations can be structured with varying degrees of openness but typically involve students in the investigation of a "problem" set in a context with some links to "everyday life".
- All stages of the investigative process potentially provide opportunities for students to share their thinking with each other and with the teacher.
- Students who are more used to highly structured practical activities may need carefully structured support from the teacher as they begin to develop their investigative skills.
- With this support, pupils can successfully achieve a range of conceptual and procedural knowledge outcomes from investigative practical work. They may also develop more positive attitudes to learning in science.
- There is some (limited) evidence to suggest that increased confidence and procedural knowledge outcomes may be transferred to new investigative tasks.
- Open investigations can help to extend gifted students, particularly where their work is supported by expert mentors from the wider science community.
- New Zealand students have the opportunity to engage in open investigation through the CREST programme, and participating students have developed investigative ability and scientific knowledge beyond that otherwise developed through the school curriculum.
- Many schools, particularly low-decile schools, have low rates of participation in CREST and other science extension programmes for students with special interests/abilities in science.

6.3 "Fair testing" approaches

The development of "fair testing" as an approach for practical work in science appears to represent a halfway position between the closed "recipe" practical work investigated during the LISP projects and the more open investigations researched by Haigh (1998). The rather linear, sequential structure of this pedagogy gives teachers a secure framework from which to support a more open approach to investigation. It is commonly used when students complete the science fair projects that have been found to dominate the science programme in some New Zealand primary schools (Education Review Office, 1996). Frequently, the process of investigation begins from questions that students raise. They are then encouraged to shape these as "investigative questions", following the "generative" or "interactive" learning models introduced during the LISP research.

6.3.1 Uptake of fair testing as an approach for teaching primary science

While it was *not* the intention of the LISP researchers to emphasise one particular way to "investigate" children's questions, *SNZC* has commonly been interpreted as emphasising "fair testing", especially at the primary level. It is the basis of the investigative approach modelled in the "Framework for Introducing Investigative Methods" in all four titles of the New Zealand primary science curriculum support series "Making Better Sense of…" (Ministry of Education, 1998; Ministry of Education, 1999a; Ministry of Education, 1999b; Ministry of Education, 2001b). The series appears to be widely used and fair testing is a familiar concept to most primary teachers. The pedagogy has clearly been successful in helping students achieve some outcomes related to science inquiry. NEMP trend data have shown substantial gains in children's achievements in carrying out fair tests.

Internationally, this model for investigative pedagogy has been so successful that one team of British science educators suggests that it has come to overly dominate practical work in UK classrooms (Watson, Goldsworthy and Wood-Robinson, 1999). They carried out a large-scale research project in which 1,000 UK teachers teaching at key stages 2 (ages 8-10) and 3 (ages 11-14) completed questionnaires about the investigations conducted in their classrooms. Fifty percent of investigations at key stage 2, and 82 percent of investigations at key stage 3, fell into the fair tests category. Watson et *al.* question this balance and ask whether the emphasis on other kinds of investigations should be increased. They describe five other kinds of investigations to which pupils are exposed in science: classifying and identifying; pattern seeking; exploring; investigating models; and making things or developing systems.

6.3.2 Problems with fair testing outcomes in primary science

Jenkins (1996) critiques the sequential, linear visiting of each of the four skill sets during every practical investigation, noting that scientists use very different methods of investigation in different circumstances (Jenkins, 1996). He argues that it is very misleading to suggest there is such a thing as "the scientific method". In common with "recipe practicals", the pedagogy for "fair testing" does draw on a linear model and this affords some certainty for teachers when planning and preparing practical experiences within the constraints of school life. However the "fair testing" teacher may have different groups of students investigating the same basic problem from different perspectives, for example by choosing to control different combinations of variables. In this respect it is slightly more open to student input at the planning stage than typical "recipe practical" pedagogy.

Despite the practical advantages, there is a danger that the emphasis on "making the test fair" becomes an end in itself, leading Watson *et al.* to ask:

> For example, is it acceptable that the vast majority of students never attempt to collect evidence to support or refute a scientific model? (Watson *et al.*, 1999).

The narrow focus of fair tests could be preventing students from understanding the links between theory and evidence, either in their own work, or in professional science. Section 6.2 introduced research that points to a significant lack of achievement of this kind of learning during school science because students can have difficulty in relating any relevant science theory to the evidence they collect. When fair testing is seen as an end in itself the question investigated may bear little obvious link to any theory – for example *"which is the best/strongest/hardest/most absorbent...?"* questions can easily relate to technological consumer considerations (Jones and Simon, 1991), rather than to any clearly identified aspects of materials science or classification according to material properties (to name two types of potential theoretical links to such questions).

Another criticism of the dominance of fair testing is that it is more relevant to the physical sciences, where variables can be more easily be isolated and manipulated in classroom situations. The "systems sciences" (Mayer and Kumano, 1999) such as ecology, geology, astronomy and meteorology use quite different methods of investigation. All of these areas are included in *SNZC* and so appropriate methods for investigating them should be a part of practical work in school science. Mayer and Kumano describe the differences in investigative methods as including:

- location – investigations in systems sciences frequently involve field work, with some confirming "experiments" done in the laboratory;
- treatment of time – investigations in systems sciences often monitor change over time, whereas in fair tests time is another variable to be controlled;
- parts versus wholes – fair tests look at one variable at a time whereas systems must take account of how the parts interact to make the whole system; and
- presentation of concepts and results – systems science investigations are often reported as rich description/narrative accounts rather than as mathematical relationships (Mayer and Kumano, 1999).

These characteristics lend themselves to simple observational experiences that can begin in early primary school (see the "Moon Journal" research reported in section 7.2.4, Chapter Seven) and extend through to the fieldwork that is an established part of senior biology courses (Chapter Nine). They can be integrated with reading literacy experiences (section 7.1, Chapter Seven) and can provide high interest EOTC activities that broaden children's rich experiences of the natural world (section 9.3, Chapter Nine). One large U.K research project has clearly demonstrated the value of simple observational activities (in this case the growth and metamorphosis of caterpillars) for uncovering children's ideas about natural phenomena and for stimulating their questioning and inquiry skills (Russell and Watt, 1990).

Science teaching approaches which emphasise fair testing are well supported by primary teachers. It would seem more sensible to help teachers widen their familiarity with a range of other types of investigations, than to suggest that fair testing be discouraged. For some teachers, such a widening of focus will confirm that what they already do well does constitute legitimate investigative pedagogy for the "systems sciences".

Summary of section 6.3

- Fair testing is a common and well-supported pedagogical approach to carrying out science investigations, especially at the primary school level.
- Fair testing has been successful in helping students to achieve investigative skills outcomes – if the investigation falls within the structured framework that has been modelled for this approach.
- However, fair testing is just one of several possible approaches to investigation in science, including: classifying and identifying; pattern seeking; exploring; investigating models; and making things or developing systems.
- The predominance of fair testing may give students a distorted view of both practical work in the classroom, and the nature and characteristics of scientific inquiry.
- International commentary links fair testing to the construction of misleading NOS views when students do not have opportunities to use and reflect on the diversity of ways in which investigations can be carried out.
- Students may not become aware of theory/evidence links when fair testing is the predominant pedagogy that they experience.

6.4 Evaluating the effect of science teaching on students' understandings about the nature of science

6.4.1 Open investigations and the potential for developing NOS learning outcomes

The beginning inquiry stage of an investigation, identified in *SNZC* as the "focusing and planning" set of investigative skills, is often presented as an important opportunity to develop students' understanding about the nature of science. Frequently, the importance of hypothesising is stressed:

> Pupils should be taught that scientists develop hypotheses and predictions about natural phenomena. This process is essential to the development of new knowledge claims (Ratcliffe *et al.*, 2001, p. 20).

However, there is a difference between students recognising what scientists purportedly do and being able to do these things themselves. Hogan (2000) provides a comprehensive meta-analysis of studies that have sought to describe the status of students' knowledge about the nature of science and to illuminate possible relationships between the development of this knowledge and classroom practices. As a result of her analysis, Hogan identifies two distinct but inter-related ways that school students' knowledge about the nature of science has been measured in studies of teaching effectiveness. Hogan describes these as "proximal knowledge" and "distal knowledge". These are defined in the following way:

- proximal knowledge – defined as personal understandings, beliefs and commitments regarding the science knowledge that students produce for themselves as a result of their experiences of learning science at school. (This clearly encompasses the *SNZC* specification that students develop appropriate attitudes towards scientific inquiry – as outlined in section 2.6); and

- distal knowledge – defined as declarative knowledge about professional science, that is, "knowledge about protocols, practices and products of the professional science community" (p. 52). (This encompasses the *intent* of the *Making Sense of the Nature of Science and its Relationship to Technology* strand of *SNZC.*)

Hogan's meta-analysis indicates the important point that many studies which have sought to evaluate the impact of classroom teaching practices on the development of students' understandings about the nature and characteristics of science have only probed students' distal knowledge of the process and practices of science. In these studies, students are asked questions such as "What is science?"; "What do you think the goal of science is?"; and "What happens when scientists get unexpected results?". This assumes unproblematic transfer of understandings between proximal and distal types of views. However, students' proximal views – that is, the personal understandings, beliefs and attitudes that mediate their day-to-day science learning, can only be identified in the context of students' actual classroom experiences. There appear to be few studies which explore whether students' knowledge of the nature of professional science differs from their personal knowledge about the nature of school science and of learning science (Hogan, 2000).

Several studies indicate that students are not achieving the intended learning outcome of developing working hypotheses for their own investigations (Wenham, 1993; Haigh, 1998; Robertson, 1999).

In a Scottish study of 500 students aged 14-16, Robertson (1999) found that most students could not carry the relationship between theory and evidence in their heads sufficiently clearly to continue to relate these to each other right through an open-ended investigation. Specific difficulties related to:

- procedural problems in tracking variables in a "real" context;
- inadequate mathematical knowledge;
- inadequate procedures for recording;
- inadequate processing of variables; and
- language difficulties when discussing all of the above.

As a result, most students resorted to the use of qualitative observations for evaluating evidence against their hypotheses in spite of the purportedly quantitative procedure that had been adopted.

Several large British studies have shown that the reciprocal interactions between theory and evidence are not comprehended by many school students, even at the senior levels of secondary school. One research group worked with 30 pairs of 9, 12, and 16-year-old students, who were encouraged to collaboratively complete a series of tasks that drew out their implicit nature of science understandings.

Some of these tasks drew on familiar "practical work" contexts (Driver, Leach, Millar and Scott, 1996). Few of the students in this study could rethink their personal theories in the light of evidence. Furthermore, the few, mostly older, students who could do so, did not reason in this way with any consistency. In a large cross-age study involving nearly a thousand UK secondary school pupils (nearly 800 pupils aged 14-15; 120 pupils aged 12-13; and 80 pupils aged 17-18), Solomon, Scott, and Duveen (1996) found that less than half the pupils they interviewed could describe an experiment they had done and relate it to a science theory. Only 20 percent could correctly describe the theory they had identified.

These results could reflect a developmental progression in children's ability to differentiate between theory and data. In both studies those who were able to make such a distinction tended to be older students, but many of the older students failed to develop this outcome in the context of their science learning. One significant group of older students, whom Solomon *et al.* called the "imaginers", were able to both name and describe the theory that underpinned the experiments they had identified. Furthermore, they shared a number of other attributes that suggested they were achieving a wide variety of NOS outcomes as a result of their learning. Specifically, they were more likely than any of the other students in the study to:

- avoid making assumptions about the ontological status of theoretical entities (such as that they could see atoms under the microscope);
- appreciate that people living at different times have different ways of explaining things; and
- enjoy learning science at school (Solomon *et al.*, 1996).

There was also a positive correlation between the presence of the characteristics listed above and the classes from which this small group came. Since the study did not collect data about the classroom practice of the teachers so identified, it is not possible to draw conclusions other than that it is *possible* to teach in such a way that clear links are made between theory and practical work. Given the weight of evidence suggesting that this does not often happen, this could be a fruitful area for further research.

As outlined in Chapter Three, NEMP findings report that New Zealand students are not as strong in planning procedures, solving problems, or giving explanations for practical investigation strategies as they are in actually carrying out specified practical tasks, and TIMSS-98/99 reported that few Year 9 teachers in New Zealand place a high emphasis on scientific reasoning and problem solving.

While NEMP studies and TIMMS findings cannot establish a direct link to pedagogy, these findings would make sense if students are mainly experiencing practical work in which planning decisions are substantially made for them in advance. However, the findings are problematic if students are actually carrying out more open investigations but still not developing a clear understanding of the nature and characteristics of scientific inquiry.

6.4.2 Using stories from the history of science as a pedagogy to develop NOS outcomes

Irwin (1997; 2000) has researched possibilities for incorporating stories from the history of science with both practical and theoretical learning in the classroom. With one group of students he explored the possibility that differing interpretations can be made of the same evidence in the case of the phlogiston and combustion theories of burning (Irwin, 1997). In another study, two parallel groups of similar ability and background were taught the same "content" but one group also discussed the historical development of the relevant theory (Irwin, 2000). While pre- and post-tests from this study showed that the addition of the historical material did not make a difference to the achievement of content knowledge outcomes, Irwin found that NOS learning outcomes were significantly improved. Irwin probed the NOS understandings of both classes of students through a questionnaire and focus group interviews., He found, for example, that approximately half of the "historical" students appreciated the fact that the atom was a theoretical concept "imagined" by people to explain phenomena, all of the "non-historical" students believed atoms to be real entities that had been "discovered". Based on qualitative data from student interviews, Irwin suggests that the addition of accounts from the history of science:

- unsettle the belief that science concepts are self evident once sufficient empirical data has been gathered (thereby critically examining the theory/evidence link);
- exemplify the importance of creativity in scientific thinking; and
- challenge students to think about the positive role played by uncertainty as new science ideas arise (Irwin, 2000).

Summary of section 6.4

- Despite their many experiences of practical work in science, most students fail to learn to recognise links between theory and the gathering of empirical evidence.
- This suggests pedagogy which has failed to recognise the link between the conceptual and procedural knowledge demands of investigations in science.
- However, researchers believe that theory/evidence links should be a key NOS outcome from practical work in school science.
- Some small investigations report qualified success in developing materials that help students achieve NOS outcomes in professional science settings (in historical and contemporary issues contexts). No such classroom-based research has been found in New Zealand.
- Students' ability to achieve integrated conceptual, procedural, and nature of science learning outcomes appears to be correlated with their teachers' use of practical work to appropriately challenge student thinking.
- Effective pedagogy for the development of students' understandings about the nature of science appears to share all the features of effective pedagogy for developing conceptual and procedural knowledge together.

6.5 Summary of Chapter Six

Practical work in school science appears to be dominated at the primary level by "fair testing" pedagogy and at the secondary level by "recipe practical" work. Because they do not represent the full spectrum of actual scientific investigative practice, and in particular omit key investigative methods typical of the "systems sciences", both of these types of pedagogy are likely to result in students developing restricted and misleading NOS views. However they do provide secure frameworks that are familiar to teachers and they are relatively easy to manage in the classroom. For these reasons, science educators have suggested that teachers be encouraged to broaden rather than to replace their views of appropriate pedagogy and of ways to extend and develop the students' classroom experiences as they "do" science.

It would appear that secondary teachers primarily intend "recipe" practical work to support the development of content knowledge outcomes. However evidence shows that students often misinterpret the activities that they carry out and do not develop the content outcomes intended. Nor do they link the "evidence" that the practical displays to the "theory" that is purportedly being illustrated and endorsed. Students need opportunities to talk about the purposes for such activities, and to discuss key features of the methodology used for the practical as part of their learning. In this way they could develop content knowledge, procedural knowledge and NOS outcomes from the practical work experience.

When they have opportunities to carry out more open investigative work, students at all levels may initially need more support in developing appropriate skills. In particular they may need considerable support to develop theory/evidence links, especially as these relate to both hypothesising at the beginning of an investigation, and processing and explaining the data collected in the final stages of the investigation. Open investigations provide more opportunities for students to pursue their own questions, to bring their own ideas to their learning, and to widen their understanding of both appropriate procedure and of the relative flexibility and recursive nature of “real science”. While more challenging, such investigations are ultimately motivating for many students, and can be used to extend those who are gifted in science.

In New Zealand, the CREST programme offers support for students to develop their own investigations with support and mentoring from members of the wider scientific community. While the programme has positive outcomes for many participants, CREST currently appears not to be as widely supported as it could be.

Chapter Seven: "Literacy" and science learning

7.0 Introduction

The importance of elucidating and building on student thinking about science ideas emerged as a strong finding in the literature related to LISP (Chapter Four), learning for conceptual development (Chapter Five), and learning for the development of procedural knowledge and skills (Chapter Six). The importance of developing students' understandings of the nature of science, their understanding of science content and concepts, and their ability to carry out scientific investigations in conjunction with each other emerged as a finding of Chapters Five and Six, as did the importance of metacognitive awareness to be able to reflect on the considerable challenges of science learning.

If they are to achieve these multiple learning outcomes, students need to learn and/or practise the skills of communicating their science ideas with sufficient clarity to explain these to others, including their teachers. Research reported in the previous chapters has found that students require considerable teacher support as they learn how to meaningfully explore their own and others' ideas about science. A range of potentially effective strategies for this purpose has been described in Chapters Five and Six. This chapter extends the focus of the research already reported to explore "literacy" as it is related to effective two-way communication in science classrooms.

Beyond 2000, an influential, future-focused British report on science education (Millar and Osborne, 1998), suggests that science can make a special type of contribution to the development of reading literacy and numeracy at the primary school level. Research that directly or indirectly links reading literacy to science learning in New Zealand settings is introduced in Section 7.1. In Australia, advocacy for the development of reading literacy during science learning has been extended to the middle-school years and to secondary school learning. While there has been no equivalent research focus in New Zealand since the early LISP findings on the role of language in science learning, the issues raised appear to be relevant for New Zealand. This Australian research is also reported in section 7.1.

There is a potential confusion between the meanings ascribed to "science literacy" and "reading literacy". The broad sweep of potential purposes for science education has been outlined in section 2.6. In addition to educating those students who will become scientists, another widely described purpose for science education is the development of "scientific literacy", although this phrase has been attributed a wide range of different meanings (Laugksch, 2000). The broad intention of all these various meanings is that the "science-literate" citizen would be able to meaningfully engage with science in their life beyond school, when and if they felt the need to do so. Section 7.2 focuses on "science literacy" by introducing strategies that have been shown in classroom-based research to help students learn wider NOS aspects of science in the context of learning to communicate their ideas in science with more clarity. Section 6.4 (Chapter Six) reported on the difficulty students can experience in linking science theories to their practical investigative knowledge and experiences. This skill is critical to many aspects of communication in science and is central to the shaping of hypotheses that can lead to productive investigations. Students need support as they learn how to use the *words* of science to clearly communicate the *ideas* of science during their learning experiences, and during both formative and summative assessment – (see Chapters Three and Four). Finally in this chapter, sections 7.3 and 7.4 address issues specific to reading and writing when learning in science.

7.1 The case for integrating "reading literacy" learning with science learning

This section outlines advocacy for the integration of reading literacy learning and science learning, especially, but not only, at the primary-school level. Chapter Six noted the tendency of classroom research to focus on one outcome at a time, whereas findings about the nature of effective practice indicate that multiple outcomes should be carefully integrated within whole rich learning experiences. A similar situation exists in the reading literacy context. We have found no research that explicitly explores success in achieving clearly identified science outcomes when also developing reading literacy skills. However, there is a considerable body of research, much of it based in existing classroom practice, that points towards the potential of such approaches.

7.1.1 Reading literacy and science learning in the junior primary school

Scott (2000) points out that, for junior teachers in New Zealand schools, the development of early literacy and numeracy is seen as the main purpose of learning. His research in ten New Zealand primary classrooms established that 65 percent of potential opportunities to learn science were actually provided in "reading" or "language" sessions, compared with the mere 16 percent that were provided in time explicitly called "science" by the teachers. He notes that primary teachers are "confident, skilled and highly motivated" (p. 48) to develop literacy skills and that there are strong similarities between the "making sense" approaches that many teachers use for reading and language development and those advocated for science learning at this level.

While Scott acknowledges that his research did not actually link "opportunities to learn" (p. 45) to actual evidence of learning, he suggests that the usefulness of his findings lies in encouraging primary teachers to see their literacy programmes as providing rich opportunities for science learning without adding to curriculum crowding. The *Reading Science* series is designed to integrate learning to read with the learning of science-relevant concepts, patterns, and events in exactly this manner (Learning Media, 1995; Learning Media, 1996a; Learning Media, 1996b; Learning Media, 1996c). However, during their survey of science teaching practice in New Zealand schools, ERO (1996) found that "science objectives were obscured by language activities" (p. 13) in some primary classrooms where science was integrated with literacy learning. They recommend careful planning to clearly identify intended science outcomes as a means of ensuring that both sets of outcomes can be developed together. Chapter Nine further explores the issue of curriculum integration.

Phillips *et al.*, (2001) report that Maori and Pacific children in early childhood centres and in decile one schools can make great improvements in their reading literacy progress when their teachers are given professional development opportunities to learn more about multiple pathways to literacy development. Their report, *Picking up the Pace*, correlates pre-school children's exposure to a wide range of reading and text-related experiences and their readiness to make good progress at school. These researchers draw attention to the communication goals described in the early childhood curriculum, *Te Whariki*, (Ministry of Education, 1996b) and assert that young children need to:

- experience a wide range of stories;
- hear and practise story telling; and
- experience the manner in which text and illustrations together carry the story.

Several of the stories used to illustrate good pre-school practice in this report have also been selected by experienced junior primary teachers as resource material for the development of foundational science concepts in the *Building Science Concepts* series. They include *My Cat Likes to Hide in Boxes* (Sutton, 1973) which is used in the *BSC* booklet *Light and Colour* to develop the idea that darkness is an absence of light (Learning Media 2001). In a forthcoming *BSC* title *Mr Gumpy's Outing* (Burningham, 1970) is used to discuss children's ideas about instances of floating and sinking.

7.1.2 Literacy learning in the middle school and secondary years

Picking up the Pace described a "rich get richer and poor get poorer" effect for successful early literacy learning (Phillips, McNaughton and MacDonald, 2001). Students left behind in the very first years are unlikely to catch up and indeed tend to fall further behind. The Victoria, Australia, *Middle School Literacy Project* supports this assertion:

> This cycle of failure persists and even increases through the secondary school and into the senior years of schooling (Dennett and Milburn, 1999, p. 3).

However, these researchers also note that many secondary school science teachers, even when they recognise students' reading problems, are at a loss to know what they can do:

> I bite my tongue to stop myself from saying "What do you want me to do about it? I'm a secondary teacher, I'm not supposed to teach them to read."….the most frustrating thing of all is that many of us do not have a clue where to begin with literacy problems … everything we are teaching them is like building on sand (Sandy Roberts, 1999, cited in Dennett and Milburn, 1999, p. 10).

Phase 2 of the Australian *Successful Interventions Literacy Research Project* was conducted subsequent to the research reported above. A team of researchers working in 44 widely differing Victorian schools documented classroom practices and policies that were associated with demonstrable improvement of literacy skills at the secondary school level. Amongst twelve specific recommendations based on their findings, these researchers suggested that there should be explicit teaching of the curriculum literacies in each key learning area. They also recommended that students are provided with regular, planned opportunities to engage in sustained reading and writing activities, in a variety of contexts which engage their interests. In science such literacy strategies would need to explicitly address the features of science text that make it difficult to read (section 7.3). Literacy strategies that integrate with NOS understandings could also help avoid potentially misleading NOS outcomes that can arise from writing activities when these promote self expression without accompanying clarity about the conceptual and/or procedural knowledge outcomes to be developed. (section 7.4).

Summary of section 7.1

- Reading literacy is a dominant focus of early primary learning and so provides opportunities to integrate text-related experiences with science learning.
- A sustained early focus on reading literacy helps educationally disadvantaged students to get a better start on their overall school learning.
- The lack of an appropriate level of reading literacy creates barriers to science learning at all levels of schooling.
- Science provides rich contexts and text-related experiences for developing general literacy skills at all levels of the curriculum.
- Across the middle years and into secondary school, teachers are less likely to specifically teach reading literacy skills as a routine part of their subject, and may not know how to do so even if they are aware of the need.

7.2 "Science literacy" approaches in the classroom – what works?

The studies described in this section have been devised to address a range of learning outcomes and challenges. Most of them are set in school classrooms. They have in common an intention to explicitly address one or more identified aspects of "science literacy" by developing understandings *about* science as well as in science. To this end they integrate NOS, conceptual and/or procedural goals with strategies designed to help students clearly communicate their ideas in and about science. The studies model the use of explicit "bridging strategies" to transcend differences between the culture of science and the culture(s) of students' everyday worlds, including school, so that students can simultaneously achieve clearly focused science and communication skills outcomes.

7.2.1 Making the transition to a secondary school culture

Hanrahan (2001) reports on the successful use of adult literacy strategies to help overcome language barriers that were perceived to be hindering the learning of a low-stream third form science class in an urban Australian secondary school. Activities based on widely known adult literacy strategies were informally developed in consultation with the classroom teacher, and as a result of feedback gained through student journal writing, together with teacher/ researcher reflection and conversations. These strategies included:

- small group work that encouraged the explicit use of oral language by the students;
- worksheets and discussions that drew student attention to differences between everyday and science meanings of words;
- many activities that involved finding the main idea in written text in ways that drew attention to "the non-transparency of word meanings" (Hanrahan, 2001, p. 7); and
- allowing emotional responses to new learning to be expressed and discussed.

Several of these strategies are also familiar to New Zealand teachers from the second LISP project, where everyday and science meanings of words such as "animal" were a focus of the research (Bell and Barker, 1982).

Research with this class continued for a full academic year (Hanrahan 2001). Hanrahan notes that as the discourse of this classroom changed from authoritarian to more democratic, the pupils themselves began to identify learning difficulties that language strategies could address. Science became demystified and the pupils began to actively ask many more questions and to achieve beyond the low-stream tag that had initially set the teacher's expectations. Indeed they came to behave more like a top-stream class, although this did not carry through into their other subject areas. The teacher continued the same practices with a new third form class the following year (without researcher support). This resulted in a similar successful learning experience for the next third form cohort. On the other hand, the first class, who had been the focus of the research project, experienced conventional science teaching in their fourth form year and "reverted to their usual form in other classes and had become almost unmanageable" (Hanrahan, 2001, p. 12).

7.2.2 Helping middle school students to talk science

Michaels and Sohmer (2001) reported on the successful science learning of students taking part in an innovative after-school programme for "at-risk" middle-school students from predominantly poor urban American backgrounds. The students were encouraged to take part in carefully structured group discussions that followed participation in selected "discrepant events" that could cause cognitive conflict of the type outlined in Chapter Five. These events were designed to build on the students' everyday talk. To this end the language used was strongly aligned with the students' own cultural backgrounds. Thus, while exploring ideas about air pressure, the students were introduced to a mental model that designated individual molecules of gases in the air as "air puppies". As the students related these air puppies to events that they had directly experienced (in this case a spud gun in action) the power of this personification can be seen:

> Right now the air puppies are havin' space. Now I put it in, and they don't have no space. So they're like "oh let's get out of here." So they …push outta this hole thing and they all (pshoo) [flying out in motion] (Michaels and Sohmer, 2001).

While the science talks initially used the students' own vernacular, the researchers strongly encouraged them to take on the identity of science investigators and they were very explicit about what that entailed. In their talk the students were coached in theorising their ideas, using prediction, explanation, justification, and persuasion, and critiquing each other's efforts as they listened to the talk of their peers. They learnt that the narrative talk by which they came to understand the conceptual ideas was a bridging strategy that needed to be left aside when making a scientific argument:

> Juan: He says that they [air puppies] can't think// it's just like an active response for them//
> Teacher: Right// that's exactly it// You said … that they wanted to run out/ that they needed to run out//
> Juan: They can't want// it's a desire (Michaels and Sohmer, 2001)

The transcript illustrates how the students were supported as they thought about how to move from their first mental models of air pressure created by gas particles, which were structured in the vernacular as "air puppies", to more scientifically appropriate forms of language. Thus, the students were not only talking science, they were talking their way into the discourse structures of science. In this way, it was intended that they would simultaneously develop content knowledge about air pressure and the ability to communicate that knowledge in a manner appropriate to science as they first used, and then deliberately set aside, the personification.

7.2.3 Helping young children to talk science

Karen Gallas (1995), an American researcher and junior primary teacher, provides rich descriptions (including extended verbatim sequences) of young children's *Science Talks*. In these free-flowing conversations, the children in her class were encouraged by Gallas and by their peers to consider the theory building processes in which they were engaged and to develop a metacognitive awareness of the warrants for their personal science beliefs. Gallas wanted her children to:

> feel the power of collaborative theory building and in fact understand the excitement of building a theory, *even if it is an incorrect theory*. Incorrect theories are better than no theories at all! Incorrect theories are better than silence! Incorrect theories are, in fact, often the basis for correct and revolutionary theories in the field of science (Gallas, 1995, p. 99, emphasis in the original).

Gallas describes the impact of *Science Talks* on one child who was normally silenced in the classroom because his limited range of experiences of the world rendered him less confident than his peers. From silence, to participation as a listener, to the confidence to become a talker too, Germaine's world opened up and his creativity, imagination, and great curiosity about the natural world became more evident. He began to "pop with questions" (p. 98). However, Gallas makes it quite clear that the *Science Talks* were just the first stage of learning. Describing traditional pedagogy that begins from the science ideas as "outside-in" science, Gallas argues for an "inside-out" approach. Children's ideas and questions – more often addressed in the talks to each other than to the teacher specifically – provide an opportunity for the teacher to access their private worlds of experiences and idea building. Only then can the teacher plan investigations and learning opportunities in response:

> How can Germaine study about "The Seashore" if he's never been to one? How can he begin to speak and participate in a unit on "Pets" if he's never had one? When we talk about "growth" and a child refers to "the holes inside homemade bread" to explain that bread "grows" before it is cooked, Germaine is appalled. He's never eaten homemade bread: The bread he eats doesn't have holes. Another child cross-references that remark by citing "the holes in Swiss cheese". Germaine, now completely at sea, says, "What's Swiss cheese?" If we, as teachers, don't begin to develop the science curriculum based on our knowledge of the children we teach, how will all of our students ever be fully engaged with the world of science?
>
> Germaine needs to make the bread, eat the cheese, have the pets, and go to the seashore with his class and his teacher! As his teacher, I have to figure out how to help him bring his rich observations of the city and his spontaneous questions to our study of science (Gallas, 1995, p. 103).

Here Gallas directly links the lack of rich experiences of the everyday world to limited opportunities for learning in science. Analysis of TIMSS 94 and 98 questions at Year 5 (section 3.6.4 in Chapter Three) noted that 50 percent of questions at this level drew on experiences of everyday life. Similarly, NEMP studies (section 3.5.3 in Chapter Three) have found that Maori students from *Kura Kaupapa* schools are more positive than their mainstream peers about learning science – and they also report experiencing more field trips and other similar rich experiences outside the classroom. The review returns to the benefits of experiences outside the classroom in Chapter Nine.

The LISP research (Chapter Four) highlighted the importance of beginning the science learning process from students' own experiences, whatever these are. If the gap between achievement of students in low-/high-decile schools, reported from both NEMP and TIMSS data, is related to differences in opportunities to develop a wide range of life experiences, "rich experience" approaches should hold great promise for New Zealand teachers and their students. Gallas explicitly connects opportunities for rich contextual experiences to the generation of children's own science questions during the science talks. She also connects her *Science Talks* pedagogy to the development of children's metacognitive awareness of their personal theory building as an intended learning outcome. Students' lack of awareness of theory/evidence links was noted in the discussion of argumentation (section 5.4.2 in Chapter Five) and as an unintended result of much practical activity in science (section 6.4 in Chapter Six).

7.2.4 Bringing other languages and cultures into the science classroom

Classroom research outlined in Chapters Four to Six identifies the importance of eliciting and working from children's own ideas, for the purpose of helping them reconstruct their thinking towards more scientifically accurate ideas, as a key feature of effective pedagogy for science learning. This can pose special challenges when students are not able to shape their ideas fluently in standard English, either because it is a second language, or because they speak a vernacular which varies significantly from standard English. The US studies reported here suggest that the use of first languages and/or vernacular variations of standard English can allow students to express themselves more fluently. These qualitative accounts suggest that enhanced communication is linked to improved achievement of science outcomes. New Zealand classroom research (Alton-Lee & Nuthall 1998) has also demonstrated the effectiveness of using non-text forms of communication (for example, diagrams, pictures and visual images) to provide English-as-second-language students direct access to curriculum content. The recently released preliminary findings of the PISA survey noted that New Zealand has 10 percent of "minority language" students, the fifth highest percentage of such students amongst the surveyed nations. The results for these students showed a substantial achievement gap in both reading and science literacy in the PISA survey, and a smaller gap in mathematics literacy (Ministry of Education, 2001).

The impact of vernacular language differences in secondary school science

Wilson Orr (1987, republished 1997) provides detailed documentation of a longitudinal study that established how the "Black English Vernacular" (BEV) of some of her students impeded their ability to learn mathematics and science when instruction was provided in standard English. Over a period of nine years, beginning in 1972, she followed the progress of 320 students, 98 percent of them from relatively poor black American families. Despite success in other subjects, this group of students initially showed a strong pattern of failure to achieve in science and mathematics. This pattern was eventually attributed to the different signals these students took from function words – that is the everyday words such as "of" that link together the specialist vocabulary of mathematics or science to give meaning to a sentence. Differences in the grammatical structures of BEV and standard English were identified as the likely cause of this difficulty.

The teachers gradually devised strategies that assisted the students to build bridges between their BEV reasoning patterns and the reasoning patterns of standard English. For example, the students needed to learn new ways to think about "as….as" relationships (e.g. "half as long as") so that they could diagram geometrical relationships in the manner needed to solve given problems. Another diagram strategy was devised to help them overcome problems with the use of the word "of" when manipulating fractions. Students who had been in danger of failing experienced dramatically improved results when taught how to use these bridging strategies. Some students were able to go on to study mathematics and science at university level after graduating from high school.

The impact of first language use on communication in a primary school setting

In a small self-reported classroom study, Roberts (1999) describes the rich learning that her first grade American students experienced when they kept observational Moon Journals with the help of their parents. The children were encouraged to talk about what they observed, both with their parents and subsequently at school, and to do so in whichever language they used most comfortably. (For many this was Spanish.) As the children displayed their pictures and spoke to these, Roberts observed non-Spanish speakers learning new words in Spanish and many children shared different cultural perspectives on the Moon that their parents had in turn shared with them. The children asked numerous questions of each other's ideas and rich writing activities resulted. Parents responded enthusiastically because they felt they could genuinely engage with the children's homework and Roberts reports her stronger sense of connection to Spanish-speaking parents as a result of the activity.

This sense of connection makes a significant link to the *Picking up the Pace* report on the literacy development of children in South Auckland schools. Reviewing literature related to literacy development, this research team observed that:

> There are predictions that the more schools become part of their communities and incorporate community patterns of teaching, learning and language the more effective instruction will be with "minority" children (Phillips, McNaughton and MacDonald, 2001, p. 23)

In the same vein, the recently competed AIMHI research reported that effective teachers in the eight decile one secondary schools all placed a high value on frequent and positive contact with their students' parents (Hill and Hawk, 2000). Hill and Hawk also report instances of effective teachers encouraging students to provide synonyms in their first languages for some of the specialist terms used during lessons, although they do not specifically cite science in this regard.

7.2.5 Developing language to link "doing" science to conceptual outcomes in the early years

A major research-based curriculum development for kindergarten and first grade science is currently underway in Pennsylvanian schools. The team developing the curriculum materials has commented that, while young children need developmentally appropriate science activities, this is too often interpreted as the simple provision of "hands on" experiences and no clearly identified conceptual development is built into the procedural activities (Roth and Massey, 2000). Part of their vision for developmental appropriateness is the explicit teaching of age-appropriate vocabulary so that children have access to words that they can use to express key ideas:

> For example, children learn to use the word "light blocker" to describe opaque materials, not because the word "opaque" is too difficult, but because the phrase "light blocker" conveys a process and is therefore more meaningful (Roth and Massey, 2000, p. 11).

The conversion of a word to a simply expressed process reverses the *nominalisation* identified in section 7.3 as a difficult feature of science text. However, Roth and Massey also stress that their curriculum does not assume that young children will already have reading and writing skills. Rather their materials make extensive use of iconic representations – pictures, stickers, small samples of materials, so that children gain confidence in recording and "reading" evidence such as sequences of events and comparative continuums. This helps add a more formal structure to discussions of the concepts they are exploring. Roth and Massey have compared conversations about the target concepts undertaken with two groups of children. They report that those children who have experienced their curriculum are significantly more likely to draw on the targeted science concepts to explain phenomena, and to correctly use appropriate vocabulary (Massey and Roth, 1997).

7.2.6 Unanswered questions

The studies that have been reported in section 7.2 have used various bridging strategies to link children's everyday ideas and experiences to their intended science learning. It has also been noted that the importance of making such links was recommended as a significant outcome of LISP research in New Zealand in the 1980s, and has been comprehensively endorsed by research from a range of areas of science education in the intervening years (Chapters Four to Six). Most of the bridging strategies described in this section have been designed to draw students' attention to aspects of their implicit NOS views, identified by Hogan (2000) as *proximal* understandings (see section 6.4, Chapter Six). As students develop the metacognitive awareness to link their thinking about their own NOS views to the ways scientists think and shape their ideas, they can develop their *distal* NOS understandings as distinct but related ideas. In this way multiple types of outcomes could be achieved.

Despite the still-accumulating evidence affirming the original LISP findings on the importance of beginning science learning from children's experiences and questions, there appears to have been little change in actual classroom practice in this area. However we have found no *recent* systematic analysis of the questions this raises about teacher beliefs and practices, either in New Zealand or internationally. Barnes (1976) carried out extensive classroom-based research on the nature of student and teacher talk and their respective impacts on learning. Barnes' much quoted assertions include that:

- teachers often ask closed "pseudo-questions" rather than seeking to genuinely find out their students' own thoughts; and
- when teachers use such teacher-centred questioning, their purposes include both social control and teaching. Thus, they maintain their role as the arbiter of the status and validity of knowledge.

Clearly teachers' pedagogical decision-making in the day-to-day reality of their classrooms is not straightforward, and may be related to factors other than, or in addition to, intended learning outcomes.

Summary of section 7.2

- Children need rich experiences of their everyday worlds as a foundation for building science learning.
- Teachers need the communication skills to work with students' ideas and experiences and the communication must be genuinely two-way – the teacher is a learner of the students' thoughts, not solely the authoritative arbiter of content.
- Rich student talk can begin in contexts, genres, and in some case languages other than "standard English", that have personal meaning for the student group.
- Explicit bridging strategies can effectively assist students to cross cultural divides between their everyday worlds and the world of science.
- Students need to be coached in the communication styles of science – this aspect of the nature of science is an integral part of learning.

7.3 Reading for science learning

Research presented in section 3.6.3 suggested that the achievement of some students in TIMSS test questions was hampered by their inability to read and decode questions correctly (Harlow, 2000). Many children find the process of learning to read generally challenging and this section outlines the additional reading challenges imposed by the vocabulary and language structures used in science. Wellington and Osborne (2001) review a wide range of international research that has informed the recognition of the difficulties that the language used in communicating science ideas poses for learners. Many of the studies they report were carried out in the 1980s, as shown in the Timeline Overview at the end of Part I of this review. The difficulties reviewed in their research are likely to be experienced by *all* students at some stage in their learning, but may be compounded for students from other than "middle-class Western" cultural backgrounds. The literature suggests that specific language challenges in science are of two main types: vocabulary and grammatical challenges.

7.3.1 Vocabulary challenges when reading science

Wellington and Osborne cite several large research studies, predominantly carried out in the 1970s, showing that students' understanding of *everyday vocabulary* creates learning difficulties in science. Words that have dual meanings (e.g. contrast, volume, transfer, rate) cause even more difficulties than words with one meaning (e.g. linear, minimum, factor, external). This was a finding of the early LISP projects in New Zealand (Chapter Four). In a small local study, Milne (2001) illustrated this in a *Material World* context when he probed the meanings given to the words "material" and "chemical" by 75 children in their first year of school. The young children understood the terms to apply to solids, with one mention of liquids and none of gases.

Other specific types of vocabulary difficulties identified by Wellington and Osborne include:

- technical terms that give new names to familiar objects ("trachea" for windpipe);
- technical terms that give new names to unfamiliar objects, including those that are only encountered in laboratory settings (conical flask);
- technical terms for processes that can be demonstrated and observed (evaporation, distillation, combustion);
- technical terms for processes that cannot be observed in direct action (photosynthesis, evolution);
- theoretical entities (electron, gene, atom) and totally abstract idealizations (point mass, frictionless body); and
- mathematical words and symbols (Wellington and Osborne, 2001)

Wellington and Osborne question whether students meet some of these technical terms too early in their schooling. They suggest there is a danger that new words, given too soon, may actually encourage students to use these words in superficial ways that conceal misunderstandings. At the very least, teachers need to be aware of the layers of difficulty posed by language in science. Congruent with other research reported in section 5.3, Wellington and Osborne recommend the explicit use of models and analogies as effective pedagogical strategies for building the shared meanings which are necessary for successful communication of individual understandings of science technical vocabulary.

7.3.2 Grammatical features of the scientific genre

Wellington and Osborne identify a number of significant features of written text (whether in textbooks intended for science education or in actual scientific writing) that pose specific types of learning challenges for students. They report earlier research that identified problematic grammatical features of science text that can cause reading and reasoning difficulties. These features include:

Logical connectives

Words such as frequently, simultaneously, consequently, thus, and conversely are vital components of the language of hypothesising, comparing, sequencing, attributing causes, and other such key aspects of scientific reasoning. However, Wellington and Osborne caution against responding to these findings by simplifying the language structures used. If pupils never have the chance to read and learn about logical connectives, they are less likely to learn notions of sequencing and causality, nor will they recognise these NOS features in other texts they read. They advocate the use of argumentation (section 5.4, Chapter Five) for practising the explicit use of logical connectives, both in oral and written communication. Research on students' difficulties with hypothesising, and with recognising theory/evidence links when doing practical work (section 6.4, Chapter Six) also supports this recommendation.

Qualifying words

Scientists' typically cautious use of qualifiers ("the majority of"; "in a few cases") can cause readers to hesitate, thereby putting "a barrier between the reader and the information" (Bulman, 1985, cited in Wellington and Osborne, 2001, p. 43). In this case the basic literacy strategies advocated in section 7.1

could potentially help overcome such difficulties but we have found no research to support this connection.

Objectification/use of passive voice

The personal and subjective is typically removed from science writing so that it seems that events happen regardless of human agency. This can lead to students recording their personal actions in a nonsensical manner, for example "the test tube was smelt" (Sheldrake, 2001). As with the use of logical connectives and qualifiers, the use of the passive voice is part of the process of reporting science as it is currently practised, although there has been recent influential advocacy that this practice be discarded by professional scientists (Sheldrake, 2001). Wellington and Osborne assert that students need help to actively explore text that displays this feature.

Lexical density

Words that refer to content or factual knowledge are present in much higher density in typical science writing than in more narrative prose styles, as illustrated by the following example (where content words are underlined):

> But we never did anything very much in science in school.
>
> The atomic nucleus absorbs and emits energy in quanta, or discrete units.

The second of these sentences is obviously more challenging to read.

Nominalisation

This can take two forms. Nouns can be substituted for verbs or for a whole action sequence (crystalization, evaporation, acceleration) or nouns can be used as adjectives (glass crack growth rate). Typically, sequences of such nouns construct casual relationships economically and efficiently, with obvious benefits for the logical communication of science ideas but with inherent challenges for learners. Harlow's research (section 3.6.3) noted that nominalisation was responsible for at least one instance of misinterpretation of a TIMSS question (Harlow, 2000).

If students were explicitly coached in the recognition of these grammatical features and in strategies to cope with the difficulties they pose, clearly they could achieve both reading literacy and science literacy (NOS) outcomes. Research exploring the degree of reading challenge in science learning materials commonly used in New Zealand classrooms during science learning could provide insights into the extent to which these various factors are issues for New Zealand students. However, only one small study with such a focus was found during the literature search, as outlined next.

7.3.3 Reading science textbooks

Meyers (2000) carried out a small case study in a New Zealand low-decile, multicultural urban secondary school related to his Year 11 students' ability to access information from science textbook material. He found that over 50 percent of the scientific terms introduced in the selected piece of text were not understood by any of his students on first reading, despite the explicit definitions provided in the text. Meyers used Chall's Qualitative Assessment Method to assess the reading levels of eight commonly used New Zealand science textbooks, spanning Years 9 to 11, that were in use across a range of years from the 1960s to the present. Because he was not an experienced assessor of reading levels, Meyers asked the school's specialist ESOL teacher to carry out an inter-rater checking of his data. This validated the judgments he had made. Meyers reports that:

> Of the eight textbooks assessed only two – *Science Makes Sense Book 3; Five Science Book 3* – were within normal reading levels of the students for whom the books were intended. …All the other textbooks are set from one up to four years beyond the reading levels of the students who are meant to use them (Meyers, 2000, pp. 42-43).

While Meyers' research reports on just eight textbooks, not all of them still in common use, Wellington and Osborne's analysis of scientific grammar and vocabulary indicates that high reading levels will be a feature of many such texts. This suggests that pedagogy to support the development of reading skills in science may be effective in raising student achievement. A range of teaching strategies to address this issue has been devised and disseminated to teachers. They include:

- DARTS - Directed Activities Related to Text (Wellington and Osborne, 2001); (Henderson and Wellington, 1998);
- EXIT - Extending Interactions with Text (Wellington and Osborne, 2001); and
- Three Level Reading - strategies for drawing meaning from text at three levels (literal, interpretive, and applied).

In New Zealand, LISP research findings were used to develop guidelines for pedagogy that supports student language development (Hill and Edwards, 1992) and these have been available to New Zealand secondary teachers since before *Science in the New Zealand Curriculum* was officially mandated. We have found no research that has evaluated either the uptake or impact of these guidelines on classroom practice. The *Applications* series (see section 8.2, Chapter Eight) uses a "language across the curriculum" approach for lower secondary level science and technology learning. Again, we have found no research that investigates the actual effectiveness of this resource in raising student achievement in science. Limited evidence of its non-use in lower secondary science classrooms is, however, discussed in section 8.2.

Summary of section 7.3

- Specialist language and grammatical features of science can significantly increase demands on students' reading and comprehension skills. These factors may hamper some students' ability to read science-related textbooks without significant teacher support.

- The few New Zealand textbooks that have been systematically evaluated mostly have a higher reading level than the age group for whom they are intended.
- There is a considerable amount of resource material/advice to guide development of appropriate pedagogy for the development of reading skills when using science texts.
- There is little research to indicate the uptake or effectiveness of these resources for increasing achievement of either general literacy skills or science outcomes for New Zealand students.

7.4 Writing for science learning

This section of Chapter Seven moves on to the capture of ideas on paper – that is, some form of text production or writing. While this may mean a grammatically arranged flow of words, the wider meaning of "text" can be taken to also include flow charts, spider diagrams, concept maps, Vee diagrams, Venn diagrams, and other such heuristics that capture thinking on paper for later re-examination and reflection. These strategies can be productive for structured conceptual development tasks (Chapter Five) and immediately useful for formative assessment purposes (Chapter Four).

The strategies listed above do not, however, require students to engage in extended writing that can challenge them to logically structure their thoughts in to coherent arguments. Thoughts written down in extended sequences can be useful "raw material" for metacognitive reflection about learning in relation to conceptual, procedural and NOS outcomes. The difficulties that New Zealand students can experience in writing down their planning ideas have been noted in Chapter Three. These difficulties could be related to the relative absence of extended writing from science learning, especially at the secondary school level. Research reporting on the frequency of use of different types of writing tasks during science learning is reported next.

7.4.1 Patterns of writing tasks in secondary science learning

Rowell (1997) carried out a meta-analysis of research related to the purposes and outcomes of student writing during science learning. She reports on a large 1960s British research project – *The Development of Writing Abilities 11-18* – that found that 92 percent of writing in secondary school classrooms was "transactional" in nature. Rowell summarises a variety of other research evidence to suggest that little has changed since the 1960s in this regard. Whether note taking, or describing the results of practical investigations, such writing precludes expressive or poetic language. Rather it is "language 'to get things done'" (p. 32) and the purpose of such writing is "displaying the assimilation of information to teachers" (p. 33).

Wellington and Osborne (2001) cite research carried out by Lunzer and Gardner in the late 1970s that found that the teacher-as-a-learning-helper is seldom likely to be the audience for student writing in science. Rather 87 percent of all students writing in science had the teacher-as-examiner as the intended audience, compared with 18 percent in English and 81 percent in geography. By contrast a trusted adult or pupil-teacher dialogue was the intended audience of 70 percent of student writing in English, 13 percent in geography and just 7 percent in science. In Lunzer and Gardner's research, no students were encouraged to write with themselves or their peers as their primary audience.

The patterns described above suggest that traditional practice dominates writing during science learning at the secondary school level. (Writing at the primary school level is discussed in section 7.4.3 below.) This limited and limiting range of writing experiences could well be constraining opportunities for students to develop outcomes related to both science and reading literacy, as outlined next.

7.4.2 Classroom studies of the use of writing to develop ple outcomes

Hanrahan's small study (see section 7.3.4, Chapter Seven) illustrates one very effective way of drawing students into exploring their learning through written text. As they kept their learning diaries, and as they came to trust that these would be acted on to provide positive help, students became better able to identify stumbling blocks and to articulate the nature of the help they needed to overcome these.

Some secondary teachers have recently experimented with the writing of brochures and other types of creative stories to demonstrate new learning of science concepts. Kuhn and Hand (1995) report success in using this strategy with junior secondary school students in Australia. They discuss the assessment insights to be gained from encouraging students to personalise their learning in this manner and present examples of student work to illustrate their assertion that at least some students engage more deeply with the target concepts to be learned. A subsequent report of a four-year research project presents an analysis of student responses to a range of writing tasks (Kuhn and Hand, 1999). They use these responses to argue that, when students are taught how to write for different audiences and different purposes, they make cognitive, metacognitive, and epistemological gains.

7.4.3 Conflicts of outcomes when writing for primary science learning

Rowell (1997) found that patterns of science writing at the primary school level are different from those typically employed in secondary school classrooms. At the primary level, science activities are often co-opted as "language development" opportunities to practice skills of transmissive writing. This is usually associated with the doing of a stimulating activity that will provide the rich experiences to get children's thoughts flowing. To this end, teacher scaffolding often takes the form of prompt questions, typically formulated along the lines: "What did I do?" "What happened?" "What did I find out?" Such prompt questions are a feature of the investigative framework modelled in the *Making Better Sense…* series for New Zealand primary teachers. (Ministry of Education 1998; 1999a; 1999b 2001b).

While such tasks can undoubtedly be effective for language development through personal expression of ideas, Rowell argues that there is a conflict of outcomes between science learning and literacy learning. She argues that when the “doing” of an activity serves as the source of scientific knowledge, theorising about science is pre-empted and an important NOS idea – the nature of theory/evidence relations – remains invisible. Yet this has been identified in several research projects as a key understanding that can integrate conceptual, procedural and NOS outcomes. Evidence presented in sections 5.4 (Chapter Five) and 6.4 (Chapter Six) suggests that students are not currently achieving this theory/evidence link from their science learning.

While some of the secondary level research reported by Rowell documents an awareness of NOS ideas that teachers were endeavoring to develop (mostly related to precision of language use), most teachers were unaware of the potential for writing to develop NOS outcomes, intentional or otherwise. In fact, Rowell found that students may come to so strongly associate writing about science with transmissive styles that they opt not to use science contexts when practising other writing styles. This again constrains their views of the nature of science by precluding:

- the selection of science as a context for developing creative thinking/writing;
- the use of writing to marshall the evidence for an argument; or
- the use of writing to outline the reasoning behind their planning decisions.

These findings add support to those of section 7.3. Students who need additional support for their still developing reading literacy could increase their achievement in science when this type of literacy is made an intentional focus of the pedagogy employed by their teachers, and all students could achieve increased science literacy from the same learning experiences. However, in order to attain these benefits, teachers would need to be aware of, and use, strategies to develop a variety of extended writing tasks, structured in such a way that they did not unintentionally lead to misleading NOS outcomes. The review returns to this challenge in Chapter Ten.

Summary of section 7.4

- Writing, in all its forms, provides a valuable tool for clarifying ideas in and about science.
- The purposes for which writing is used, and hence the pedagogical issues arising, are likely to be different at primary and secondary school levels.
- At all levels students could write in science for a wider range of purposes, developing expressive and creative thinking skills, as well as practising the writing of logical sequences of ideas – as explanation and/or as argument.
- When primary children are encouraged to always use their practical investigations as contexts to practise transmissive writing, they may not develop their understanding of links between theory and evidence.
- When secondary students only practise transactional writing, they will miss rich opportunities to deepen their conceptual learning, to learn more about the nature of science, and to become more metacognitively aware of their own thinking processes when learning in science.

7.5 Summary of Chapter Seven

Learning in science presents opportunities to develop reading literacy skills and to integrate these with science literacy outcomes (NOS, conceptual, procedural and/or metacognitive). Students need to learn and practice the skills of communicating their science ideas with sufficient clarity to explain these to others, including their teachers. As they learn how to use the *words* of science, they also shape their thoughts about the *ideas* and *activities* of science.

At the junior primary level both rich learning experiences and text-related activities can stimulate children's science questions, helping them to make links between their everyday worlds and their science learning. Teachers at this level typically focus on the development of literacy and numeracy but when they integrate science into the planned learning experiences, care needs to be taken to clearly identify the science learning outcomes. Learning for early writing is supported by science learning when students record the findings of their science investigations in systematic ways. Such recording can begin with stickers, icons and actual materials before children have the skills to write down their thoughts.

As students move through primary school and into the middle years explicit coaching in the special language features of science (vocabulary and grammar) can support the development of reading literacy and science literacy simultaneously. However specialist vocabulary should not be introduced before students are able to develop their understandings of the concepts that it encapsulates. Children need to develop a metacognitive awareness of the theory building aspects of science and their relationship to the evidence that is collected from science investigations. Teacher awareness of this relationship is particularly important when children are encouraged to develop their writing skills as they record ideas about their investigations.

There is evidence to suggest that many students no longer receive explicit reading literacy support during their science learning as they move into the secondary school system, and that this can disadvantage students who are already not achieving the learning outcomes their teachers intend. Teachers do not appear to have the pedagogical knowledge to provide such support in the context of science learning, despite the existence of a wealth of well tried reading and text-related strategies. Writing at this level tends to serve traditional purposes. Students use short, structured writing episodes to record and report their learning, with the teacher as their audience. There is some evidence to suggest that extended writing opportunities could assist students at this level to develop their reading literacy and science literacy outcomes simultaneously.

PART III: THE INTEGRATION OF SCIENCE PEDAGOGY WITH RICH STUDENT EXPERIENCES

Chapter Eight: New approaches to science education in the New Zealand cultural context

8.0 Introduction

Chapter Seven suggested that attention to both reading literacy and scientific literacy strategies at all levels of school offers potential prospects for narrowing the achievement gap that surveys such as NEMP, TIMMS, and the very recent PISA survey highlight as a significant issue for New Zealand schools. It was also noted that many of the pedagogical approaches documented in Chapter Seven had their origins in the "language across the curriculum" focus of the 1980s. This chapter adds another layer to that discussion by exploring very recent thinking about the fusion of these communication-related pedagogies, and the effective pedagogies of Chapters Five and Six, with narrative and multicultural approaches to learning in science.

This chapter addresses new dimensions of the challenge to help all students engage and achieve in science in New Zealand's increasingly multicultural classrooms. It begins with a discussion of the nature of narrative pedagogy in section 8.1, followed in section 8.2 by an account of trials of the pedagogy and of materials intended to support its use. Section 8.3 then outlines some issues of relevance to Maori and Pacific students in New Zealand schools, as these could relate to science education. McKinley (1999; 2000) noted this as an area where there is a dearth of actual classroom research. Section 8.4 addresses issues of alignment of other cultural world-views with the culture of science, as the latter is represented in the classroom. Because this is a relatively recent debate in science education, we have found no New Zealand classroom-based research to support this final section of Chapter Eight. We suggest that it would be premature to try to implement such approaches in our schools until the policy issues that arise have been appropriately debated and resolved.

8.1 The case for narrative pedagogy

Prominent calls for more inclusive and more broadly relevant teaching of "science for all" (see section 2.6) have recently focused on the promise of narrative pedagogy (Millar and Osborne, 1998). The logico-scientific mode of communication typically used by scientists is very different from traditional/everyday narrative modes of communication used in most other contexts. When scientists review their own procedures, they often "wash the stories away" (Bruner, 1986, p. 13) and one strategy that has typically been employed to do this is the use of the passive voice (see section 7.3, Chapter Seven). By contrast, narrative accounts:

- are grounded in recognisable contexts;
- have *characters*, *events,* and *situations* that are recognisable; and
- have a *plot* that gives the narrative *direction* and *coherence.*

Ogborn, Kreiss, Martins, and McGillicuddy (1996) undertook a detailed linguistic analysis of the explanatory style of a range of experienced British secondary science teachers, and discuss what they call the "language of description" in science teaching. These researchers concluded that, with some differences in personal style, many of the teachers they observed were skilled "tellers of tales" who turned their explanations into stories with "protagonists", each having powers of action, to enact a series of events with an identifiable outcome. However, such tales were not restricted to verbal communication. Rather, they were told in a "multi-semiotic environment" (p. 139) where gesturing, drawing, showing visual material, and demonstrating with real objects were variously pressed into service as the story unfolded. These researchers suggest that the use of the metaphor of explanations-as-stories would be a useful tool for helping new teachers to learn the subtleties of explanation, and to find their own personal style.

Some science educators are calling for less conventional uses of narrative to develop strategies for more equitable science teaching and learning. In this more innovative sense, narrative pedagogies can be owned, initiated, told, and resolved by the teacher and/or by the students at any stage of the story telling process. For the students the stories become a means of connecting their everyday worlds to the new learning challenges of school science. In this way, different cultural perspectives can become part of the classroom dialogue, as happened for the Spanish-speaking children and their parents in one small classroom study (see Roberts, 1999 discussion in section 7.2, Chapter Seven). For the teacher, the students' stories can be a means of revealing their thinking, providing the essential foundation on which conceptual development pedagogies are built (Chapters Five and Six). Examples of the wide diversity of approaches to narrative pedagogy that have been advocated and tried are outlined next.

8.1.1 Variation in approaches to narrative pedagogy

Using stories from other cultures

McKinley (1997) suggests that teachers draw on traditional stories to explore the manner in which scientific principles underpin Maori legends. Linkson (1999) and Read and Rose (2001) make similar suggestions for the use of Aboriginal legends. Finding ways to make mutually respectful comparisons of science and other cultural world-views is a particular challenge when using narrative pedagogy in this way. This challenge is addressed in section 8.4.

Grugeon and Gardner (2000) describe the retelling of a news item that showed environmental activists chaining themselves to trees, which led on into an exploration of deforestation and issues associated with global warming. The children were then introduced to an ancient Indian folktale that carried essentially the same conservation "message" and they explored the links between the two quite different types of stories to develop a play that integrated the science concepts, the news event, and the folktale. The whole class performed the play at a school assembly.

Fleer and Robbins (2001) used a story telling approach to encourage young Aboriginal children to share their own ideas about astronomy. They found that when telling their own stories the children were able to say much more about what they actually knew than they did when questioned about exactly the same phenomena in a one-to-one interview situation.

Using everyday stories

Favourite children's stories can make rich contexts to create cognitive conflict and hence to begin science investigations. For example, Grugeon and Gardner (2000) describe how a UK teacher used *Goldilocks and the Three Bears* as a context to explore heat transfer during cooling with primary school students. (In the scientific sense, Mother Bear's porridge should be "just right" and the smaller bowl of Baby Bear's porridge should be the coolest.) The study did not report directly on student learning outcomes in this instance, but describes how the use of the story assisted students to develop their own investigatable science questions.

Kuhn and Hand (1995) describe a case of the successful use of narrative when writing brochures and other types of creative stories to demonstrate new learning of science concepts. They report success in using this strategy with junior secondary school students in Australia and also discuss the assessment insights to be gained from encouraging students to personalise their learning in this manner (see section 7.4, Chapter Seven).

Michaels and Sohmer (2001) used personification of science entities, couched in children's everyday language, to introduce new concepts (see section 7.2, Chapter Seven).

Children telling their own science stories

As already outlined in Chapter Seven, Gallas (1995) describes young children's *Science Talks*. In these free-flowing conversations, children are encouraged by the teacher and by other students to consider the theory building processes in which they are engaged and to develop a metacognitive awareness of the warrants for their personal science beliefs.

Telling stories from the history of science

Matthews (1994) advocates the use of stories from the history of science to help students to understand the complexity and creativity of the origins of important science ideas. An important proviso is that history should not become "fictionalized idealizations and covey[s] the Whig[12] view of history that science is a steady and cumulative progression toward the pinnacle of modern achievement" (Monk and Osborne, 1997, p. 406).

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[12] Named after a 17th century political interest group in the UK, the term "Whig" is used to describe "a historical approach which interprets the past in terms of present ideas and values, elevating in significance all incidents and work that have contributed to current society, rather than attempting to understand the then social context and the contingent factors in its production" (Monk and Osborne, 1997, p. 406).

The possibility of achieving multiple kinds of learning by teaching science using historical models is succinctly illustrated in a study by Barker (1986;1997). Barker describes how five historical theories about photosynthesis were used, in conjunction with the generative teaching model (Osborne and Freyberg, 1985a), to help 13-year-old New Zealand secondary students wrestle with the counter-intuitive aspects of contemporary photosynthesis theory. The conceptual learning of these students was compared with another class of students who were taught using a more traditional "guided discovery" strategy. The guided discovery class engaged in teacher-contrived experiments (such as iodine testing for starch) that were intended to lead students inevitably to the scientists' view. Comparative tests showed that 70 percent of students who were taught using the generative teaching model and historical ideas could describe photosynthesis in terms of carbohydrate production, compared to only 19 percent of students in the other class taught in a more traditional way. Barker notes:

> …qualitative observations of the [teaching resource which included historical ideas about photosynthesis] in action showed that it achieved its purpose of promoting clarification and discussion about the two models[13]. The students vigorously reassessed their own ideas on the functions of plant roots and leaves, they speculated about what views their parents might hold (Barker, 1997, p. 193).

While the students' attempts to explain the five scientists' "wrong" views reinforced their own concepts of photosynthesis, Barker also noted that their "somewhat patronising" (p. 95) views of the historical scientists indicated a need to discuss with these students whether this was an appropriate attitude to hold. Barker also identifies a range of stories of scientific discoveries, many set in New Zealand contexts, that could be used to explore various identified aspects of the nature of science.

The converse effect was found in a similar study by Irwin (2000, see section 6.4.2, Chapter Six) in the UK. In this study, a class of 14-year-olds learning atomic theory using historical material were compared with a parallel group of students learning with no reference to history. In Irwin's study, while tests showed no difference in conceptual understandings of atomic theory between the two groups, the students learning with historical accounts did clearly demonstrate a less judgmental awareness of the complexities of past – now known to be incorrect – theory building of historical scientists.

8.1.2 Making NOS an explicit feature of narrative-based discussions

Some of the narrative strategies introduced above are focused directly on scientists and their actions and/or ideas. In such stories the NOS aspects may be *implied* rather than explicitly developed. Ogborn *et al.* (1996) identify the frequent use of certain stories as "parables" (p. 68). They caution that when teachers use some traditional stories (Archimedes leaping out of his bath shouting "Eureka"; Newton conceiving the theory of gravity when an apple fell on his head) they are actually conveying the "moral" that "one may make discoveries by taking pure thought" (p. 68). By contrast, when used in another way, story telling can help children to *explicitly* compare their stories and their thinking to the types of ways in which scientists think about and investigate ideas and events (see section 7.2). Such stories keep students' own ideas and experiences at the heart of the story-telling process while supporting them to develop conceptual and/or procedural outcomes together with NOS outcomes. The *Science Talks* of young children (Gallas, 1995 – see Chapter Seven) are an example in which awareness of the nature of scientific theory building (a NOS learning outcome) is used to challenge personal conceptual theories already held by children (a conceptual learning outcome).

Summary of section 8.1

- Narrative pedagogy includes but extends beyond teachers' traditional use of "explanatory stories" of science concepts.
- When new narrative pedagogies are used, children are encouraged to take an active role in the story-telling and/or interpretation.
- Stories for use in science can be: set in everyday contexts; related to the history of science; drawn from different cultural views of the natural world; and may be used to develop either or both the nature of science and science conceptual understandings.
- The most innovative narrative strategies explicitly integrate NOS with conceptual and procedural outcomes in the manner intended by *SNZC*.

8.2 Integrating narrative with other classroom pedagogy

Because the use of narrative has only recently been widely advocated as a means of promoting more effective classroom pedagogy in science, there is little direct research available by which to evaluate its effectiveness. One small U.K. study is reported in this section. Following that, materials already available to support narrative pedagogy in New Zealand classrooms are described, and indications of their present uptake by teachers are outlined.

8.2.1 Narrative as an "added extra" in senior chemistry classrooms

Hughes (2000) provides an analysis of what can happen when teachers plan and implement lessons using materials that *intend* innovative pedagogy, but where such materials are an "added extra" rather than an integral part of the planned learning experience. She carried out a combination of survey/classroom observation research in two classes working with *Salters* Senior Chemistry resources in the UK. The course materials were planned around narrative stories that portrayed chemistry as an activity carried out by people and relevant to the lives of the students studying it. Hughes found that despite the commitment expressed by both teachers to the use of these innovative resources a range of factors interacted to reinforce a traditional approach to science teaching and learning in both classes. The factors identified in the research are:

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[13] The two models were: (1) that earth is the source of plant nutrition and that plants absorb this food through the roots; and (2) that air and leaves are the source and site of plant food production.

1. Language and structure of resources

There were two course texts – the "hard" science was set out in one substantial textbook, the more discursive "stories" were in a separate and less-substantial book. The course content objectives used the verb "describe" for the factual aspects of the science but used "show awareness" for the socio-scientific aspects. Hughes argues that both these factors established a hierarchy that was applied in the classroom. The textbook was the important resource for the essential content and the socio-scientific resource was constructed as optional and largely ignored.

2. Timing/lesson structure

Abstract chemistry always took precedence to story-related activities. The latter were omitted when time was constrained or relegated to "end-of-term fun". At this time they were enjoyed but there was no evidence of serious engagement with the ideas and alternative perspectives presented.

3. Students' interpretation of the socio-scientific discourse

In most instances, the students drew on localised private experiences in their discussions, rather than the wider "think as citizens" approach that the resources required. The teachers were both concerned about their lack of training and expertise in the discussion of complex issues, which may have contributed to this effect.

4. Gender/power relations

The teachers experienced tensions between their conflicting roles as gatekeepers of higher science learning and of encouraging inclusivity in science. Hughes suggests that female teachers have the worry of how their own status with respect to science is affected if they introduce "soft" material and some male students did leave these classes to attend more traditionally presented courses. Students clearly saw the teacher's authority as residing in the traditional science content, not in the narrative materials. Hughes thus concludes that:

> ..when socioscience is the icing on the cake, not an essential basic ingredient, part of a good-quality product but not fundamental to teaching science, dominant discourses of science as an abstract body of knowledge are not destabilised and implicit gender hierarchical binaries are readily reinforced (Hughes, 2000, p. 437).

In this case the use of socio-scientific contextual stories did not appear to be effective in helping students to achieve any identified conceptual or procedural learning outcomes, nor did it appear to add to their NOS understandings. However, Hughes' critique of the complex web of teacher-student relationships and motivations suggests that the purpose of this pedagogy would need to be more widely understood and supported before it could be successfully implemented in the classroom. Both students and teachers would need to be able to explicitly address the NOS issues that became apparent, especially traditional patterns of gender relations within science.

Gender issues in relation to learning, generally and in science, have recently been addressed in one comprehensive New Zealand literature review (Alton-Lee and Praat, 2000). The researchers describe gendered differences in interactions between students and their peers, and between students and their teachers. Alton-Lee and Praat, (2000) signal the necessity to focus on gender differences as part of science teaching to develop NOS outcomes*:*

> Teachers need to challenge the notion of science and its framing of human history as they develop pedagogical approaches that make science meaningful to students of different cultural and ethnic heritages (Alton-Lee and Praat, 2000, p. 90).
>
> A critique of the interactive teaching approach has been that it does not sufficiently unsettle science and its relationship with society. The inherent masculine construction of science may influence both males and females to distance themselves from the feminine (Alton-Lee and Praat, 2000, p. 93).

Numerous contexts that could support a more narrative approach to science teaching and learning are described in *SNZC*, including contexts assumed to be of relevance to girls, and to students from other cultural backgrounds, especially Maori students. The curriculum developers intended that these contexts would become an integral part of the learning experience, thereby providing a link between students' everyday worlds and their science. However the evaluation of the use of contextual stories in Salters chemistry illustrates the level of careful thought about format, and teacher and pupil "readiness", that will be needed if such resources are to effectively fulfill their intended purpose. The complexities of this issue are further explored in section 8.2.2.

8.2.2 Weaving "stories" into traditional learning materials

Research carried out by Ninnes (2000) and Ninnes and Burnett (2001) provides evidence that good intentions to provide inclusive learning materials in Canadian, Australian, and New Zealand secondary science textbooks may give mixed messages. While none of the resources analysed by Ninnes and Burnett were developed to directly support innovative narrative pedagogy, the cautionary themes identified by Hughes (2000) are clearly evident.

Ninnes and Burnett critiqued the inclusion and representation of cultural diversity in Australian textbooks (Ninnes, 2000) and in textbooks written to support *SNZC* (Ninnes and Burnett, 2001). The researchers found that the suggestions for contexts included in *SNZC* unintentionally support the appropriation of Maori and other indigenous knowledges. These become a vehicle by which science ways of knowing can be transmitted and thus serve colonising interests rather than addressing issues of power and inequality. While all the New Zealand textbooks have photos of Maori or other cultural groups, these are invariably in contemporary classroom settings, which supports a "myth of consensus by all to the privileging of science knowledges and ways of knowing" (Ninnes and Burnett, 2001, p. 30). The researchers also identified several types of *essentialist* "messages" about Maori that were implied by various features of the textbooks. These messages were:

- all Maori are environmentally sensitive users of resources;
- all Maori live in harmony with their surroundings;
- all Maori are eager receivers of colonising technologies; and
- all Maori are practitioners of the same religious practice.

The historical settings typically used also give the message that traditional knowledge belongs in the past – before science knowledge was available. However, essentialisms are also problematic when contemporary issues provide the learning context. The choice of issues with negative connotations, for example Maori smoking or poor housing conditions suggests, unhelpfully, that these issues pervade all Maori and no other groups. Ninnes and Burnett also report patterns of text layout that marginalise other ways of knowing when cultural contexts are introduced first, then science picks up the story to have the last word. Alternatively, cultural contexts may be merely suggested as "research topics" or this material could be isolated in text boxes (Ninnes and Burnett, 2001).

Despite the negative impact of these findings, Ninnes and Burnett suggest that students themselves could analyse messages of power and cultural dominance in published learning materials. Gilbert made a similar suggestion of learning to "read" resources and science stories on three levels to deconstruct gendered assumptions in science theorising (Gilbert, 1997). However, issues of essentialism and cultural dominance could be diminished if students can retain their personal identities while learning science and their voices are clearly heard in the classroom discourse. Challenges that this would pose for teachers, students, pedagogy and curriculum are outlined in section 8.4.

8.2.3 Innovative resources to support narrative pedagogy in New Zealand schools

This section outlines the nature of several series of narrative-based resources that are already widely available in New Zealand schools.

The "Applications" series

Shortly before the introduction of *Science in the New Zealand Curriculum*, Learning Media began production, for the Ministry of Education, of an innovative resource series called "Applications" (Ministry of Education 1992a; 1992b; 1992c; 1992d). The concept was consciously modelled on the presentation of science in the widely circulated *New Scientist* weekly magazine. Ratcliffe (1999) lists the narrative elements of *New Scientist* as they are typically sequenced:

- an opening paragraph with some context followed immediately by a summary of the research outcomes;
- names and affiliations of those engaged in the research with indications, at different levels of detail, of the data collection or experimental methods;
- summary of the results;
- explanation of the results using quotations from the researchers involved;
- further details of methodology/results/background; and
- Implications of the results/further work using quotations from researchers or those for whom the work has implications (Ratcliffe, 1999, p. 1088).

In *New Scientist,* rich narrative description of the processes and the products of a science investigation are woven together into a coherent story. Each title in the "Applications" series also presents a narrative story, set in a context anticipated to hold high interest for adolescents. Science and technology concepts relevant to the curriculum at levels 4 and 5 (Years 9 and 10) are embedded within the narrative, then made more explicit via text boxes which have been separated from the "action" of the main story. Earlier titles took a language- across-the-curriculum (*LAC*) approach but were typically used by English teachers. Later titles have been designed more explicitly for use in science and/or technology classes.

The **"Connected"** *series*

The "Connected" series is a recent Learning Media resource that supports narrative-based, in- context, science pedagogy at the primary school level. Developed in a similar format to the already familiar "School Journal" series, "Connected" journals contain collections of stories, articles, poems, puzzles and games intended to connect the more abstract concepts of science, mathematics, and technology to the everyday worlds of a diverse range of students.

The "Building Science Concepts" series

This series is another recent Ministry of Education-funded initiative. Its primary purpose is to make explicit for primary teachers the links between context and concepts, and to present these in a manner that will help them to develop their own science content knowledge (Hipkins and English, 2000). Where possible, well-known children's stories are used to model the linking of narrative and science ideas. Thus the "black" inside big boxes, vividly illustrated in *My Cat Likes to Hide in Boxes* (Sutton, 1973) is used to help develop awareness of the way absence of light causes what we experience as "night" (Learning Media, 2001).

8.2.4 Patterns of use of narrative-based resources

Despite the ready availability of all the resources outlined in section 8.2.3, research suggests that they are not currently being widely used to support science teaching in New Zealand schools. Evaluative surveys have shown that:

- The "Applications" series was not generally being well-used by 1998. The minority of science teachers who knew of and used titles from the series found them valuable, but most of their reported feedback comments related to presentation ("well laid out", "good graphics"), motivation ("interesting", "enjoyable") with some reported use as a "reading tool" (Scott, 1998). In this survey, no teachers made comments on the ability of the series titles to clarify and/or promote discussion of science concepts, or the nature of science itself.
- Promotional material and a revised Teachers' Guide (Learning Media, 1998) resulted in significantly increased awareness of the "Applications" series, although a range of reasons for **not** using it were recorded. These included lack of time, shortage of copies, and difficulty of incorporating materials into school planning (Murrow and Gilbert, 1999). Of the five titles explicitly surveyed, the only one in a bicultural setting (*Waka*) was rated the least well used.
- Primary teachers are significantly more aware of the Connected series than their secondary colleagues are of the Applications series (Wilson, Murrow and Matheson, 2001). Teachers reported finding the material useful for students of diverse backgrounds, with many using it as part of their reading programme as well as in science.

These broad indicators suggest that the use of contextual narrative-based materials in science has not yet been incorporated into the routine practice of many secondary teachers. A national survey in 1998 of science teachers' thoughts and practices with respect to implementation of *SNZC,* found that some teachers believe:

- Contextual learning can be difficult for many students, especially when applying the principles learnt to another context.
- Teaching science in context is far too fuzzy.
- Students tend to remember contexts rather than content.
- …doesn't offer a continuity of knowledge gained in a topic and yes my focus is on knowledge and basic skills.
  (Verbatim survey quotes, Baker, 1999, p. 5)

In this survey, 71 percent of teachers agreed that they only use the suggested context (from *SNZC*) "sometimes" (Baker, 1999) despite this being a key strategy in developing a curriculum responsive to the needs and interests of diverse groups of students (Baker, 1994).

Hipkins and Arcus (1997) found that primary student teachers struggled to identify relevant science concepts in everyday contexts, and that they were instead likely to develop rich language activities that they called science. The data about the use of the "Connected" series (Wilson *et al*., 2001) do not allow for an analysis of how stories were used in the classroom. However, the ready uptake of contextual material at the primary level suggests at the very least a willingness to adapt curriculum to the interests and needs of the children being taught. In any case, as reported in Chapter Seven, a focus on the development of rich activities is seen as a preferred basis for later more conceptually based science by some primary curriculum commentators.

Summary of section 8.2

- Narrative pedagogy is one way to integrate contexts with science learning as specified in *SNZC*.
- Secondary students and teachers may not take narrative pedagogy or contextual teaching and learning seriously when compared with traditional lessons.
- Narrative pedagogy can raise issues that require teachers to have clearly developed NOS understandings.
- Curriculum and curriculum support materials require careful development if inadvertent messages of essentialism (with respect to both culture and gender) are to be avoided.
- Narrative-based resources are available to support science teaching and learning at all levels of New Zealand schools up to the lower secondary school.
- Primary teachers are more aware of, and more likely to use, these resources than their secondary colleagues.
- Teachers cite lack of time and unfamiliarity with the resources. However, uncertainty about how to incorporate the resources and their narrative approaches into existing programmes and purposes for learning science appears to be a significant factor in their lack of widespread use.

8.3 *Kaupapa Maori* pedagogy in the New Zealand science education context

In her survey of issues related to the implementation of *SNZC,* Baker (1999) reported high levels of “don’t know” responses when teachers were asked about the support that *SNZC* learning and assessment activities provided for Maori students (25 percent responded this way) and Pacific students (50 percent responded this way). Indeed no New Zealand research that specifically addresses this question, as it relates to effective pedagogy in science, has been found at any stage of the review process. In view of this significant gap in the research literature, this section reviews discussion of what general recommendations for culturally inclusive pedagogy might look like when they are related to what is known of specific learning challenges within the very distinct and strongly bounded culture of science itself.

Bishop and Glynn (1999;2000) define *Kaupapa Maori* as a pedagogy incorporating the reassertion of Maori cultural aspirations. Section 8.3 introduces the metaphors of *Kaupapa Maori* that these researchers have identified, and they are briefly discussed as they relate to science education.

8.3.1 Metaphors for *Kaupapa Maori* pedagogy and their relevance to science education

Metaphor 1: tino rangatiratanga

> Parents and students should be able to take part in decision-making about curriculum planning, to the extent of sharing power over decisions about curriculum content and the directions that learning will take (Bishop and Glynn, 2000, p. 4).

At the recent *Curriculum Stocktake Science Discussion* day, Maori teachers present placed on record their disappointment that there was to be no opportunity to discuss "*Pütaiao* as it sits parallel to the curriculum statement in English" (Ministry of Education, 2001a). They reminded all the scientists and science educators present of the many Maori students who are in mainstream classrooms and asked that *Pütaiao* be developed first in any further curriculum revision. They pointed out that the philosophy underpinning *Kura Kaupapa* education has been considerably refined since the writing of *SNZC*. They also expressed their concern that the approach to be taken should reflect the inclusion of a Maori perspective that involves *equal collaboration* rather than being framed as simply an *equity issue* (Ministry of Education 2001a).

Meeting this challenge would require teachers to take more account of cultural differences between the world-views of their Maori students and world-view(s) of science as a specific cultural process for knowledge building. Chapters Five to Seven have all noted the inter-related nature of NOS and other outcomes as a strong feature of effective pedagogy in science education. However, to meet the concerns of Maori science educators the culture of science needs to be directly related in some meaningful way to a quite different cultural world-view. This is a challenge that has not been addressed at the national level by any country with a distinctive indigenous culture as far as we could discover. However, there is considerable advocacy in this area and that is addressed in section 8.4.

Chapter Two noted that *SNZC* has a great deal of potential flexibility, and that the manner in which it is interpreted depends on the view of purposes for science education adopted by the reader. With the possible exception of the senior secondary level, the principle of community involvement in curriculum decision-making is compatible with wider "science for all" readings of *SNZC* but there are considerable implications for teacher expertise. These will be discussed in Chapter 10.

Metaphor 2: taonga tuku iho

> Schools and teachers need to create contexts where to be Maori is to be normal and where Maori identities are valued, valid and legitimate – in other words, contexts where Maori children can be themselves (Bishop and Glynn, 2000, p. 4).

As McKinley and Devine (2001) point out, being "Maori" is usually a self-identification that will be experienced differently in different contexts. Its meaning in contemporary educational contexts differs from historical meanings – it may even be seen as irrelevant in the context of *Kura Kaupapa* education. Self-identifying Maori students show wide variations in their physical attributes (which may or may not lead to their recognition as being Maori by teachers and other students) and in the strength of their tribal affiliations/cultural experiences of "being Maori". This clearly suggests that there is no one way for all Maori children to be themselves. This is of course also true of children from any other ethnic group. The dangers of essentialism in the preparation of science resource materials have already been noted in section 8.2.

Metaphor 3: ako

> Rather than acting always as the "expert" who conveys information to students who receive it, the teacher is *a partner in the "conversation" of learning* (Bishop and Glynn, 2000, p. 4).

The concept of *ako* is shared by all Pacific cultures, albeit with somewhat different shades of meaning. For Maori, *ako* denotes both teaching and learning – to do one is also to do the other (Metge, 1983). However, the primary meaning of *ako* in the Tongan culture is to "learn in a society where people are expected to behave in accordance with their various roles and status". The derivative *faiako* implies an active role for the teacher, with the underlying belief that one learns through "observing, listening to and imitating those who have learned and/or are learning" (Helu Thaman, 1998). This suggests that groups of students from this cultural background may expect their learning to be structured in this way. However, Bishop's view of "knowledge-in-action" supports the more active role for learners that is also described in the wide range of literature reviewed in Chapters Four to Seven, and for which very different types of pedagogy are more appropriate.

Bishop also points out that when the teacher uses an inductive questioning style the students are always working in the unknown and the teachers in the known, exacerbating existing discrepancies in power relationships. However, he cautions that the recent paradigm shift to a "community of discourse" pedagogy may still perpetuate the teachers' cultural dominance. Students need to be given the power to be the initiators of the discourse if genuine power sharing is to be developed through the process of co-construction of pedagogic interactions (Bishop 1999). Pedagogy that could achieve such genuinely two-way dialogue in the classroom was discussed in Chapter Seven.

Metaphor 4: whanau

Bishop and Glynn define *whanau* as:

> …a pattern of interactions [that] will develop where commitment and connectedness are paramount, and where responsibility for the learning of others is fostered (Bishop and Glynn, 2000, p. 5.)

Of all the principles for a *Kaupapa* Maori pedagogy, this is perhaps the one that is most familiar to teachers. However, it may be translated into the essentialist idea that all Maori students prefer to work in groups (McKinley, 1999; Hill and Hawk, 2000). The shallowness of such a view has been exposed by the research of Hohepa, McNaughton, and Jenkins (1996). They analysed interactions during extended group exchanges in a *Kohanga Reo* setting. They found that around half of the exchanges, notwithstanding the group structure, were actually between an adult and a child. The role of "leader" in these exchanges was often taken by the child rather than the adult. They point out that *tuakina/teina* (older brother/ younger brother) relationships were a traditional part of *ako* and are modelled in some myths – talented Maori children have always "pushed" adults in pursuit of their own learning (Hohepa *et al*., 1996).

Hohepa's research presents a strong critique of the assumption that group pedagogies are the only way to deal with Maori children and that interactions that focus on peer "cooperation" are the critical feature of such pedagogies. Science education research has found that effective discussion tasks need to be constructed according to relatively sophisticated principles, and the teacher needs to have clear conceptual, procedural, NOS and/or metacognitive aims in mind (Chapters Four to Seven).

Bishop and Glynn (1999) also point out that it is important that all Maori and Pacific children are explicitly taught to distinguish between intellectual challenges and situations that challenge the authority of their parents. In this way, they may become more comfortable with taking part in the conceptual development discussions that are so central to effective science pedagogy (Chapters Four to Seven).

Metaphor 5: kaupapa

> This is seen as "a collectivist philosophy of achieving excellence in both of the languages and cultures" (Bishop and Glynn, 2000, p. 5).

McKinley and Devine (2001) point out that, just as the meaning of what it means to be Maori has changed over time, so also may the meaning of achievement have changed. For some Maori parents it is an endpoint – e.g. a qualification – but many Maori parents want their children to be healthy, well-rounded adults who do well at whatever they choose to be. In her discussion of the issues inherent in developing the language needed for teaching science in *Te Reo*, McPherson Waiti (1990) pointed out that Maori people:

> …do not want to live in the past. They are a vital, living group of people who want a future, who want to live in the future, who want the best education available to them about the world around them

The discussion of *Kaupapa Maori* as a pedagogy sets out some general parameters of a distinct Maori culture. A growing body of literature outlines key areas of difference between Maori culture and the culture of science (NOS). In various research contexts, New Zealand's scientists have recently faced Maori challenges to their thinking about science, including:

- considering issues of *whakapapa* in the context of genetic engineering (Mead, 1997), with scholarly analysis of this concept and its relationship to Western science being openly discussed (Roberts and Wills 1998);
- considering indigenous approaches to sustainable management when managing for biodiversity (Millner and Sciascia, 1997); and

- looking more critically at the manner in which Western mindsets to “pest” species impact on conservation dilemmas with respect to species such as the Maori rat, the *kiore* (Haami, 1993; Roberts, 1993).

Within Western science itself there are those who argue for more widespread adoption of “systems”-based approaches (Mayer and Kumano, 1999) which are more compatible with Maori values of a “sacred balance” between use and protection of Earth’s resources (Mead, 1998).

Debates about cultural difference that are taking place within the professional science community in New Zealand expand the focus of the argument in support of more culturally inclusive pedagogy. When learning in science, *Kaupapa Maori* pedagogy could help raise achievement for those Maori and Pacific students who are currently performing least well in national measures of achievement (Chapter Three). However, it is likely that many of New Zealand’s future scientists will come from the ranks of our current school students who are already achieving well in science. For them, an understanding of Maori cultural values could impact directly on their future professional lives.

Summary of section 8.3

- Metaphors described for *Kaupapa Maori* pedagogy could be used to help meet the equity challenges associated with science education in New Zealand schools.
- *Kaupapa Maori* pedagogy is congruent with the “science for all” interpretations of *SNZC* outlined in Chapter Two.
- There are differences between the cultural views of *Kaupapa Maori* and Western science, and these differences are contributing to current debates in the community of professional scientists in New Zealand.

8.4 Teaching science in multicultural classrooms

While *Kaupapa Maori* may provide useful metaphors for effective pedagogy to meet cultural diversity in the classroom, there is no New Zealand research available as yet to evaluate the effectiveness of such recommendations in action in the classroom (McKinley, 2000). The small research study reported below comes from the Northern Territories of Canada, and relates to teachers’ interpretations of the issues and challenges of multicultural teaching and learning. While this research does not fall directly within the parameters of the literature sought for the review, it is included as an indicator of the complexity of actually implementing more inclusive pedagogy within a subject such as science that has its own very strong cultural (NOS) features. Teacher understanding of NOS, and its explicit integration in classroom learning, has already been identified as a key aspect of effective pedagogy (Chapters Five to Seven) and so the issues raised here are central to the implementation of effective pedagogy in science education more generally. The issues identified in this section will be further discussed in Chapter Ten.

8.4.1 A case study of the use of local culture to support science learning

Aikenhead and Huntley (1999) used in-depth interviews to research the pedagogical practice of ten Canadian science teachers, four of whom were indigenous to the Northern Territories. The researchers found that, whilst most of the teachers showed respect for local aboriginal culture, they generally viewed Western science as the only course content. A "token amount" of aboriginal knowledge was drawn on and no attempt was made by any of the teachers to integrate it with school science. Reasons the teachers gave for inclusion (or not) of cultural materials and ideas were analysed to identify *barriers* to the accommodation of different cultural views in classrooms:

- **conceptual** – the teachers did not recognise science as being a culture;
- **pedagogical** – none of the teachers appeared to understand that students' existing ideas could interact with the learning of new ideas, nor did they use any sort of cross-cultural instructional strategies;
- **ideological –** teachers blamed students' personal deficits for their learning difficulties and failure to take science at senior levels;
- **psychological –** although they cited different types of reasons for cultural conflict in their classrooms, none of the teachers acknowledged that it could be a barrier to student achievement;
- **cultural –** approaches used within the overall culture of the school tended to support memorisation rather than deep understandings; some students were thought to be already disconnected from their aboriginal cultures and would have no interest in them; a few male teachers saw no place for aboriginal knowledge in science classes; and
- **practical –** even where they were willing to incorporate aboriginal perspectives, teachers had trouble locating appropriate resources/people. One of the aboriginal teachers was away from her home area and did not feel confident about approaching local people, so indigineity was not, in itself, a sufficient solution to this issue (Aikenhead and Huntley, 1999)

While some of these identified barriers are specifically related to issues of science as a distinct type of culture, others relate more generally to teacher expectations of what it means to learn and achieve in science, and raise issues already discussed in Chapters Four to Seven. Again, the critical factor is the teacher's *awareness* of the impact of children's ideas and prior experiences on their learning, and the teacher's *willingness* to act on this knowledge by using children's authentic experiences of the world as the beginning point from which to help their science understandings grow.

Teacher awareness and willingness provide a foundation, without which appropriate pedagogy cannot be successfully developed and widely implemented. However, there are a number of issues of principle that have not yet been addressed at the policy and/or curriculum level in New Zealand. These are the focus of the remainder of this chapter.

8.4.2 Potential pitfalls when relating science to other world-views

Australian science educators Michael Michie and Mark Linkson (1999) have described their experimental development of curriculum support materials that would allow aboriginal Northern Territory students to learn Western science without becoming alienated from their own world-views. The *Kormilda Science Project* (Read and Rose, 2001) has also developed curriculum materials with these aims in mind. Linkson (1999) advocates the compartmentalisation of concepts related to each world-view so that neither is compared with the other in a judgmental way. The strategies for compartmentalisation that he has tried and found successful include:

- temporal separation (different experiences – probably on different days); and
- spatial separation (e.g. use of text boxes where both world-views are included on the same page of a resource).

Michie, Anlezark, and Uibo (1998) acknowledge the risk of "tokenistic" use of knowledge about indigenous Australians in science teaching for all students, although they do not suggest a clear resolution for this issue. The token use of everyday stories as an "added extra" in Chemistry has been outlined in section 8.2. Monk and Osborne (1997) caution that this can also happen when history of science stories are additional, rather than integral, to classroom learning and Ogborne *et al.*, (1996) have documented the misleading NOS ideas such "parables" may create (section 8.2). While Linkson's suggestions, as outlined above, are undoubtedly pragmatic, they avoid an issue of comparison that must eventually arise if cultural views are to be *integrated* into classroom learning using the type of conceptual development strategies identified as effective in Chapters Four to Six. A key question that must be addressed when exploring pedagogy for multicultural classrooms is this:

- How should science be related to other world-views, so that students come to understand those aspects of science that give it authority, power, and reliability, without being undermined in their respect for the world-views of their own and others' cultural backgrounds?

8.4.3 The notion of border crossing

Aikenhead (1996) reviews literature from the first half of the 1990s that explored the possible ways in which students' world-views can interact with science world-views during learning. If students are coerced into replacing aspects of their world-views that are incompatible with Western science they are said to have been **assimilated** into its culture. On the other hand, students who are **enculturated** already have world-views that harmonise with Western science. More recently, Aikenhead (2000) has added a third type of interaction. Students are **acculturated** if during their learning they are able to *compare* Western science and other knowledge systems and justify selection from each of those features which have personal meaning and usefulness in any given situation.

Aikenhead (1996) argues that teachers need to assist all students to make "border crossings" between their own world-views and those of Western science. Teachers should do this by modelling how to consciously move between their various life-worlds and the science world (some would say science *worlds*) without actually requiring students to adopt a scientific way of knowing as their personal way (Aikenhead, 1996). This aim describes the strategies that have already been identified in Chapters Five to Seven as those that can help students achieve NOS outcomes as an integral part of their learning. It seems the terms "border crossing" and "bridging strategies" intend the same purposes and outcomes. A sample of such strategies already described in this review could include:

- Teaching students to begin with, but then deliberately move away from, the use of anthropomorphic explanations for actual events ("Air Puppies" – section 7.2).
- Teaching students to diagram numerical relationships in ways that move their own thinking closer to the patterns envisaged by scientists and/or mathematicians (African American students – section 7.2).
- Teaching students how to use the scientific process of justifying their theoretical claims on the basis of available evidence (Argumentation – sections 5.4 and 6.4).
- Helping students to differentiate values that are part of the knowledge-building processes of Western science from those that are widely adopted by identified cultural groups (section 8.4.4 below).

Clearly, teachers need a sound NOS awareness to assist students to use such strategies. Once teachers know how their students' world-views might differ from science world-view(s), they can begin to act as "anthropological guides" (Cobern and Aikenhead, 1998), helping their students see these differences too.

8.4.4 "Border crossing" pedagogy: issues of principle for policy debate

Pedagogy for "border crossing" purposes is currently being hotly debated. The January 2001 edition of *Science Education* is devoted to the epistemological complexities of three broadly different approaches. These are outlined next, with illustrative examples of how each might be implemented in a secondary school science lesson. (It should be noted that the examples in boxes are interpretations of the literature, made by authors with essentially Western world-views, and reviewed by Maori colleagues, in an attempt to clarify what is otherwise a rather abstract argument.)

The cross-cultural perspective

Snively and Corsiglia (2001) argue that the view of what counts as science in the school curriculum should be broadened to include traditional ecological knowledge (TEK). They acknowledge that TEK embraces some epistemological features that are explicitly ruled out of Western science – for example, spirituality. However, they believe that an accommodation between the best of Western science and the best of TEK can lead to more effective solutions for contemporary problems and thus students should be encouraged to draw on both when seeking a consensus amalgamation of both. Thus in their view:

> Cross-cultural science teachers will need a curriculum that recognizes a community's indigenous knowledge or world-view in a way that creates a need to know Western science (Snively and Corsiglia 2001, p. 27).

Box 8.1 The cross-cultural perspective

What this might look like in practice

Students could be undertaking an inquiry into a water pollution problem in their local area. From Western science they could learn about nutrient over-enrichment of water (eutrophication) and its effect on living things in the waterway. They would probably learn how to identify a variety of indicative species, and various ways of measuring aspects of water pollution. From the perspective of *Te Ao Maori* they could learn about *wairua* - the idea of water having a life force that should be treated with respect. They would merge this with their science understanding/ methods of inquiry to make an action plan for lobbying for solving the pollution problem.

The multicultural perspective

Stanley and Brickhouse (2001) argue for a more metacognitive approach in which epistemological debates about the nature of science (which they term "gray areas") should be a focus of study. In this approach the content known as TEK would serve as counterpoint for interrogating the cultural features of Western science and students would thus learn that there are many different ways to view the natural world. For them, debate about the contested nature of knowledge is a key feature of a multicultural education:

> Typically, the school science curriculum contains only ideas on which there is a very widespread consensus; that is, they are uncontroversial in the field. However, although almost everyone agrees that we ought to teach students about the nature of science, there is considerable disagreement on what version of the nature of science ought to be taught. It is interesting that, while educators often argue about what should be taught among themselves, they rarely include students in such controversies. This is quite unfortunate, since the debate itself is potentially of enormous educational value (Stanley and Brickhouse, 2001, p. 47).

Box 8.2 The multicultural perspective

What this might look like in practice

Students could be undertaking an inquiry into a water pollution problem in their local area. From Western science they could learn about nutrient over-enrichment of water (eutrophication) and its effect on living things in the waterway. They would probably learn how to identify a variety of indicative species, and various ways of measuring aspects of water pollution. However they would also learn about the way in which, by framing the various aspects separately in order to make them measurable, Western science may lose the complexity of a more holistic indigenous approach. This critique would then frame their learning about the perspective of Te Ao Maori – including learning about *wairua* – to illuminate how this world-view values some aspects that are missing from the Western science perspective. Students would be helped to identify which of the two world-views underpinned statements they might make as they worked towards a solution of the pollution problem.

Note however that philosophers of Western science debate whether values perspectives are actually missing (Allchin, 1998), hence Stanley and Brickhouse's acknowledgement that this would be a contested approach is illustrated by the example we have devised here.

The pluralist perspective

In some respects, Cobern and Loving (2001) take the opposite view to Stanley and Brickhouse. They argue that it is critically important to help students learn about the key epistemological features of science, about which there is indeed broad agreement amongst philosophers of science. They define these features and call them collectively the "Standard Account" (pp. 57–61). Unless students can learn about these features they are left with no reliable basis from which to judge the validity of competing knowledge claims – a position that, if widely adopted, would undermine the very rationale for inclusion of science in the curriculum. This position would thus be helpful for countering some recent criticism of New Zealand's science curriculum as allowing an "anything goes" view of science to emerge (Matthews, 1995).

Cobern and Loving (2001) also argue that if science is seen as the "gatekeeper" to positions of power and prestige in Western society, then angling for the inclusion of traditional knowledge's within what counts as science simply accedes to the existing power game. Thus they argue for keeping other world-views and knowledge's *distinctly separate* from science. They should be taught and valued on their own epistemological terms (which makes an unapologetic space for inclusion of spirituality, for example).

Box 8.3 The pluralist perspective

What this might look like in practice

Students could be undertaking an inquiry into a water pollution problem in their local area. They would develop a detailed description of the evidence that suggests the water is indeed polluted, drawing on measurable aspects of Western science (perhaps turbidity, biological oxygen demand, indicative species, etc). They would also learn how what is to be measured is selected by reference to existing theory about the causes of water pollution. They would thus be explicitly taught about the manner in which science description and science theory interact in any process of inquiry. They would represent their learning through an agreed report format that explicitly modelled the manner in which science findings are shaped and reported for peer scrutiny.

In a separate class (perhaps "Cultural Studies") they would learn about the way in which the *Te Ao Maori* perspective shows a deep valuing of the health of water. This might include learning *waiata* and *whatatauaki* that describe features of water with its *wairua* intact and its vital importance for the health of the environment. Students might use a narrative format to create a dramatic representation of their personal learning journey.

As a final integrating assignment they might be asked to compare and contrast the two knowledge systems to discuss the manner in which the "framing" of the concept of water pollution allows different but complementary issues/questions to be addressed.

All of these approaches have been accepted or rejected, in whole or in part, by various science educators. Of the three "cultural" approaches, the least criticised would appear to be the pluralist approach, although it would undoubtedly be the most challenging to implement. As described here, this approach could not be implemented without cross-disciplinary planning. Issues of curriculum integration in science are further explored in Chapter Nine. In common with both cross-cultural and multicultural approaches, the pluralist approach is still viewed with caution from two key sociological perspectives:

The post-colonial critique

From the post-colonial perspective, no curriculum or pedagogical innovation can achieve its stated goals if deeply structural issues of power are not explicitly addressed:

> What makes the cultural diversity approach inadequate in various pedagogical moments is not so much that it is wrong, for people are diverse and do have culturally specific practices that must be taken into account, but that its emphasis on cultural diversity often descends to a superficial reading of differences that makes power relations invisible and keeps dominant norms in place. As such, the approach reinforces an epistemological cornerstone of imperialism, that the colonised possess a series of knowable characteristics and can be studied, known, and managed accordingly by the colonisers whose own complicity remains masked. The strategy all too often becomes an empty form of pluralism (McKinley, 2000, p.76)

The feminist critique

In a previous review of literature on gender issues, Alton-Lee and Praat (2000) documented a shift in feminist thought during the 1990s, such that the "masculinist discourses and gendered binaries" (p. 76) of Western science were exposed as supporting existing "regimes of power relations". While the concern with power issues is shared with the post-colonialists, feminists have also asked how science and science education might be different if different types of questions were asked in the first place:

> I therefore argue that the questions to begin with are not about, for example, universalism versus relativism. The questions that should serve as a point of departure concern goals for living; how we want to shape our future society, how we want human relationships to be, and about the environment. With these goals in mind, we can discuss science education; what science education would be like when it helps us achieve these goals. But a meaningful discussion about these issues requires an epistemological pluralism (recognition of and respect for different ways of knowing) based on an ontological pluralism (recognition of and respect for different world-views). Only then can knowledge from TEK and IK, and feminists be taken seriously and contribute answers to these questions (Svennbeck, 2001, p.81).

Svennbeck's critique returns the focus to the purposes for learning science within the overall curriculum and suggests a much closer integration of science and environmental education. This argument is further developed in Chapter Nine.

There is clearly a need for policy debate on the various approaches outlined in this section if we are to consciously develop a more inclusive science curriculum in New Zealand that could lead to changed pedagogy at the school level. The manner in which we educate our prospective secondary school teachers in science as well as in science education would appear to be especially influential. This issue will be returned to in Chapter Ten of the review.

Summary of section 8.4

- Science world-views may conflict with aspects of other world-views held by students. This is potentially an issue for all students but is of special significance for students whose cultural backgrounds are other than West European (the culture within which modern science was embedded as it developed).
- Border crossing/bridging strategies are an important part of pedagogy if students are to learn to move consciously between their various world-views. A range of examples are available for use in different situations.
- Teachers need to understand the culture of science themselves before they can begin to use border-crossing strategies purposefully.
- Three models for inter-relating science and other world-views have been proposed in recent science education research literature. Of these, the pluralist model and associated pedagogy would appear to have most support, although this model has also been criticised.
- Use of the pluralist model would require some degree of curriculum integration.

8.5 Summary of Chapter Eight

Narrative pedagogy draws on innovative uses of story telling, in which the stories are as likely to be told and/or interpreted by students as by the teacher. This pedagogy provides opportunities to begin learning with an exploration of students' own experiences when the stories take account of their world-view(s), culture(s), interests and gender. Narrative pedagogy is unlikely to achieve its intended benefits if it used as an "add on" to traditional lesson structures. Rather it should be fully integrated with carefully planned learning experiences that have clearly identified learning outcomes, including explicit NOS learning outcomes. Resources to support this (or any other) pedagogy need to be carefully developed to avoid giving unintended essentialist messages about any group of students or their culture. Some innovative student materials to support narrative pedagogy are already available in New Zealand schools.

Students can hold world-views that are different from science world-views, especially, but not only, when they come from other than Western European cultures. When narrative pedagogy draws on these different views and beliefs, teachers need to know how they are going to resolve differences that emerge without undermining either students' beliefs or the development of appropriate NOS outcomes. Three different pedagogical models have recently been proposed for this purpose. None are without criticism but the "pluralist" model appears to be the best supported, at least at this emergent stage of the debate. Use of this model in New Zealand schools would probably necessitate some degree of integration with other subjects, in particular cultural studies. However, debate about these models and the possible implications for curriculum first needs to take place at the policy level.

Chapter Nine: Curriculum Integration and Experiences Beyond the Classroom to Enhance Science Learning

9.0 Introduction

The synthesis of classroom research evidence reviewed in Chapters Five to Eight strongly suggests that many New Zealand students' participation and achievement in school science may be improved when science teaching:

- engages students' interests;
- uses strategies which help students to see links between science knowledge and their own knowledge and experiences; and
- helps students develop better understandings of the nature and characteristics of science.

Research reviewed in those chapters suggests that improved conceptual, procedural, and nature-of-science learning outcomes may be achieved when science is taught in contexts that are both relevant and meaningful to the learner, as well as relevant and meaningful in terms of reflecting characteristics of the nature and actual practice of science. In many cases, the achievement of these different learning outcomes is highly dependent on the degree to which these are explicitly built in as intended learning outcomes in the design of teaching strategies and activities.

The analyses of recent TIMSS, and NEMP results in Chapter Three also suggested that, particularly for younger learners, having broad background experiences and a wide general knowledge of the world is an important factor in students' making links between their daily lives and their science learning. An emerging issue is that effective science pedagogy involves not only taking into account students' *existing* ideas and experiences, but also *providing* opportunities for students to have rich foundational experiences that they might not experience outside their school lives. These experiences thus support the further development of science learning outcomes, as well as being an outcome of science learning.

Chapter Nine adds to the main findings of Chapters Five to Eight with a specific focus on three areas:

- curriculum integration;
- environmental education; and
- learning experiences outside the classroom.

Each of these areas involves aspects of teaching "beyond the classroom walls", and/or teaching across traditional subject discipline boundaries within the classroom walls. While specific Ministry of Education policy statements exist in each of the areas listed above, we have found relatively little New Zealand classroom (or "beyond-the-classroom") research that investigates the implementation and effect of these policies on New Zealand students' science learning in practice. This chapter reviews available New Zealand research and international research in these areas to provide indications about the kinds of policies and practices that may enable the incorporation of integrated and/or out-of-class experiences to promote effective and engaging science learning for a wide range of students.

Teaching which integrates subject-content and learning objectives from more than one curriculum area into classroom learning activities is a common practice in New Zealand primary classrooms. The explicit integration of multiple curriculum areas appears to be a less common teaching approach in secondary schools, although there is growing interest in possibilities for curriculum integration to be used more widely at Year 9 and 10 level. Section 9.1 reviews recent international and New Zealand research on curriculum integration involving science, and assesses the current strength of evidence for effective curriculum integration, which can effectively support science learning. The section also demonstrates some of the complexities and misconceptions about the meaning of "curriculum integration", what it means in the context of science education, and how it might be achieved in practice.

Environmental education is one example in New Zealand where curriculum integration involving science is a relevant issue. In this country, environmental education is not prescribed as a separate learning area. Instead, it is intended to be integrated or infused across the seven existing learning areas of the curriculum. Section 9.2 considers the opportunity in New Zealand for integrating science education with aspects of environmental education in ways that might support students' science learning.

Learning experiences outside the classroom, particularly those involving the natural environment, are part of the New Zealand primary teaching tradition. At secondary level, science-related field trips outside the school are less frequent, though they do have a strong history in senior level Biology education. Section 9.3 reviews international and New Zealand research evidence for the role of education outside the classroom (EOTC) in enhancing students' science learning.

9.1 Emerging issues in curriculum integration to support science learning

New Zealand and international literature suggest that the term "curriculum integration" is widely used to describe a range of different curriculum models, but that there is a lack of consensus about the issues involved (Fraser, 2000; Joyce and Taylor, 2001; Wallace, Rennie, Malone and Venville, 2001).

One obvious issue is the difference between curriculum integration at the primary and secondary levels. At primary level, teachers are expected to teach in all the learning areas, and to plan their teaching in a way that meets the curriculum requirements in a way that best meets the needs of their students. This often results in the combination of learning objectives from several areas of the curriculum into integrated/thematic teaching units. Fraser (2000) suggests a potential problem associated with curriculum integration at primary level is that it may lead to a loss of subject integrity and depth of learning in the areas that are being combined. For example, Chapter Seven (see section 7.1) noted that concerns have been raised that science teaching and learning opportunities in New Zealand primary schools are sometimes missed, or underdeveloped, when science learning objectives become obscured by language development activities (Education Review Office, 1996; Scott, 2000). On the other hand, Chapter Seven provided strong research evidence for both the crucial role of reading literacy in the development of "scientific literacy", and the link between "language" development and the development of students' abilities to understand and communicate the ideas and concepts represented by scientific language. The linkage between the developments of both kinds of "literacy" suggests that the integration of science and language learning can actually enrich science learning, particularly for students who begin with lower-than-average reading literacy, or who come from homes in which the *lingua franca* is something other than "standard English". A critical factor in effective language/science pedagogy identified in Chapter Seven was that language learning outcomes must be carefully planned to support, rather than overshadow, meaningful science learning outcomes. The studies reviewed in that chapter suggested that these kinds of pedagogy could lead to meaningful science learning in terms of both students' conceptual understandings, and their understandings of the nature and characteristics of scientific ways of thinking and communicating. These approaches also appeared to break down barriers to participation for particular students.

The traditional separation of subjects into distinct disciplines, taught by subject-specialist teachers, poses different kinds of challenges to the integration of curricula at secondary level. Research on curriculum integration involving secondary science confirms that there are many approaches that have been described as "curriculum integration". Research on curriculum integration at the secondary level usually reveals much about the practical difficulties associated with integration in the structure of secondary schooling, and may or may not look in detail at the specific pedagogical issues involved in curriculum integration at this level.

9.1.1 The many possible forms of curriculum integration

Wallace, Rennie, Malone and Venville (2001) report a synthesis of findings from a three-year study of Year 6-9 classes in sixteen Australian primary and secondary schools who were attempting curriculum integration in science, mathematics, and technology. Classroom observations, interviews with teachers and students, and document analysis from these schools, led Wallace *et al.* to conclude that instances of successful integration were idiosyncratic. In the schools under study, integration was rarely a school-wide phenomenon and over time teachers tended to drift away from integrated practice towards discipline-based teaching. The researchers observed many different forms of "integration". Some forms involved modifications of the school timetable and the formation of teaching teams. Examples of "integrated teaching" ranged from deliberate thematic and cross-curricular approaches to more informal or incidental efforts such as science fairs and local community projects. In terms of evidence of positive learning outcomes for students, the most promising forms of integration:

> …were those approaches where the course content was focused around problem-based projects or issues where the subject boundaries were blurred. That is, integration involved some form of culminating event or events requiring the assembly and application of an array of outcomes that might come from different subjects (Wallace *et al.*, 2001, p. 11).

Examples where integration did lead students to make interdisciplinary links and transfer knowledge and skill from one context to another, tended to be in which students and teachers were found to be working in team environments and students were able to call upon community and family support. One case study details the learning of Year 9 students in a programme for academically talented students working on an integrated science, mathematics, and technology project to build a solar-powered boat (Venville, Wallace, Rennie and Malone, 2000). Venville *et al.* describe several examples in which students tested ideas, developed questions, reviewed concepts, and consolidated understanding of relevant science and mathematics concepts applied in the context of the solar boat project.

Based on what they found in the sixteen Australian schools, Wallace *et al.* (2001) concludes that there is still much that is not known about curriculum integration. They suggest that integration is a "curriculum ideology" (p. 10), which has often been proposed as a potential way of promoting greater relevance and cross-disciplinary connections for students, but that these fundamental questions about integration still remain largely unanswered:

- What is the problem that integration is addressing?
- How is integration addressing this problem?
- What are students learning in integrated contexts?

9.1.2 Student learning in "integrated curriculum" contexts

In answer to the last question posed above, there are few recent New Zealand studies which provide comprehensive descriptions of actual teaching and learning interactions in New Zealand classrooms where science is being taught in an "integrated" context. One exception to this comes from a study by Nuthall and Alton-Lee (Nuthall and Alton-Lee, 1995; Nuthall, 1999), which systematically investigated 11- and 12-year-old students' learning outcomes in the context of an integrated science and social studies unit on Antarctica. The unit, which was considered to contain a large amount of science content, was typical of the way the topic was taught in that region, where resources of the Antarctic Centre were available.

The students' learning was assessed using pre- and post-unit knowledge tests. Test questions were developed based on: (a) interviews with the teacher about possible and expected learning outcomes for the unit; and (b) interviews with students in other similar classes about their understanding of the topic. At least one question was created to address each concept, fact, idea, or principle included in the content of the unit. Students' responses to these tests were complemented by student interviews, and detailed analysis of videotaped and audiotaped records of the students' classroom activities during the unit. The data were put together into a “concept file” containing records of all of the students’ classroom experiences, their private and public conversations, and actions which were relevant to their learning or non-learning of a particular concept.

The study illustrates how different students’ experiences of the same classroom unit led to quite different results on post-unit tests of knowledge. For example, although there was no focus on plant life as a distinct topic, students were expected to learn about plant life (or lack of it) in Antarctica because information about plants – usually in relation to references to the terrain and what Antarctica looks like – came up on several occasions during the unit. One of the outcome test questions was whether lichens were found in Antarctica. One student (Joy) learned this concept. Analysis of her concept file indicated that she had read relevant texts and been involved in class discussions at the appropriate moments in which the topic of vegetation in Antarctica came up. Another student (Jim) did not learn this concept and in an interview a year later had no recollection of the word “lichen” at all. Analysis of his concept file showed that Jim’s attention had been focused on other things in the two instances when the subject of lichens came up in the classroom.

Nuthall indicates that students’ “lack of involvement” was a major factor involved in their non-learning of the concepts that the unit was intended to teach. In addition, when students were given a choice of activities (e.g. choosing between two different articles to read), some students chose activities that did not provide them with the information they needed to be able to answer the test questions. Many of these students did not complete required tasks set by the teacher that would have helped them answer the test questions. At one point in the unit, students were asked to make up one or two questions they would like to answer or have answered during the unit. Many students demonstrated a lack of engagement with the task of preparing the question or seeking to answer it.

9.1.3 The Freyberg Integrated Studies Project

Ostensibly, the most well-researched and successful example of curriculum integration involving science in a New Zealand secondary school is the Freyberg Integrated Studies Project (Nolan and McKinnon, 1991; Nolan and McKinnon, 2000), which began in 1986 as a four-year project at a Palmerston North secondary school. The project involved teachers, administrators, and educational researchers working together to develop and field-test programmes which incorporated three curriculum design elements:

- out-of-class educational activities;
- student use of computers as an information processing and analysis tool; and
- integrated approaches to teaching and learning.

A pilot study in 1986 involved an Integrated Studies course designed for Year 12 students. The course combined elements from the existing senior subjects of Biology, Computer Studies, English, and

Geography, drawn together around a central theme: preservation and management issues confronting New Zealand National Parks. An out-of school component of the project involved two eight-day national park field trips (Nolan and McKinnon, 1991). Positive outcomes from the pilot study led to the expansion of the approach to involve students from Years 9 to 12. The integration model at Freyberg began by identifying the attitudes, knowledge, and skills of the existing subject-based secondary curricula, in other words, “the substantive concepts and ways of thinking to be acquired by students through their secondary education” (Nolan and McKinnon, 1991, p. 3). Integrative pedagogical approaches, in which out-of-class and computer-supported activities played a major supporting role, were then designed to incorporate these concepts. The integrative approaches included elements of four strategies, described in table 9.1.

Table 9.1 The four integrative strategies employed in the Freyberg project (Source: Nolan and McKinnon 2000)

1. The correlation of subjects involving simple co-ordination and sequencing of subjects around common topics.
2. Thematic studies involving the investigation of topics and issues of the day by bringing together and applying elements from relevant subjects.
3. Practical problem solving which involved students investigating and proposing solutions to “real life” problems in the community.
4. Student-centred inquiry that permitted individual students or groups of students to study personal interests and concerns.

In the Year 9 and 10 classes, groups of three teachers were associated with each Integrated Studies (IS) class (one teaching English and social studies, one teaching math, and one teaching science). In Year 11, separate teachers taught each subject, and in Year 12 two teachers worked together in an Environmental Studies course which incorporated elements from English, geography, biology, analytic chemistry, and ecology. Out-of-class trips were used to provide motivation and experiences and also the gathering of data suitable for computer analysis. Class activities often involved collaborative problem-solving and collaborative learning. Students typically produced computer-generated reports and gave presentations to audiences other than the class teacher. For example, Year 12 students produced a formal report for the conservator of a national park proposing strategies to minimise track erosion, based on a spreadsheet analysis of environmental impact data they had collected.

Freyberg student achievement data

A research programme associated with the project collected extensive quantitative data on student outcomes from the project over five years. This included measures of:

- student motivation and attitudes to computers, out-of-class activities and subject integration (assessed through attitude-scale questionnaires, supplemented with some interviews); and

- student academic performance (assessed through examination scores in school certificate mathematics, science, and English).

An analysis of data from three cohorts of students, including data collected from students in IS and from comparable non-IS students in the school, is described in Nolan and McKinnon (2000). An analysis of variance (ANOVA) of the School Certificate achievement scores shows that the IS students (n=192) performed significantly better than non-IS students (n=103) in all three subjects at a statistically significant level. The average effect size for science over the three cohorts was 0.84.

These quantitative measures provide some evidence that the integrated curriculum project did support students' science learning, though little qualitative evidence has been reported about the particulars of teaching and learning interactions that occurred in the classrooms in the project. No further research on the Freyberg integration programme has occurred since the completion of the project in 1991 (Patrick Nolan, personal communication, November 2001), though the school features as a case study of integrated curriculum on *Te Kete Ipurangi,* the Ministry's online learning centre (Te Kete Ipurangi, website). Although the curriculum integration format still features in the school's teaching programme, particularly at Years 9 and 10, it appears that the current Integrated Studies course involves the curriculum areas of English, social studies and technology and no longer incorporates Science.

9.1.4 Pedagogical issues in curriculum integration

Taken together, the three large studies described in the sections above give some clear indications about both pedagogical and practical issues involved in the integration of science with other curricula. This section will focus on the former issue, and section 9.1.5 will focus on issues relating to the practical implementation of curriculum integration (primarily at the secondary level).

According to Fraser (2000), the most common confusion about curriculum integration in New Zealand is the conflation of "curriculum integration" and "thematic units". Fraser's distinction between the two is illustrated in table 9.2.

Table 9.2: Fraser's distinction between thematic units and curriculum integration (after Fraser, 2000)

Thematic units	Curriculum integration
• Centre around a particular topic. • The teacher usually chooses the topic. • The central topic is considered through the lens of each curriculum area. • Teachers' plan how each curriculum area could contribute to the exploration of the theme. • Curriculum objectives are considered within each subject area and assessment decisions are made by the teacher.	• Does not usually involve a theme that the teacher plans in advance. • The core of the unit is based on an issue of concern, rather than a topic. • The issue is identified, discussed, debated, and clarified by both teachers and students. • Students identify what they already know, ask questions they wish to pursue. • Ideas for investigating the issue are also negotiated.

A characteristic of Fraser's model of curriculum integration (see table 9.2) is a genuine negotiation of curriculum with students. In a report to the Ministry of Education on curriculum integration, Fraser and Whyte (1998) describe an actual example of such a curriculum integration pedagogy in a low-decile New Zealand primary school class of five-to-eight-year old children[14]. The teacher in this classroom capitalised on the students' interest in a newspaper article brought in by one of the children, which concerned the presence of *Giardia* and *Cryptosporidium* in water supplies. The region the children lived in was also coping with flooding at the time. The children decided on a central issue that formed the hub of their discussion: "Water is precious but it can be a nuisance". The teacher had the children list what they already knew about water, discussed which questions might go together, and grouped all their questions into categories. For example, two sets of questions were: (1) "How does the rain come? How does the rain start?" and (2) "If we get our water from the river why don't we get the bug when we drink it? Can we see the bug in the river? What does it do to people?"

Once the questions were sorted into categories, the children were asked what skills they would need to investigate their questions. As the children pursued various lines of inquiry based around their questions, the teacher needed to ensure she had the necessary concepts and knowledge about the questions raised. The teacher's role included: teaching children the skills they needed to undertake their research; helping them clarify their questions and issues; and scaffolding ideas for communicating their findings and assessing key objectives that naturally emerged from the study.

Using the negotiated-curriculum model of curriculum integration pedagogy, units and activities cannot be entirely planned in advance because the process of negotiation requires teachers to take cognizance of their students' concerns, questions, and prior knowledge and use these as the basis for classroom activities. This kind of pedagogical strategy has a strong congruence with much of the research

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[14] Because the classroom study described above does not include a systematic evaluation of students' learning outcomes, it is reported here only to illustrate the pedagogical features of Fraser's model for curriculum integration.

reviewed in earlier chapters. The description of the teacher's role in the example above is synonymous with the interactive teaching approach (Biddulph and Osborne, 1984) developed during the second LISP project (see Chapter Four, section 4.2), which emphasised the importance of starting from children's own questions in science. Pedagogy of this kind was also described in Chapter Five, in studies which demonstrated the potential for classroom discussions to be used to positive effect to enhance students' conceptual knowledge development in science, and again in the "student talk" pedagogies described in Chapter Seven (section 7.2). There are also similarities with the pedagogy of "open" investigations discussed in Chapter Six.

The form of curriculum integration involved in the Antarctica teaching unit studied by Nuthall (1999), appeared to include neither curriculum negotiation in the manner described by Fraser's somewhat purist model (2000), nor to be based around problem-based projects or issues involving some form of culminating event or events requiring the assembly and application of an array of concepts, skills, and processes relevant to the problem, as in the study described by Venville *et al.* (2000) or Nolan and McKinnon (1991; 2000). While students were expected to construct their own questions at particular points *during* the unit in the Antarctica classrooms, it is difficult to assess the extent to which these students' own ideas, interests and experiences were used as a basis for *planning* the teaching and learning unit. Fraser suggests that in many New Zealand classrooms:

> …teachers are in fact planning the units in advance, and consulting with the students only on a few minor details. The core elements, activities and direction of the units, as decided by the teacher, remain unchanged (Fraser, 2000, p. 35)

Such an approach would appear to conflict with one of the key features of effective science pedagogy that have been identified in Chapters Four to Eight – namely, using students' own ideas, interests, and experiences as a basis from which to develop meaningful science learning. This provides an interesting counterpoint to the problems associated with the use of pre-planned "recipe practicals" discussed in Chapter Six. In Chapter Six, the use of these pre-planned practicals often resulted in students failing to develop the intended science concepts although they may have been happily engaged in carrying out the learning activity. In the study above (Nuthall 1999), the use of a teaching unit with pre-planned learning goals and objectives resulted in a lack of engagement by some students in the classroom activities, with an associated failure by these students to learn specified science concepts.

9.1.5 Implementation issues for curriculum integration at secondary level

Nolan and McKinnon (1991) report that differences were noted between primary- and secondary-trained teachers involved in the Freyberg project. Primary trained teachers were more willing to adopt integrative approaches, while secondary trained teachers were more concerned with coverage of prescribed syllabus content coverage and tended to be sceptical of integration. The successful implementation of IS was considered by the researchers to depend heavily on teacher related factors such as:

- enthusiasm;
- the feeling that they were able to contribute effectively;
- having reasonable time within which to collaboratively plan programmes and develop activities and materials;
- knowing what they were to do and what their peers in the programme were doing; and
- having the knowledge and resources to do the job.

Teacher and school-wide factors can present major barriers to secondary curriculum integration. Factors such as teacher recruitment and identity, subject histories, department politics, and subject status serve to protect subject interests and thwart integration across subject boundaries. These issues have been identified in research by Wallace *et al.* (2001) in regards to curriculum integration in Australia, and in Jones' (1999) research which was associated with the development and implementation of *Technology in the New Zealand Curriculum* (Ministry of Education, 1999d). This research showed that attempts to integrate technology education within existing secondary subject areas often resulted in fragmentation of the goals of technology education, as subject teachers tended to concentrate on the features of technology education that would align with their traditional subject views.

Jones, Moreland and Earl (2000) researched a recent attempt to introduce teaching and learning strategies based around the introduction of integrated curriculum units and information and communication technologies (ICT) at a New Zealand secondary school. In this school, the integrated curriculum innovation was trialled with a single Year 9 and 10 class. The project researchers discovered many within-school difficulties and obstacles to the innovation. Foremost of these were issues of sustainability, staff resistance, and inequalities in the resources and opportunities offered to the trial class. The majority of teachers understood the aims of having an integrated curriculum class as improving student motivation and learning outcomes, but the project also encountered staff resistance due to conservative traditional relations between subject departments.

The examples in this section show that there is strong interaction between the pedagogical ideals of curriculum integration, and the practical issues that make it difficult to work towards these ideals in practice. For example, Fraser's model can be considered as a "purist" view of curriculum integration. While the pedagogical value of this model for science teaching appears to have a strong research backing, there are factors which mitigate against the achievement of this "ideal" in the realities of both primary and secondary classrooms. At primary level, teachers' science knowledge, and their ability to teach the children the skills they need to investigate their own science questions, may be underdeveloped. At secondary level, traditional subject divisions may be difficult to work around. Finally, at both levels, the requirement to plan their teaching by deriving learning outcomes from achievement objectives can limit teachers' opportunities to work from students' own questions and interests.

Summary of section 9.1

- There are many definitions of "curriculum integration".
- Attempts to integrate curricula can be problematic, particularly in the absence of a clear understanding of the learning goals and purposes for integration.
- At primary level, combining learning objectives from different curricula may result in a loss in the integrity and depth of learning in the subject areas being combined.
- Science learning appear to become obscured by language learning in some NZ primary schools, although research suggests ways that science and language learning can be integrated to enhance both kinds of learning.
- At secondary level, attempts at curriculum integration can run into problems because of resistance to breaking down traditional subject discipline divisions.
- Research on curriculum integration in practice suggests that effective forms of integration are those that begin with topics of relevance and interest to learners, involve real-life problems and issues, and involve learners developing and investigating their own questions.
- Successful integration requires teachers to have strong pedagogical content knowledge in order to be able to help students to develop and apply the appropriate subject area knowledge and skills they require in the context of an integrated project.
- There is currently only limited research evidence in New Zealand for effective curriculum integration practice which supports students' science learning.

9.2 Environmental education: a test case for curriculum integration in New Zealand

9.2.1 New Zealand policy context for environmental education

Environmental education did not appear as one of the seven learning areas when the *New Zealand Curriculum Framework* was released in 1993. The absence of environmental education as a discrete learning area in the framework reflected a debate at the time over whether environmental education should be a stand-alone learning area, or whether it would be most effective when infused into other learning areas (Barker, 2001). In the end, New Zealand has taken the latter approach. The production of a national strategy for environmental education (Ministry for the Environment, 1998) was followed by the release of *Guidelines for Environmental Education in New Zealand Schools* (Ministry of Education, 1999c). Environmental education is described as:

> A multidisciplinary approach to learning that develops the knowledge, awareness, attitudes, values and skills that will enable individuals and the community to contribute towards maintaining and improving the quality of the environment
> (Ministry for the Environment, 1998 p 9)

The *Guidelines* are intended to assist teachers and schools to identify opportunities within existing national curriculum statements to plan and provide environmental education activities, and provide examples of opportunities for exploring environmental education in relation to each of the seven learning areas. As such, environmental education represents a test case for curriculum integration in New Zealand.

Environmental education and science education have a historically close relationship, to the extent that earlier draft versions of the curriculum framework included "Science and the Environment" as a suggested learning area. While the word "environment" was eventually removed from the title, references to the relationship between science and the environment occur throughout *SNZC* (Ministry of Education, 1993a). This includes the aims of helping students to develop knowledge and a coherent understanding of the living, physical, material, and technological components of their environment and helping them to explore issues and make responsible and considered decisions about the use of science and technology in the environment. The *Guidelines* identify several strands and achievement objectives from each level of *SNZC* (Ministry of Education, 1993a) that could be used to meet the aims of environmental education. A recent survey of 705 schools throughout New Zealand (Chronis, 2001), indicated that 51 percent of primary, 95 percent of intermediate, and 70 percent of secondary schools were aware of the guidelines. However, only 43 percent of the schools said they were using these for planning their environmental education activities or programmes.

The successful integration of environmental education and science education requires educators to have a clear understanding of the relationship between the disciplines, not only as they are currently taught, but also as they may be taught in the future. Gough (1999) reviews the global development of environmental education, and argues that science education can be an appropriate platform for environmental education providing that it is a reconfigured science education. Science education must allow for the integration of facts and values which includes "developing students' abilities to make decisions that include ethical considerations of the impact on people and the environment of the processes and likely products of science" (p.257). Barker (2001) provides a substantial review of the history of school-based environmental education in New Zealand and provides a number of recommendations for the way in which science educators can contribute most effectively to environmental education. Among these include the acceptance of the "values-drenched" nature of both science education and environmental education; and that human participation in decision-making is central to both disciplines. Barker further suggests that serious engagement with environmental education might have enormous beneficial feedback for science education. There is an extremely underdeveloped research focus on "values" learning outcomes in the context of New Zealand science education at present. The intersections between science education, values and New Zealand's multicultural society outlined in Chapter Eight (section 8.4) suggest that environmental education would provide a fertile area in which to further explore these issues.

Many recent local and national initiatives in environmental education suggest opportunities for integrated science and environmental education. For example, the National Waterways Project (Royal Society of New Zealand, website) seeks to: involve students in learning by gathering and interpreting their own waterways data; obtaining other data and making comparisons; involving their caregivers and family groups in local waterway monitoring activities; and becoming water wise and able to make lifestyle choices to improve the quality of our environment.

In spite of these and other similar programmes and initiatives (Yorke, 2001), it appears that comprehensive research evidence concerning the integration of environmental education and science education in practice, and the impact of such integration on students' science learning, is as yet scarce in New Zealand. An anecdotal example at the primary level comes from a school in Dunedin (Opoho Primary School, 2001). Working with a scientist, a class of upper primary children at Ohopo School learned first hand about some investigation techniques in the field. For seven days they helped with a capture/tag/release programme that sampled possum numbers in a Dunedin suburb. As they monitored trap numbers, taking into account types of bait, trap placements, "history" of catches per trap, weather and other variables, the children learned about predicting, subsequent hypothesising, designing tests to eliminate incorrect hypotheses, careful data collection and numerical processing, including graphing. Values were taken into account as the children assured the welfare of the animals while temporarily trapped, and while being sedated, tagged, weighed and released. While methods of population control were discussed, including the feasibility of sending all possums back to Australia, the children came reluctantly to realise that sometimes some types of animals have to be killed when their welfare conflicts too sharply with survival of other species. The children role-modelled scientific reporting as they presented their findings to a school assembly. Thus this unit of work *appears* to have incorporated science "content", science investigation, ideas about science, and values in science – all in an environmental education context of personal relevance to the children. A teaching programme such as this one would be a ripe example for research to fully investigate the effects the degree to which each of these learning outcomes were actually achieved by students.

A few isolated studies of children's science learning involving education experiences outside the classroom (Arcus, 1995; Wilton, 2000) centre around some of the objectives in *Science in the New Zealand Curriculum* which have been identified in the *Guidelines* as having some overlap with the aims of environmental education. These will be reviewed in the next section.

Summary of section 9.2

- Environmental education represents a test case for curriculum integration in New Zealand.
- Science education and environmental education have historically a close relationship, and

some aspects of science education are pertinent to the goals of environmental education and vice versa.

- Integrated science-and-environmental education approaches have the potential to provide contexts which engage students in real-life activities, and involve them in decision-making in science and about the environment.
- Environmental education may provide a rich context for research on the interaction between science education and the development of students' values.
- Further research is needed to investigate the integration of environmental education and science education and its impact on New Zealand students' science learning.

9.3 Science and education outside the classroom (EOTC)

9.3.1 New Zealand policy context for EOTC

Education outside the classroom (EOTC) refers to all learning activities that occur beyond the classroom or early childhood centre building. These activities are accepted as an essential part of the New Zealand curriculum. *Anywhere, Everywhere,* the Ministry's EOTC curriculum guidelines document for primary, secondary and early childhood education (Ministry of Education, 1992e, p. 5), states that EOTC experiences are intended to enable New Zealand children to gain new knowledge, understandings, skills, abilities, and attitudes, as well as building on those they already have. In this section, international and New Zealand research evidence for the role of EOTC in enhancing students' science learning will be reviewed.

9.3.2 Science-related visits to the outdoor environment

Together, New Zealand policy statements on EOTC, anecdotal and survey evidence of the high incidence of and importance attached to EOTC by New Zealand schools, and the growing focus on the integration of environmental education across curriculum areas including science, suggest that opportunities for science learning involving the outdoor environment must be abundant. However, despite much anecdotal evidence, we have found very few instances of New Zealand research that has investigated the relationship between outdoor experiences and students' science learning.

One very small study by Wilton (2000) examined nine Year 6, 7, and 8 students' science learning and retention of understanding following a visit to a local stream to study fresh-water plants and animals. The teaching unit had been designed to meet two objectives from the *Making Sense of the Living World* curriculum strand: to "investigate special features of common animals and plants and describe how these help them to stay alive", and "use simple food-chains to explain the feeding relationships of familiar animals and plants, and investigate the effects of human intervention on these relationships". Wilton's observations of students, interviews with students and teachers, and samples of student work following the excursion, indicated that the trip to the stream had been characterised by high levels of watching, listening, collecting, discussing, and questioning. During subsequent class work, students developed ideas about the variety of organisms found within the habitat; about methods for evading predators such as hiding under rocks and weeds; about the existence of stages in life-cycles; about the food-webs that existed within the stream; that variations in water level are caused by irrigation; and that there are dangers from the presence of stock or people. Wilton found the students could discuss these ideas, with reference to their observations and experiences at the stream, twelve weeks later.

A more detailed study by Arcus (1995) links together several of the elements under review in this chapter: science education involving education in and about the environment; the use of informal science learning environments (reviewed further in the next section); and the relationship between classroom science pedagogy and education experiences outside the classroom in New Zealand primary science education. The study aimed to investigate the learning children might be involved in during the EOTC elements of their science programmes, what conditions might support these learning processes, and how teachers might facilitate successful learning. The study involved three classes from three Wellington area schools, each of whom used a different sort of EOTC as part of a science teaching unit. A Year 1/2 class doing a science study on dinosaurs visited a science centre dinosaur exhibition. A Year 5/6 class used a visit to a Botanical Gardens and tree-planting activities at a local retirement home as part of a unit focusing on guardianship of the local environment, the sources of material used in everyday goods, and the effect these materials have on the environment. A Year 7/8 class studying flight took a trip to see a wind turbine in action. Arcus used a case study approach to collect extensive naturalistic data on the work of the children and their teachers before, during and after the EOTC, through participant observation, and interview-conversations with teachers and children.

Arcus noted that none of the teaching/learning processes observed in the case studies were intrinsically exclusive to EOTC experiences. The teachers in the study, each of whom had a special responsibility for science within their school syndicate, were concerned to ensure that pupils had as rich a knowledge base as possible prior to and during the units and were anxious to ensure that their children were actively involved in the learning experiences. The teachers recognised the important role of children's pre-existing ideas in further learning and worked to ensure that base was as extensive as possible. They saw an important part of their role as assisting learners to make connections between prior ideas and novel experiences. For example, the Year 5/6 class went to the Botanical Gardens with a number of personal questions they wished to answer in response to at-school focussing experiences prior to the visit. Their teacher had developed a number of other strategies to get the most value from the EOTC experience. These included: a de-emphasis on worksheets while at the Gardens; "priming" parents with suggested questions and having them encourage children to look closely at things; and actively assisting the children to make links between what they had learned elsewhere and the current experience.

9.3.3 Learning experiences outside the classroom (LEOTC)

Since 1994, the Ministry of Education has run a contestable annual tender round for the purchase of Learning Experiences Outside the Classroom (LEOTC) services on behalf of New Zealand schools. Organisations such as science and technology centres, museums, observatories, zoos, galleries, and historic parks and other providers can apply for LEOTC contracts by submitting proposals for programmes which demonstrate relevance to national curriculum statements and the *New Zealand Curriculum Framework* (Ministry of Education, 1993b). Project specifications for LEOTC (Ministry of Education, 2001) state that such programmes should complement students' in-school learning and provide experiences other than those that a suitably trained classroom teacher can provide in the wider school environment. As of September 2001, 61 organisations were listed as LEOTC providers, and 23 of these were classified as providing programmes in the curriculum areas of either Science/Putaiao, Mathematics/Pangarau, or Technology/Hangarau[15] (Ministry of Education, 2001).

In 1998 an evaluation report of LEOTC, involving a survey of 102 schools, found that these schools engaged in a wide range of education outside the classroom (EOTC) activities (including all camps and field trips other than those which are part of an arranged LEOTC programme). Both LEOTC and EOTC trips were highly valued by schools (Jordan and Strathdee, 1998). The four main reasons schools said they attended LEOTC programmes were:

- their compatibility with the New Zealand curriculum framework (73 percent);
- to provide hands-on experiences for students (29 percent);
- to gain access to specialised resources and expert staff (27 percent); and
- to provide out-of-school learning experiences for children (27 percent).

Jordan and Strathdee's evaluation only looked at schools' participation in and views and attitudes towards, LEOTC programmes. It did not include information about how the LEOTC programmes were integrated into school curricula nor which curriculum areas were involved. Another evaluation which involved a telephone survey of 40 schools who had participated in LEOTC programmes in 1997 (Julian, 1997) indicated that half the schools had participated in programmes relating to the science curriculum.

Despite the importance given to education outside the classroom in New Zealand education policy, New Zealand studies that provide classroom evidence of the role of LEOTC or EOTC specifically in relation to student learning in science are relatively rare. When examined in conjunction with international research, these studies do provide some indication of ways that pedagogy which incorporates EOTC might be most effectively used to support and enhance students' science learning.

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[15] The data were not broken down to specify how many of the programmes were classified in to each of these learning areas

9.3.4 Visits to informal science learning environments

There is a substantial body of international research on the use of visits to informal science learning environments such as science museum, science centres, nature centres, zoos and aquariums, as a means to enhance school science education. A recent review described 141 studies that have investigated various learning outcomes from science centre visits, including those relating specifically to visiting school groups (Rennie and McClafferty, 1996). Studies confirm that these visits can provide valuable and often motivational opportunities for students to learn science. The nature of students' learning appears to be influenced by factors including: the degree of students' familiarity with the setting; their prior knowledge; the degree of structure of the visit, the provision and nature of cues for learning; and the social aspects of the visit (Rennie and McClafferty, 1995). A frequent and unsurprising finding from studies of school visits to informal learning environments is that that teachers play an instrumental role in determining the type of learning outcomes which can come from such visits.

It would appear from some international studies that a strong link between class visits and school science activities is not always achieved in practice. For example, Tuckey (1992) conducted a study of learning at a Scottish science centre involving 153 children aged 8-12 and their teachers. The teachers were interviewed and said their reason for visiting was to enrich the school science curriculum but evidently no special preparations had been made in this regard, nor were the visits apparently linked to any topic that children were studying in class. Griffin and Symington (1997) investigated the relationship between primary and secondary school class visits to either a museum or a science centre, and school science learning. The study, which involved 735 students in 30 classes ranging from Grade 5 to Grade 10, looked at strategies used by class teachers before, during, and after the excursion. Data were collected through observations and interviews before, during, and 2-3 weeks after the visit. The results indicated that teachers used mainly task-oriented teaching practices and made little effort to link topics being studied at school with the visit. Only four of the school groups were actually studying the topic of their excursion at school at the time of the excursion.

Visits to informal science learning environments in New Zealand

Recommendations in the science education literature for bridging the gap between EOTC and school science learning indicate that the relevant ideas and experiences which students encounter during the visit must be scaffolded back in the classroom if successful science learning is desired. This presumes that science learning is a desired objective. If teachers have other intended outcomes in mind then the follow-up activities they engage in may focus on other aspects of an EOTC experience. Bolstad (2000) studied six New Zealand primary school classes (ranging in age from Year 1 to Year 4) to evaluate the role that a visit to a science and technology centre played in primary education. The classes were observed during their visits. Six teachers and five children from each class were interviewed before, and 7-10 days after, their visit. Both the teachers and the children valued the science and technology centre primarily due to its child-oriented design characteristics, and all six teachers expressed the view that class trips made valuable contributions to the children's life experience. For example, a teacher at a low-decile rural school described a class visit to an exhibition on "flight" as a chance for the children to experience something that they might not otherwise encounter in their everyday lives, for example, sitting in a model of an aeroplane seat:

> Experiences that a lot of them won't have the opportunity to have. To feel, to see, to touch things that they won't be able to do later on (teacher quoted in Bolstad, 2000, p. 97).

Few of the teachers in the study pursued a list of possible science curriculum links and teaching activities suggested by the science and technology centre, and where this did occur, it was only when the suggestions coincided with the teacher's own intended activities for after the visit. This in turn depended on the particular circumstances of each class including: the teacher's long-term teaching plans; the teacher's knowledge and confidence in teaching science; the ages and abilities of the students; the teacher's own perceptions of their students; and what they hoped to achieve with their students. The interviews and follow-up activities which occurred in the classrooms indicated that the teachers had a strong interest in observing how the children responded to their EOTC experience and knew how to draw out these experiences afterwards through talk, writing, and classroom activities, as recommended in the EOTC guidelines (Ministry of Education, 1992e). However, the teachers were less able to draw out the potential opportunities for extending the children's *science learning* through classroom activities that would scaffold the science-related concepts encountered during the science centre visit, primarily because science learning *per se* was not an explicit teaching objective, nor was it an area most of the teachers felt comfortable teaching.

Otrel-Cass (2000) conducted a study around an LEOTC-funded science centre exhibition designed specifically to provide a hands-on interactive resource for teaching concepts in earth science, to address a perceived lack of resources in earth science following its introduction as a learning strand ("Planet Earth and Beyond") in *SNZC*. Thirty-seven primary and secondary teachers were interviewed in the study. Most of these teachers were particularly excited by the fact that the earth science exhibition highlighted a particular curriculum area, and felt that the science centre visit worked best in combination with preparation before the visit. Interviews and tests of teachers' earth science knowledge suggested that their confidence to teach earth science was dependent on their knowledge of the curriculum area. Many of the teachers who had low earth science confidence, but scored well on a knowledge test, exhibited a limited depth of knowledge in activities which required them to apply this knowledge (for example, drawing and labelling the internal structure of a volcano). Teachers perceived earth sciences to be dominated by visual learning, and said that practical experiences were an important component of earth science learning. They felt that the curriculum-targeted exhibition allowed them to plan and fully include the out-of-school activity into their science programme.

Otrel-Cass interviewed 47 students from five different classes, aged between 8 and 13, three months after visiting the earth science exhibition to determine what students could still remember from the exhibition, whether they were able to explain what the exhibits sought to portray and the students' interpretations of geological aspects. Otrell-Cass found that students often did not differentiate between information gained at the exhibition and the information that they had gained through post-visit work at school or at home.

9.3.5 School science programmes in informal learning environments

Although resource materials may be developed to support LEOTC programmes neither resource material development or teacher professional development are currently focuses of the scheme. This contrasts with partnerships between schools and informal science learning environments in other countries. For example, according to a national survey conducted in the United States (St John, Dickey, Hirabayashi and Huntwork, 1994), there is one informal science learning institution for every 50 schools, and one for every 1,000 elementary school teachers in the United States, currently serving upwards of 150,000 teachers teaching science, approximately 10 percent of the total in the teaching force. St John *et al.* describes these institutions as an important part of the national infrastructure for science education.

St John *et al.* found that the types of school support activities offered by science centres could be grouped into three levels: short programmes, medium-term/more intensive programmes, and long-term/very intensive programmes (St John *et. al.* 1994). Almost all the institutions surveyed engaged in short-term programmes. These include teacher open nights, educationally supported single-visit field trips, and outreach programmes such as travelling demonstrations and support of school science fairs. About half engaged in medium-length, more intensive programmes, which include multi-day teacher workshops, teacher coaching and classroom support, assistance with materials and classroom kits, and helping schools with curriculum development. Finally, only the large and well-funded institutions typically engaged in long-term or intensive programmes, which included programmes for pre-service teachers, teacher internships, and collaborative projects involving co-operation between several local educational institutions (i.e. schools, industry, and tertiary institutions).

Reviewing findings from 35 evaluation studies of school science programmes at institutions such as museums and science centres in the United States, Price and Hein (1991) found that teachers were most enthusiastic when they:

- received pre-programme orientation;
- had input into the design of the programmes;
- were actively involved by institution staff running the programmes sessions; and
- participated in teacher-only workshops.

Price and Hein found that teacher workshops had the potential to affect teachers' pedagogy and attitudes towards science. One evaluation by Price and Hein of teachers involved in a long-term collaborative programme found that participation in the programme led many teachers to increase the amount of time they spent on science and also provided teachers the opportunity to learn from each other. Teachers involved in a programme spanning two to three years described both increased confidence in handling the curriculum material, and an increased ability to integrate programme materials and classroom science.

Summary of section 9.3

- Although education outside the classroom is promoted in *NZCF* as contributing to learning in all curriculum areas, only a small number of New Zealand studies have investigated EOTC and science education involving either the outdoor environment or the use of informal science learning environments.
- International and New Zealand research provides recommendations for effective pedagogies for making best use of EOTC.
- Research indicates that teachers must have a clear and meaningful knowledge and understanding of the science learning experiences that EOTC can provide and how they can scaffold these experiences through their in-class and out-of-class pedagogical strategies.

9.4 Summary of Chapter Nine

This chapter has reviewed recent international and New Zealand research to seek evidence about effective pedagogies involving curriculum integration, environmental education and science education, and education outside the classroom.

Research suggests that curriculum integration has been defined in many different ways, and attempts to integrate can be problematic, especially in the absence of a clear understanding of the goals and purposes for integration. At primary level, integration may lead to a loss in the depth and integrity of the science that is taught and learned, while at secondary level, curriculum integration can be thwarted by traditional subject discipline divisions. The most promising and successful kinds of integration appear to be those which begin with topics of relevance and interest to learners, involving real-life problems and issues and require the assembly and application of skills and knowledge that might come from different subjects. This form of integration requires teachers to have strong pedagogical and pedagogical content knowledge to help students develop and apply appropriate subject area knowledge and skills as necessary. However, while there is a strong research backing for the effectiveness of this form of integration, practical issues need to be taken into consideration when thinking about how to infuse more effective curriculum integration pedagogies into the reality of primary and secondary classrooms.

Environmental education can provide a rich context for the integrated science learning. Science education and environmental education have a historically close relationship, and it has been suggested that integrated science and environmental education can have benefits for both kinds of education. Despite evidence of recent initiatives in environmental education which may enhance students' science education, this area of research in New Zealand is still underdeveloped. One area for further investigation is the relationship between environmental education, science education and the development of students' values.

Despite the promotion of education outside the classroom as a valuable part of learning in all curriculum areas, there has been little New Zealand research on the role of EOTC in science education. International and New Zealand research provides recommendations for effective pedagogical strategies to make the best use of EOTC for science teaching and learning. This research indicates that teachers need clear and meaningful understandings of the kinds of science learning experiences that EOTC can provide, and teachers need to know how to scaffold these experiences inside and outside the classroom. International research suggests that teacher professional development as well as accessible resources and programmes can assist teachers to integrate theory and practice in this regard.

PART IV: SUMMARY AND POLICY IMPLICATIONS

Chapter Ten: Summary, Synthesis, and Implications

10.0 Introduction

The objective of this review has been to synthesise the findings of significant international and New Zealand research on effective pedagogy and to draw links between student learning, curricula, and pedagogy in science education across the compulsory sector. The research question posed in Chapter One was:

> How does the national and international literature on science education inform our understanding about effective teaching practice/pedagogy on student achievement in science education for the diversity of students in New Zealand?

A key focus of this literature review has been to search for evidence that links particular types of classroom pedagogy to enhanced achievement in science for *all* students. To that end classroom-based research with a focus on the outcomes that students had actually achieved was sought and evaluated.

Science in the New Zealand Curriculum (Ministry of Education, 1993a) specifies that three kinds of learning outcomes should be developed together during classroom learning. They are:

- content/conceptual knowledge outcomes;
- procedural knowledge/skills outcomes; and
- nature of science (NOS) outcomes.

Section 10.1 summarises the key features of effective pedagogy to support these kinds of learning outcomes, based on the classroom studies reviewed. It became evident during the course of the review that many factors were implicated in effective practice to achieve these kinds of learning outcomes. These factors are somewhat complex because they can serve as both inputs and outcomes of effective learning. They include: the utilisation of rich experience for making meaningful learning links; reading literacy skills; the utilisation of metacognitive thinking about personal learning; and awareness of cultural diversity and values. These have been included in the analysis presented in section 10.1. Finally, section 10.1 relates the achievement of “attitudes” and “values” outcomes that are implicit in *SNZC* to the overall findings for effective science pedagogy.

The complex nature of classroom action raises questions about research that isolates individual factors for concerted attention. When the focus is on one learning goal, other goals become less apparent or even temporarily invisible. This is, of course, as true for teachers as for researchers. Yet a significant finding of the review was that all the factors described above need to be the explicit focus of the teacher’s attention, decision making, actions, and classroom dialogue, if they are to be achieved. Teachers work in the complexity of a whole classroom situation and must integrate all aspects of their practice in the moment. Accordingly, section 10.2 synthesises findings from those aspects of the review that inform teachers' actual work in the classroom, with the associated implications for teacher learning and professional development.

Finally, section 10.3 outlines the implications of the overall review findings for policy debate and possible curriculum redevelopment.

10.1 Raising student achievement in science: a synthesis of the features of effective pedagogy

There is an anticipatory aspect to "effective" pedagogy. If teachers know about factors that are likely to impede their students' learning, they can plan to address these via the pedagogical approaches that they employ. Thus, research about the nature and origins of learning challenges provides an essential lens through which to interpret and explain the features of effective pedagogy that emerge in classroom-based research. It is important for teachers to know "what works", but even more important to know "why it works", in order to be able to adapt and modify the pedagogy to suit individual classroom circumstances. This section begins by listing the features of pedagogy found to be effective for developing the learning outcomes specified by *SNZC*, then outlines the likely reasons for their effectiveness.

10.1.1 Recommendations for effective pedagogy

Pedagogy for conceptual, procedural, and NOS learning in science education could be more effective and inclusive when:

- the existing ideas and beliefs that learners bring to a lesson are elicited, addressed, and linked to their classroom experiences;
- science is taught and learned in contexts in which students can make links between their existing knowledge, the classroom experiences, and the science to be learnt;
- the learning is set at an appropriate level of challenge and the development of ideas is clear – the teacher knows the science;
- the purpose(s) for which the learning is being carried out are clear to the students, especially in practical work situations;
- the students are engaged in thinking about the science they are learning during the learning tasks;
- students' content knowledge, procedural knowledge, and knowledge about the nature and characteristics of scientific practice are developed together, not separately;
- the students are engaged in thinking about their own and others' thinking, thereby developing a metacognitive awareness of the basis for their own present thinking, and of the development of their thinking as they learn;
- the teacher models theory/evidence interactions that link conceptual, procedural, and NOS outcomes and discussion and argumentation are used to critically examine the relationship between these different types of outcomes;

- key features of the nature of science are made visible to students and they develop a metacognitive awareness of the similarities and differences between their own personal theorising, and scientific theorising;
- conversations and investigative skills are scaffolded by the teacher, with explicit modelling of the type of discourse/activity that is appropriate and of the type of outcome/product to be achieved;
- the role of models, modelling, metaphor, and analogies in science is made an explicit focus of practical investigation and of discussion; and
- teachers engage in formative interactions to help students as they learn.

10.1.2 Learning challenges that are addressed by effective pedagogy: a broad synthesis of research findings

LISP research demonstrated how science content significantly shapes teaching and learning processes. Existing understandings of a concept held by teachers and by their students interact in communication and individual thinking during teaching and learning to strongly influence the learning outcomes achieved. Unless these interactions are taken into account during the learning process, students are highly likely to construct outcomes other than those the teacher intended. A substantial and growing body of international research has catalogued a wide range of such possible unintended (and scientifically incorrect) outcomes from the interaction between students' school science learning and their everyday experiences of the world around them. The *active* nature of the learning process for each student (individually and/or for the class as a whole depending on the theoretical stance adopted) is thus the central unifying aspect of the pedagogical features listed above.

Research reported in Chapter Six demonstrated how beliefs about the nature and characteristics of scientific inquiry significantly shape learning in practical situations. Existing beliefs, both those held by teachers and those held by their students, about how science is "done", interact in communication and individual thinking before and during the investigative process to strongly influence the learning outcomes achieved. A lack of explicit awareness and examination of these beliefs may act to constrain the types of practical work that are carried out, and the manner in which students' learning is focused and supported.

A consistent finding of this review was that the relationship between theory and evidence – a key relationship that integrates the "ideas" of science with the "doing" of science – remains relatively invisible to many students, and arguably to many of their teachers. Explicit attention to this fundamental relationship can lead to improved scientific reasoning, deep processing of ideas, greater conceptual understanding, and explicit opportunities for students to experience and develop understandings of the characteristics of science.

10.1.3 Reading literacy and communication outcomes

Reading literacy and students' abilities to communicate their ideas in science ideas emerge from this review as an issue that needs to be addressed in science education. TIMSS and NEMP data have indicated that many students exhibit an inability to write clear descriptions and explanations, even in cases where task performance was carried out successfully. The features of effective pedagogy listed above draw heavily on structured discussion. Language-related factors are implicated in low achievement findings for students where English is not the main language spoken in the students' homes, and New Zealand has a growing proportion of such students relative to other nations.

Teachers need to be aware of particular difficulties associated with reading *in science*, and the fact that science language and formal science communication is a genre with particular characteristics. If opportunities to develop multiple outcomes are clear to the teacher, students are able to achieve reading literacy, communication, and science-specific learning outcomes simultaneously.

In addition to the features of effective pedagogy listed above, pedagogy that contributes to the simultaneous development of reading literacy and meaningful science learning outcomes will be most effective when:

- reading material is set at an appropriate level of challenge and engages student interest;
- the teacher has a clear and meaningful reading literacy *and* science learning outcomes in mind as they plan and carry out their teaching;
- the teacher helps students to identify and work with the features of science text that make it challenging to read;
- narrative reading materials introduce ideas and contexts through which students can make links between their existing knowledge, the classroom experiences, and the science to be learnt; and
- a range of different types of writing are practised, with explicit attention directed to audience, genre, and the development of clear argument.

Opportunities also exist to develop "mathematical literacy" during science learning. Interestingly, research on effective classroom pedagogy for this purpose has not emerged through our search of the science education literature. This would be a fruitful area for further investigation.

10.1.4 Rich experience outcomes

Rich experiences of the natural world can support the development of other science learning outcomes, and can in turn emerge as outcomes of science learning. There appears to be a clear "rich get richer and poor get poorer" effect in this recursive loop. TIMSS data have shown that the number of books in students' homes is associated with science achievement at both Year 5 and Year 9. At Year 9, students who indicated that their mother or father had attended university, college of education, or polytechnic achieved higher science scores on average than students who reported that their parents did not attend a tertiary institution. Maori students in immersion classes are more likely than their peers in mainstream classes to report that their class frequently does really good things in science-conducting science experiments with everyday things, going on field trips, and visiting science centres. They are also very positive about how good they think they are at science and about their suitability to be good scientists when they grow up (NEMP).

The recommendation that teachers should draw on students' own experiences as a beginning point for learning is a very strong finding of this review. However, science also provides opportunities to extend and enhance those types of experiences, especially where students' circumstances constrain the opportunities provided by their lives outside school. In addition to the key features listed above, rich experiences of the natural world can emerge as outcomes from science learning when:

- students are given frequent opportunities to directly experience new phenomena and to explore their thinking about these;
- issues, events, patterns, and phenomena in the outside world are explicitly linked to science learning outcomes; and
- science learning is integrated with relevant learning in other subject areas.

10.1.5 Recognising science as a particular type of culture

Culture and language influence the ways in which learners' thinking is structured. NEMP and TIMSS data correlate culture and achievement in science in the following ways:

- Maori and Pacific students generally have lower achievement than other students (TIMSS/NEMP), though Maori students in immersion classes have better self-concept as scientists (NEMP).
- NEMP trend data show an overall modest increase in achievement for Maori and Asian students.
- The mean achievement of Pacific students is lowest of any ethnic group, with approximately one-half of the students in the bottom 20 percent (TIMSS).

The challenge of teaching in ways that are more supportive of a diversity of cultures can be met by drawing on the features of effective pedagogy that have been outlined in all the sub-sections above. There are, however, particular challenges in using other than "Western" cultural contexts for science learning when students' world-views provide explanations for phenomena that are at odds with science world-views. In addition to the features listed above, effective pedagogy in science education could address cultural challenges by:

- giving students whose first language is not English opportunities to discuss their learning in their first language where possible; and
- coaching students whose language or cultural ways of thinking differ from those encountered in a typical science classroom in bridging strategies that make the cultural features of science more transparent.

10.1.6 "Attitudes" and "values": the invisible outcomes

Positive attitudes to *learning* science are described as outcomes in several of the studies that have been discussed in the review. TIMSS data report a correlation between positive attitudes to learning science and achievement in science. On the other hand, attitudes to science *as a discipline* will be influenced by NOS views. Both types of attitudes are likely to be positively influenced by the features of effective pedagogy outlined above. Only one other feature of effective pedagogy was identified in one of the studies described in the review:

- Students can identify and express their feelings about their personal learning.

There are no NEMP or TIMSS data to report with respect to values. None of these surveys has developed ways to measure values outcomes. Nor have the reviewers found any research that explicitly focuses on the development of values outcomes during science learning. This is not unexpected – calls for the consideration of values as part of science learning are relatively recent and have mainly been made in conjunction with the teaching of contentious science-related issues, including some aspects of environmental education. While environmental education has the potential to provide rich meaningful contexts for students to learn science, New Zealand research in this area is still scarce.

The reflective consideration of different worldviews, and of science as a particular type of culture, would also require students and teachers to take values into account. The review cannot make any recommendations of effective pedagogy for this purpose, at least as it has been demonstrated during classroom-based science learning. However, Levinson and Turner (2001) suggest that teachers in the arts areas of the curriculum (for example English, history, social studies) could provide pedagogical models for this purpose.

10.2 Teachers and teaching: rhetoric and reality

The focus of this literature review has been on *student* learning in science. A notable feature of many of the effective pedagogies identified in section 10.1 is that they require considerable teacher energy and expertise. A key finding, critical to many of the possible science learning outcomes, is that the teacher needs to actively elicit their students' ideas and then to respond to these in ways that promote conceptual challenge and development. However, the reality of doing this in a classroom situation requires teachers to be able to:

- understand the science concepts related to the intended learning;
- be aware of the range and nature of possible student understandings of the science concept(s);
- recognise the significance and meaning of students' ideas when these are volunteered;
- know strategies to elicit student understandings, and to give formative feedback on learning;
- know how an appropriate progression of the science ideas could unfold during learning;
- select contexts that allow for the development of the intended content while engaging student interest and interaction;
- select learning strategies and shape learning materials to appropriately challenge students' conceptual thinking; and
- foster small group and whole-class dialogue.

Many of the studies reported in this literature review were relatively small "one-off" interventions. While the effort, skills, and knowledge listed above might be achievable in the intensity of such a research intervention, it seems a lot to ask of teachers who work with large numbers of children all day, every day. Unless "scaling-up" effects are taken into account, the sustainability of some research findings seems questionable.

Another, equally important consideration, is that research must take account of teacher beliefs as an integral part of the complexity of each classroom situation:

> It is necessary to think of research as mapping not just children and their interactions with each other and the learning environment, but also mediation by other cultural tools, such as the teacher. Most specifically, the documentation of what teachers do, say and think alongside of children's interactions is critical for determining how participation changes over time. Therefore research needs also to include detailed observations of teacher interaction (Fleer and Robbins, 2001, p. 5).

When the focus is on student outcomes, it is difficult to keep the teacher's thinking and beliefs in full view. However, some of the studies reported in this review have addressed issues of outcomes for teachers as they are challenged to make their teaching more effective. For example, Haigh's study of open investigations in biology classrooms (section 6.2, Chapter Six) included an examination of its influence on the participating teachers. The teachers involved completed evaluative questionnaires and interviews. Haigh found that the teachers had experienced changes in their roles, beliefs, and expectations about the activities of the biology classroom as a consequence of their experiences of the investigative approach. They became much more aware of the types of support they needed to provide if students were to be challenged in their own thinking and learning. Haigh concludes:

> Learning will be enhanced by an open recognition of the influence of cultural and social processes-in-action in a science classroom on the teaching of both subject knowledge and procedural concepts of science. It is also enhanced by the necessarily very active and significant role of the teacher. Students have to learn from their teachers about the concepts and cultural conventions of science before they can become autonomous and self-regulating (Haigh, 2001, p. 41).

10.2.1 The intervening influence of teacher beliefs

Burns' study of the teaching of sixth form chemistry (section 5.2, Chapter Five) found that lessons in six different classrooms were mainly teacher-centred, and did not utilise peer-group discussion, as the teachers tried to cover as much material as possible. According to Burns, the teachers generally believed that students' achievement of understanding was dependent on students' interactions with them. As one teacher explained, "I try to make a difficult course less pressured for them. I teach them to recognise hoops and teach them to jump through the hoops." (Burns, 1997, p. 30). Most saw peer-group discussions as a poor substitute for student-teacher discussion.

Lumpe, Haney, and Czerniak (1998) examined the factors which influenced American kindergarten to grade 12 teachers' intentions to use "co-operative" learning in their science teaching. They found that, in general, teachers believed that such pedagogy could help increase students' learning, make science more interesting, increase problem-solving ability, and help students learn co-operative skills. However, the teachers also believed it could cause problems in their classrooms such as off-task behaviour and taking too much class time. Some teachers were concerned that it would "water down" the curriculum, reducing the amount of science content covered.

In both these studies the researchers' focus was on pedagogy for student learning. They saw carefully structured student-student discussion as being very effective, particularly for low achieving students or students who tend to link achievement with ability rather than effort. In this view, students' own thinking is one resource that supports the learning, and the teacher's role is to work with that thinking to challenge and develop students' ideas. On the other hand the teacher's focus was divided between practical matters of control and lesson pace, and curriculum "coverage". In this view, the teacher is the main resource to support the learning, and their role is to share the ideas that they already know as expeditiously as possible. There is clearly a tension here between how researchers see the issues and how teachers see the issues. This suggests that change that does not accommodate teacher thinking will be somewhat futile.

10.2.2 The teacher as researcher

Very few of the teachers whose students were involved in the classroom studies reported in this review were also acting as the researcher. A notable New Zealand exception is Lowe and Fisher 2001 whose research on group discussion for assessment purposes is reported in section 5.4, Chapter Five. In his study Lowe also worked with other teachers, who then became the researchers of their own class practice. He comments that the biggest effect of his intervention was on teacher perceptions about what can "count" as evidence of student learning. While these teachers expressed some initial reservations about group work, particularly in assessment situations, their attitudes changed during the intervention as they came to personally see the value for students' learning of the pedagogical change they had made.

Given the issues of "scaling-up" effects described above, the scarcity of teachers-as-researchers raises serious questions about the ownership of many research interventions. Some of the evidence presented suggests that teachers who have had quite extensive training (in "Complex Instruction" for example – see section 5.5, Chapter Five) do not sustain the full intent of the pedagogy they have been taught when returning to the busy reality of their classrooms.

10.2.3 The researcher as teacher support

On the other hand, there is considerable evidence that teachers can and will implement innovative changes to their pedagogy when the researcher is available to provide feedback, advice, and support. In those studies where the researcher was in the classroom with the teacher, this support appeared to be of most value. For example, the teacher in Hanrahan's (2001) study (section 7.2, Chapter Seven) sustained the practices that had been collaboratively developed with researcher support. This support was available over a period of a whole teaching year and the intervention was sustained by the teacher over the following year at least. Like Hanrahan, Jane Gilbert (1990) used her researcher expertise to devise strategies and material that could be used in a specific classroom situation, in full consultation with the classroom teacher. A number of studies of the use of models and modelling in science learning have also featured successful collaboration between teachers and researchers and teachers-as-researchers (Venville *et al*., 1994; Abell and Roth, 1995; Boulter and Gilbert, 2000).

Since such sustained support could scarcely be provided to a large number of individual teachers, collaboration between one researcher and a group of teachers would seem a more practical option. The successful reading literacy intervention reported by Phillips and McNaughton (2001) entailed work with a group of teachers, with some in-class support and coaching.

10.2.4 The teacher as learner

The complexities of learning for conceptual development apply to all learners, including teachers. France's research year (1997; 2000) of teacher use of biotechnology models (section 5.3.4, Chapter Five) found that teachers do indeed construct meanings other than those the researcher intended when they are learning about new pedagogy. France's findings resonate with much international research that has investigated the intervening role of teachers' knowledge and beliefs about models and about teaching using models and analogies on teacher practice (Thiele and Treagust, 1994; Abell and Roth, 1995; Van Driel and Verloop, 1999; Zimmermann, 2000). Teacher professionalism and quality professional development programmes appear to be an integral component of successful implementation of a model-based approach to science teaching. In the Netherlands, a curriculum innovation project which emphasises the role of models and modelling in science is accompanied by a nation-wide 60-hour in-service development programme for science teachers (Van Driel and Verloop, 1999).

10.2.5 Implications for teaching and teacher education

The studies reported here collectively suggest that teacher professional development must be an important part of any planned initiative to raise achievement in science. The clear message from the literature is that teachers need the opportunity to engage in long-term professional development experiences. Just as the process through which students collaboratively build scientific understandings requires sufficient time, so too do teachers need the time and experiences to develop their own professional capability. A significant finding of this review is that teachers cannot focus simultaneously on all the various possible strategies and outcomes that present themselves. What actually happens will be mediated by:

- the teacher's view of learning and what constitutes evidence of learning (especially when implicitly held rather than explicitly developed);
- the teacher's intended purpose(s) for the students' learning;
- the manner in which the students respond (including behavioural issues and their level of interest and connection with the material presented);
- the depth of the teacher's grasp of the content;
- the teacher's familiarity and confidence with a variety of different types of strategies and their experiences of success in using these;
- the teacher's nature of science views (especially when implicitly held rather than explicitly developed); and
- the learning support materials that are available and/or familiar.

In her study of open investigations, Haigh (1998) (see section 6.2, Chapter Six) outlines the practical support that the teachers involved identified as helping them to implement the investigative approach. The factors she identified include:

- sufficient time for the preparation of tasks, equipment, and materials;
- time for the completion of activities and for assessment;
- the availability of prepared resources; and
- adequate departmental and technical support.

This section has outlined a number of issues related to teacher professional development and has identified a range of factors that can impact on change and innovation in pedagogical practice. Ultimately, teachers decide what will transpire when they are in control in their own classrooms. Without their active involvement in decision-making about effective pedagogy, little lasting change seems likely to occur. While practical issues such as the support requirements listed immediately above would be reasonably straightforward to address, given sufficient resources, other issues are more complex. In some cases further research and/or policy debate is needed before the actual benefits to be gained from the cost of pushing for change can be ascertained with more confidence. These less directly resolvable issues are the focus of the final section of this review.

10.3 Implications of the review findings: directions for policy in New Zealand science education

This review has presented a very wide-ranging survey of research relevant to both current and future science education. The review has demonstrated the interconnectedness of many different variables which, when taken together, provide compelling evidence for ways to provide more engaging and effective science learning for all students.

In the past, efforts to raise achievement in science education have tended to focus on isolated individual variables, for example: teaching thinking skills; addressing students' existing concepts; investigating patterns of classroom interaction; addressing students' language difficulties in science, and so on. However, it is clear from the synthesis of research presented in this review that addressing factors in isolation will not raise achievement for all students.

Based on the findings of the review, implications for future policy directions can be made in three broad areas: Professional development and pre-service teacher education; Curriculum; and Research.

10.3.1 Professional development and pre-service teacher education

To conceptualise and plan for meeting a wider range of purposes for learning in science, teachers need to develop deeper understandings of the nature and characteristics of science and, in some cases, a richer pedagogical content knowledge to draw on when teaching science. The available evidence suggests that freely available materials that have already been developed to support innovative pedagogy in New Zealand classrooms are not being as well utilised as they could be. Developing teachers' knowledge requires enough time for in-depth engagement with new ideas. The short length of pre-service teacher education programmes, and sporadic opportunities for in-service teacher development in science education, do not appear to currently provide teachers with opportunities to develop new conceptual frameworks that can be successfully applied in their teaching.

We have found some differences in the extent and significance of issues related to effective practice at different levels of schooling. Primary teachers, particularly in the early years, need to be legitimated and supported in the development of their children's reading literacy, and in the provision of rich learning experiences for their students. However, they may need support with the explicit linking of these experiences to clearly identified science learning outcomes.

At higher year levels, teachers need opportunities to learn and practice:

- basic literacy strategies related to the particular challenges of reading and writing in science;
- a wider range of pedagogies for the purpose of drawing out and exploring a range of student ideas and opinions;
- a wider range of pedagogies for practical work in science;
- new strategies such as the use of narrative in science learning; and

- using the innovative New Zealand curriculum resources that are already available.

Key policy recommendations

- The effectiveness of current teacher education and support programmes, both at pre-service and in-service levels, is an issue that needs to be urgently addressed.
- Further, resources for teachers should support and enable the teachers to apply the appropriate conceptual frameworks to their science education pedagogy.
- Research is needed into the extent to which secondary teachers have opportunities to learn about the nature of science during their initial tertiary science education.

10.3.2 Curriculum

The imperative of "curriculum coverage" appears to be deeply ingrained and may be constraining the use of a wider range of pedagogies in many classrooms, despite the possibility to interpret *SNZC* in ways that do not require this. Effective pedagogy requires sufficient time for students to develop coherent and meaningful understandings and so necessitates teacher choice from amongst the breadth of curriculum achievement objectives that are indicated in *SNZC*.

Many of the most successful pedagogies analysed for this review require teachers to have a well developed understanding of aspects of the nature of science, as appropriate to the level of the students. "The Making Better Sense of the Nature of Science and its Relationship to Technology" strand of SNZC currently gives very little guidance in this regard, and can be read as emphasising fair testing, especially at the primary level.

Key policy recommendations

- The curriculum strand "Making Sense of the Nature of Science and its Relationship to Technology" needs to be redeveloped in line with current international thinking about content and pedagogy for teaching the nature of science and the use of technological contexts to introduce science concepts.
- A clearer alignment of curriculum content with the pedagogies recommended in this review is needed to support change in teachers' pedagogical practice, especially with respect to curriculum "coverage".

10.3.3 Research

Since the LISP research projects, there has been no long-term sustained classroom research in science education in New Zealand. While larger-scale international projects can inform general areas for attention and can suggest possible directions for change, local evidence is also needed, particularly with respect to the science learning of Maori and Pacific students, and the increasing number of students for whom English is a second language.

In particular it would be helpful to know:

- New Zealand teachers' beliefs and perceptions about the nature and characteristics of science and the purposes of science education;
- the nature of current New Zealand classrooms practice with respect to the various features of effective pedagogy that have been identified in this review, and how these pedagogies might be better realised in New Zealand classrooms;
- the impact of these pedagogies on the science curriculum experienced by students and on students' perceptions and beliefs about science;
- how culture(s) impact on learning in New Zealand classrooms and how teachers are taking account of cultural diversity in their current pedagogical practice; and
- the strategies that would be most effective for introducing the key ideas to emerge from this review to pre-service and in-service teachers and teacher educators.

Finally, all future research and policy in New Zealand science education must acknowledge the complex interaction of variables, which contribute to effective science teaching and learning for all students.

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