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A Literature Review  
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# Key Issues in Science Education: A Literature Review

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June 2009

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Chapter 1. Introduction

The purpose of this literature review is to provide background to the Science for Life programme, which, according to its vision statement, aims to...

...offer students the opportunity to immerse themselves in real science research programmes. Students and teachers will be encouraged to develop and pursue their own innovative science research linked to the national curriculum and supported by Scion.

(Scion Science for Life overview, 2008)

The review is a component of a wider research programme underpinning the Science for Life programme, and aims to go some way towards addressing the first four goals of the broader research framework, namely:

- To provide background on the issues facing science teaching and learning in New Zealand classrooms;
- To provide a discussion of approaches, pedagogies, and classroom practices which have been trialed to improve science learning outcomes, including a detailed analysis of constructivist approaches to science teaching;
- To identify critical factors that must be addressed to improve science learning;
- To explore the potential of the New Zealand Curriculum (2007) to enhance Science education programmes.

(Scion, Science for Life research framework, 2008)

It is neither the purpose nor function of this review to act as a definitive statement which defines the nature or form of the Science for Life programme. Rather, its purpose is to provide an overview of both historical and contemporary literature from New Zealand and selected international sources, to identify key issues in science education, and discuss the merits of teaching and learning models which have been identified as offering potential in helping to address these. It is expected that this document will serve as something of a discussion paper which will promote dialogue between stakeholders about how best to develop the Science for Life programme to maximise student participation and engagement in science, by making it more accessible, relevant and authentic.
Chapter 2. Review Method

2.1. Data sources

Data for this review were accessed from a range of sources. These included:

- The World Wide Web- Search engines such as Google and Google Scholar were used to access a range of papers, articles, journals and e-Books. Electronic mail was also used to make contact with colleagues and others who suggested relevant titles and volumes.
- The University of Waikato Library – both the Education and General library provided a range of books, papers, articles and journal references. University librarians also assisted by undertaking topics searches on the author’s behalf.
- The School of Education staff at the University of Waikato – selected staff members who had been involved in the LISP research and in science education generally were approached, and they suggested relevant volume and chapter references.

2.2. Process

For the purposes of reviewing and analysing the documents, a framework of guide questions was developed aligned to the broader research goals as detailed in the Introduction. While these were generated in advance, they were subject to ongoing review and in some cases modification, in response to findings revealed in the literature. Efforts were made to access a balance of international and New Zealand literature, with the former sources being used to identify ‘bigger picture’ perspectives relating to broader philosophical and theoretical purposes for learning in science, exploring the notion of scientific literacy with an emphasis on school science, and identifying attributes of effective pedagogical approaches to science teaching.

A range of more historical New Zealand literature was accessed to background early work on constructivist approaches to teaching science, in particular the Learning in Science Projects (LISP) undertaken at Waikato University during the 1980s and 1990s. Reading these earlier texts provided very useful background into the foundations of science teaching approaches such as inquiry learning, and highlighted the significance of New Zealand research in informing the development of these which are currently being used in schools worldwide. Both New Zealand and international literature was accessed for the discussion related to the key competencies, and the possibilities for science learning presented by the new curriculum framework (Ministry of Education, 2007).

The first section of this review examines an array of New Zealand and international literature relating to the nature of effective school science programmes by identifying the planning and teaching approaches, strategies, pedagogies, and curriculum designs which underpin their effectiveness. The second section
presents an overview and analysis of a range of teaching models which research indicates are supportive of enhanced learning in science, and this is followed by the third section examining issues impacting upon science education, with particular reference to the New Zealand context. The fourth section summarises the performance of science education in New Zealand relative to international benchmarks and identifies areas where changes or improvements could be targeted, while the final section looks at the nature of learning in science for the 21st Century and the possibilities presented by the new curriculum framework (MOE, 2007).

2.3. Guide Questions

This review is guided by the following research questions:

1. What are the defining characteristics or attributes of effective school science teaching?
2. What are the theoretical underpinnings of effective school science teaching?
3. What pedagogical approaches and teaching and planning strategies underpin effective school science programmes?
4. What issues typically influence effective school science teaching and learning, with particular reference to secondary schools?
5. What is the ‘state of play’ in terms of science learning in New Zealand, and what opportunities exist for a more general movement towards effective school science programmes, as discussed in questions 1-3 above?

2.4. Significance

This review is significant in that it is to be used to inform the development of a pilot initiative which seeks to encourage and involve greater numbers of students in science-related careers, through improvements in science teaching and learning, and the positioning of science as being both accessible and desirable in terms of a course of study in tertiary education, and as a career option direct from school.

In developing this review, an array of international and New Zealand literature dating back to the 1980s was accessed. It was considered important that outcomes from some of the early 1980s-90s foundational research from the Waikato Learning in Science Projects (LISP) be included, not only to provide historical background to more contemporary studies, but also due to its continuing relevance in terms of informing about theories of learning which were viewed as being supportive of effective science teaching pedagogy. Discussion around this early work is supported by reference to more contemporary publications which illustrate how outcomes from the early LISP studies and others of its kind have influenced programmes at a school level, and have gone a considerable way towards profiling programmes and teaching performances which are seen to be enhancing the learning of science for
students. In particular, the review looks closely at the place of constructivist learning theories as being a referent for the design of curriculum and pedagogical approaches and assessment practices, and examines how these theories can act as a framework for teachers to ‘adjust’ their present teaching towards models which have been shown to greatly enhance student learning and attitude towards learning in science. The evolving role of the teacher in this process is also explored within constructivist-informed pedagogical models such as inquiry learning, and a discussion of issues and constraints teachers face in making such a transition is also documented.

This review is structured around the five primary research questions as indicated above, with separate sections generally being dedicated to each. However, where overlaps exist between key concepts or ideas within the ‘boundaries’ of each section, these will be discussed and explored as appropriate, in order to assist in ‘drawing the threads’ together in developing an overall perspective in terms of the general aim of the study, as described in paragraph 1. The review concludes by detailing a summary of key outcomes from the study, and identifying the implications this holds for the science teaching and learning in the 21st Century.
Chapter 3. What are the defining characteristics or attributes of effective school science teaching?

An examination of literature relating to what constitutes effective science teaching tended to concentrate more on the nature of desired outcomes from this process, rather than the process itself.

As Tytler (2003) commented, what constitutes effective teaching practice in science “has to do with the purpose, politics and audience” (pg.273) for science education, and that the definition may change according to the imperatives and wider social, economic and political ‘environment’ within which the educating process is occurring. He claims that arriving at a single definition of effective practice is problematic, in that different measures can be applied when evaluating teacher practices in science as in most other learning areas, due in some part to the evolving trend of many education systems to give their schools greater autonomy in being able to interpret national curriculum at a local level to meet their specific student needs (Tytler, 2003).

He comments within the context of the Victorian government’s Science in Schools (SiS) project, that one of the most significant challenges was “generating a strong and well-articulated description of effective teaching and learning in science which was well-recognised… given the freedom schools are given to adapt their (science) initiatives to local needs and concerns” (Tytler, 2003, p.273). However, despite local interpretations, Tytler’s (2003) study indicated “general problems with the teaching of science within secondary schools” (p.274), where curriculum tended to be dominated by “an emphasis on factual information, driven by textbook use and tests, lack of small group activity, negotiation of low level cognitive demand, and the concentration of conceptual activity in a minority of target students” (Tytler, 2003, p.274). This finding was also consistent with earlier studies undertaken by Harlen (1999), Tobin and Fraser (1988) and Yager, Hidayat and Penick (1988).

Whilst initially for the purposes of the SiS project Tytler (2003) attempted to develop an evaluation framework around “the description of a set of skills and techniques that effective practice teachers have access to, and knowledge of the domain” (p.274), as the study evolved such a framework was seen to be limiting in terms of its failure to acknowledge the impact that factors such as “approaches to teaching and learning, curriculum provision, and underlying teacher beliefs and attitudes” (Tytler, 2003, p.279) had on the nature of science teaching and learning. One of the most significant findings from stage 1 of the SiS project – an investigation into the “dimensions of effective classroom organisation” (Tytler, 2003, p.280) in science - therefore related to the manner in which “the teacher shaped the classroom environment” (p.280). This included an analysis of the discourse of classroom science practice, and examined aspects such as how this allowed “opportunity for engagement with conceptual purpose, clarity and openness of conceptual agenda, the focus and structure of the unit including the nature of its representation of science, ways of managing discussion (including analysis of who ‘owns’ the agenda), assessment methods, and so on” (Tytler, 2003, p.281). The evaluation framework’s focus
was also changed towards one which placed lesser emphasis on the specific actions of the teacher, but instead examined how the outcomes of these were reflected in student learning, and how this took place. This led to the development of a range of ‘descriptors’ whose emphasis was more on describing the nature of the classroom environment in which effective science teaching was deemed to be taking place, rather than on the actual performance of the teacher (although these were acknowledged to be closely interrelated).

These descriptors were:

- **The nature of student learning and the classroom learning atmosphere**: A sense of engagement with and excitement about the shared learning of science where most students contribute to class and group discussions. There is a continual stream of relevant questions and ideas that are not direct responses to teachers’ questions;

- **Representation of science**: Science as a way of thinking and acting (do experiments genuinely engage with conceptual questions?) Scientific reasoning – the use of natural evidence to construct a conceptual argument is exemplified continually through case studies and practical work. Students are continually engaged in scientific augmentation. Anomalies in practical work results are turned to advantage;

- **The teacher managing the classroom**: Bridging between student ideas and the teacher’s learning objectives. Student ideas are sought and acknowledged frequently, and used as a platform to move students towards a deeper understanding of science ideas. There is a continual interplay between students’ and the teacher’s voices as they move towards a common understanding. (Tytler, 2003, p.283)

These three descriptors were further developed into a series of eight characteristics of science programmes and how they impacted upon student learning. These include the extent to which the programme:

- encourages student engagement with key science ideas and concepts;
- challenges students to develop meaningful understandings;
- links science with students’ lives and interests;
- caters for individual student learning needs and preferences;
- embeds assessment within the science learning strategy;
- represents different aspects of the nature of science;
• links science with the broader community; exploits learning technologies for their learning potentialities¹.

(Tytler, 2003, p.285)

Tytler (2003) acknowledges that the evaluation framework has limitations in that by breaking up what is deemed to be effective practice into identifiable components for the sake of clarity, there is a significant risk that one may loose a sense of the whole, and that not all components may be visible or apparent in each or any episode which is seen to be effective. In defence of this, Tytler (2003) comments that the SiS framework should not be seen as a “one size fits all” (p.292) view of effective practice, but is intended to provide a useful series of indicators at a principle level upon which we can focus our attention in at least beginning to unravel the complexities of effective science teaching and learning.

The move towards a student-centred interpretation of effective science teaching and learning finds further support in work undertaken by Cimer (2007). He comments that the primary measure of what constitutes effective teaching in any domain lies in the extent to which learning has occurred, and that this can take different forms according to the context in which it takes place. Fundamental to this process however, Cimer (2007) sees as the philosophical stance of the teacher in terms of how he/she views learning as occurring, and the manner in which they deal with students’ existing science ideas and concepts. While the role of constructivism as a referent to effective practice will be examined in more detail later in this review, Cimer (2007) comments that before any analysis of the specific elements of effective teaching in science can take place, there must be an acknowledgement that the tenets of constructivist-referred teaching are in place, and that such understandings underpin teachers’ thinking and the selection of strategies and processes they apply to their practice.

Consistent with the views of Tytler (2003), Cimer (2007) points to aspects such as the teacher’s capacity to engage their students through the use of a range of media which both caters for a diversity of learning preferences, and “presents ideas or concepts in a way that relates to their sensory channels” (Cimer, 2007, p.24). He comments that the use of a range of media in science teaching can assist teachers in making abstract concepts and ideas more concrete and linked to ‘real world’ situations, and enable them to bring to the classroom learning experiences that may have been difficult to access in other ways. He cites studies undertaken by Nayar and Pushpam (2000) and earlier by Killerman (1998) which indicate significant learning advantages for students studying science topics from the use of multimedia simulations and film and video resources.

¹ For greater explanation of these, please refer to the full text (see references).
Aligned with this, Cimer (2007) argues strongly for teachers to provide learning opportunities or experiences for their students which allow them to apply and refine their understanding of science ideas and concepts through engagement in a range of different learning situations. He comments that failure to do this can lead to the development of concepts that hold little relevance to their lives, and that concepts explored in class can “remain in the form of acquired isolated knowledge ‘packages’” (Cimer, 2007, p.25), and of little relevance and use. Earlier work by Schaefer (1979), Schollum and Osborne (1985), Walberg (1991), and Good and Brophy (1994) also supports this, while Gallagher (2000) suggests that teachers need to actively explore links not only to ‘real world’ learning opportunities, but also between concepts and science disciplines so that students are able to “show how knowledge of one set of concepts forms the foundation for learning about other concepts” (Gallagher, 2000, p.313).

Part of this process Trowbridge, Bybee and Carlson-Powell (2004) comment should involve teachers providing examples of what science ideas mean, and what science knowledge and skills ‘look like’ when they are brought to bare on a specific problem.

The ‘enactment’ of science in this way is seen as a means of requiring students to “explain and justify their understandings, argue from data, justify conclusions, and critically assess scientific explanations” (Cimer, 2007, p.25). Traditionally teachers have used practical labs, simulations, and sometimes field trips as integral components of their science teaching practice (Kirschner, 1992; Hodson, 1993; Millar, 2002), and these have gone a long way to help students make sense of their newly acquired knowledge and skills and unravel the complexities of science theories. However, more contemporary research indicates significant benefits from more ‘first hand’ science experience, such as that being able to be gained from school-industry or school-community collaborations or ‘internships’, where students are actively involved in, and are exposed to, ‘science in action’ (Bouillion & Gomez, 2001).

As is the case for all learning, fostering student engagement and active participation in the learning process should be a central concern for teachers of science. While undoubtedly some of the ‘technical’ elements of what is taught and the methods and techniques used in this process are critical, effective teaching in science cannot be broken down into a series of what might be seen as technically competent ‘acts’. According to Saunders (1992), real understanding cannot be ‘constructed’ by someone, for another - in this case, by the teacher, for their students. According to the tenets of constructivist learning theory, true understanding is only possible when ‘meaning making’ takes place within the heads of the learner, and to achieve this they need to be an active participant not only in the actual process of teaching and learning (and in deciding what is taught), but also in the design and development of the complete environment within which this takes place. Joyce, Weil and Calhoun (2000) comment that effective teaching is as much to do with the ‘atmosphere’ the teacher allows to be established in the classroom, as it has to do with what is taught or the methods used to teach it.

Within the context of science teaching, Pope and Gilbert (1983) and Tobin and Gallagher (1987) claim that effective teachers of science structure learning opportunities for their students that set up a sense
of ‘cognitive dissonance’ (Festinger, 1957) by designing investigations and activities that challenge preconceived (and sometimes scientifically inaccurate) concepts and views. To achieve this, Cimer (2007) comments that students need opportunities in learning science, “to pose questions, conduct investigations, and be free to present and defend their science ideas, solutions and findings, and assess their own and other students’ reasoning” (p.27).

Amos (2002) considers that a critical part of the teacher’s role in supporting this is allowing a learning environment to be established which encourages risk taking, celebrates divergent thinking, and in which individual contributions are valued and treated respectfully by the group. Central to this is the nature of questions that teachers ask students, and as Amos (2002) points out, as questioning can comprise up to 20% of teacher-student interactions, the manner in which questions are asked and the teacher’s response to them can be critical in ‘shaping’ the learning environment in science classrooms. Amos (2002) considers one of the challenges in teaching science is encouraging an acceptance of divergent thinking and ideas, due to the emphasis many teachers of science place on their students getting the right (scientifically-correct) ‘answer’, and as quickly as possible. Whilst acknowledging the importance of scientific accuracy, Amos (2002) comments that accuracy should not be confused with the adoption of a particular pedagogical method, and encourages the use of open ended questioning to probe student thinking and allow them the opportunity to explore ‘alternative’ ways of constructing science knowledge. This perspective also finds support in the work of Harlen (1999), who claims that the traditional emphasis on ‘getting the right answer’ stifles students’ abilities to think freely and flexibly, and express their own thoughts and ideas.

A number of authors (for example: Cimer, 2007; Driver, Asoko, Leach, Mortimore and Scott, 1994; Kagan, 1992; Munro, 1999; Osborne, 1997; and Slavin, 1990) claim the organisational structures teachers adopt in their classrooms are critical to the level of engagement students show with learning in science, and that the selection of organisational structures such as cooperative and collaborative grouping systems based on social constructivist learning theory acknowledge “that students need to talk with their peers and the teacher in order to articulate their ideas about a concept or exploration, to clarify their thinking, and to correct their misconceptions” (Cimer, 2007, p.32). Spitulnik, Zembal-Saul, and Krajcik (1998) further comment that the use of cooperative or collaborative structures offers significant advantages over the more traditional ‘whole class’, teacher-directed approaches in that through interaction with their peers, students are able to develop deeper understanding through a greater level of ‘comfort’ in exposing their ideas, having them challenged, being able to ask questions, and being supported in refining them in creating more scientifically accurate connection between concepts.

Joyce (et al, 2000) points to the important formative role of appropriate feedback provision when using such structures, and comments that often students will need to be taught how to do this, as they may have had little experience in either providing or receiving this in their own schooling. Jones and Carter
(1998) also allude to this issue in their analysis of the pros and cons of collaborative approaches, and also flag the need for considerable teacher input to the composition and structure of the groups, to ensure equity and to enable all student views to be heard. They claim that without careful planning and monitoring, cooperative approaches offer little advantage, as some group members can become isolated and denied input or equitable access to learning opportunities and resources. However, managed appropriately “numerous studies in very diverse school settings and across and wide range of content areas have reported that cooperative learning can positively increase students’ achievement and develop their skills and attitudes towards the subject being studied” (Cimer, 2007. p.33).

Almost all of the literature accessed for this review mentioned the significant role that the teachers’ view of the purpose of learning science had in forming their approach to teaching it, and in the establishment of their “instructional theories” (Trowbridge et al, 2004, p.20). While all authors pointed to the powerful role of social constructivist learning theories as an underpinning to effective science teaching (this will be explored in detail later), Trowbridge (et al, 2004) in particular, emphasised the need for teachers to be clear on why they are teachers of science, and what the bigger picture aims of science education were. Trowbridge (et al, 2004) links these factors to a wider commitment to the concept of scientific literacy, which he identifies as having multiple dimensions and as being pivotal to the formation of effective science teaching practice. According to Trowbridge (2004), scientific literacy is characterised by dimensions which he terms nominal scientific literary, functional scientific literacy, conceptual and procedural scientific literacy, and multidimensional scientific literacy. He sees as ultimately the role of effective science teaching the development of multidimensional scientific literacy through which students are able to interact with and make sense of their world, understanding and using a range of science principles and ideas, while at the same time acknowledging the “philosophical, historical and social dimensions of science and technology” (Trowbridge et al, 2004, p.72). Trowbridge describes each of the dimensions of scientific literacy as:

- **Nominal scientific literacy** - identifies terms and questions as scientific, but expresses scientific principles in a naive manner and/or has inadequate, inappropriate or misconceived scientific ideas;
- **Functional scientific literacy** - is able to use scientific vocabulary and has a technical understanding of science, usually based on factual knowledge, often committed to memory by rote learning. Students, however, have limited deep understanding of, or experience or excitement in, scientific inquiry;
- **Conceptual and procedural scientific literacy** – understands the process of scientific inquiry and technological design. This involves the ability to pose scientific questions, undertake investigations using appropriate tools and techniques, recognise alternative explanations, and communicate scientific procedures and outcomes;
Multidimensional scientific literacy - in this dimension students understand the unique place of science in our society, and that scientific knowledge is intricately related to the social context in which it is developed. The history and nature of science disciplines is understood.

(from Trowbridge et al, 2004, pp. 70-72)

While Trowbridge (etal, 2004) indicates the general goal of science teaching should be the development of a broadly-based scientific literacy based on these dimensions, he comments that the way in which teachers achieve this is influenced strongly by their teaching or instructional theory. He describes this as “giving direction and providing guidelines for effective instruction and allowing the teacher to evaluate teaching techniques and procedures” (ibid, p.21). A teacher’s instructional theory Trowbridge (et al, 2004) comments should provide a framework for their practice, and assist them in identifying the most effective methods and techniques to enhance their students’ learning. Instructional theory should help teachers to identify “the most effective experiences to enhance learning, the most effective way in which knowledge can be structured to enhance learning, the most effective sequence in which to present material, and the most effective process for feedback and evaluation” (Trowbridge et al, 2004, pp.21-22). The cornerstone of any science teacher’s theory of instruction, Trowbridge (et al, 2004) claims, must be linked to how their actions will enable students to move their science thinking and ideas from what he terms their current conceptions, towards ones of greater scientific validity and accuracy.

In referencing the work of Posner, Strike, Hewson and Gertzog (1982), Trowbridge (etal, 2004) identifies conditions which support student conceptual change that need to be incorporated into teachers’ theories of instruction. These are based on broader ideas around constructivist learning theory, and relate to the need for students to have challenged their existing science ideas to the point where they become somewhat dissatisfied with them, thus opening the opportunity for modification or change. This process of modification can be stimulated by students being exposed to learning experiences or situations in which their existing understandings prove to be inadequate in explaining new phenomenon. It is the teacher’s role to present to students alternative views and perspectives which not only help them to better understand the phenomenon or concept being explored, but also using strategies, content and approaches which present the ideas in a form which makes better sense to them. As Trowbridge (etal, 2004) comments, “the new conception must be plausible in that it can explain a number of prior experiences and observations... and fruitful in that it opens up new areas of inquiry, primarily through predictions about future events” (p.23). In executing a theory of learning aligned to such principles, teachers, however, need to recognise that students come to any learning situation with preconceived ideas and views which may or may not be compatible with commonly held or validated scientific perspectives, and that they “are not empty vessels into which you can pour scientific facts, information and concepts” (Trowbridge, etal, 2004, p.24).

Shulman (1986) has identified three significant components through which a teacher’s theory of instruction is able to be enacted at a practical level, which are strongly related to the development of effective practice. While these are not unique to science teaching alone, they are critical components in
enabling teachers of science to clarify and add greater precision and effectiveness to their practice. These he has identified as a teacher’s knowledge of the content to be taught (the subject matter), their pedagogical content knowledge (their teaching knowledge about how to best make the content accessible and understandable to their students), and their knowledge of curriculum (both the legal framework and the resources and materials used to support practice). Trowbridge (etal, 2004) extends the idea of pedagogical content knowledge further by commenting that this involves not just understanding how best to make ‘content’ available to students, but also relates to a teacher’s ability to “establish links between new concepts and students’ current understandings” (p.25). Both Shulman (1986) and Trowbridge (etal, 2004) agree that effective teachers of science possess solid understandings and capabilities in each of these components, and in particular are able to structure student learning experiences in different ways using a range of strategies to ensure continued student motivation and engagement with subject material.

In summarising this section and responding to the first review question related to the defining characteristics and attributes of effective teaching in science, it can be seen that arriving at a single answer or definition is problematic. The literature reviewed identified effective teaching in science as comprising a combination of theoretical, philosophical, pedagogical, knowledge and dispositional components, that when appropriately ‘blended’ are able to help teachers create environments in which learning in science is able to be optimised and witnessed through high levels of student interest and engagement in ‘real world’ science inquiry, the active participation and collaboration of students in science knowledge construction, and student engagement in debate about science ideas and perspectives. The emphasis in all documents accessed was not so much on defining what effective practice in teaching science actually was, but rather on identifying the sort of ‘environmental contributors’ to good science teaching, and what it might look like as reflected in the activities, actions and attitudes of students who were exposed to it. Common to all literature reviewed for this section however, was acknowledgement that the development of effective science teaching practice was integrally linked with teachers’ views on how learning occurred, and in particular their alignment with constructivist learning theories. This relationship will now be explored in more depth.
Chapter 4. What are the theoretical underpinnings of effective school science teaching?

As introduced earlier in reference to Trowbridge’s (etal, 2004) comment on the importance of teachers’ instructional theory in the establishment of their practice, research indicates that pedagogies which emphasise, are based on, or are referred by constructivist views of learning, offer the greatest potential in terms of both their efficacy in modifying or developing accurate student science understandings, and in supporting a positive long term view of science inquiry.

Some argue that constructivism has its roots in the early work of developmental theorist Jean Piaget (for example, Olorundare, 1992; von Glaserfeld, 1987, 1995), but more latterly constructivist learning theories have been closely scrutinised in terms of their relevance to teaching and learning in science. The basic tenets of constructivism view learning as an active process in which “individuals usually construct meaning in their attempt to make sense of the world around them” (Olorundare, 1992, p.1).

Constructivism views learning as an interpretive process, whereby individuals build knowledge structures by ‘filtering’ information and experience through the ‘lense’ of existing views or understandings, and that as a result, these structures may differ from individual to individual. As Olorundare puts it, “the understanding an individual derives from a learning situation depends on both the incoming ideas/knowledge and the individual organisation and deliberate restructuring of their pre-existing conceptual framework” (1992, p.1). Much of the literature accessed for this review (for example Bell, 2005; Driver and Erickson, 1983; Tobin, 1990; Seatter, 2003) adopt a socio-cultural view of constructivism, pointing to the importance of collaboration and interaction between individuals in developing knowledge structures. They state that learning involves a process of ‘negotiation into meaning’ in which peers or teachers help individuals to “develop case knowledge through social interaction” (Olorundare, 1992, p.2). This negotiation process can be variable in nature, as the existing ideas an individual holds, and how resistant to change these are, will impact significantly upon the how receptive they are to different ideas or alternative perspectives, or how they interact with new information provided by others.

Within the context of science learning, substantial research (for example Driver and Oldham, 1986; Hewson, 1981; Osborne and Wittrock, 1983; Pope and Gilbert, 1983; Seatter, 2003; Shymansky, 1992) indicates that students bring to science learning intuitive understandings of science concepts, which are often “based upon their individual idiosyncratic interpretations of sensory impressions” (Olorundare, 1992, p.2). These structures are often referred to as a learner’s conceptual framework (Driver and Erickson, 1983), which is an organisational ‘system’ through which a learner sorts or ‘filters’ new data or information in an effort to make sense of it, in relation to their existing ideas or understandings. While these frameworks may not necessarily be scientifically accurate or correct, they are often resilient and
can significantly influence how students respond to and interact with the alternative and sometimes challenging ideas raised in the science classroom. This perspective is reflected succinctly in this quote from one of the students involved the early research of Osborne and Freyberg (1985) who commented, “you know, teachers have got all that science knowledge but we are thinking about it differently because there are so many ways you can take something in...” (p.5). For this reason, the influence of students’ prior science ideas on learning in science cannot be underestimated.

According to Driver and Bell (1986) the implications of constructivist learning theory for effective teaching of science can be summarised in terms of its relationship to planning, ‘meaning making’, and learner responsibility. They identify four key areas of impact which are summarised below:

1. Learning intentions or outcomes need to take into account what the learner already knows, and that the purposes and motivation for learning influences the way in which the learner interacts with and uses materials and resources;
2. The process of learning science is interactive. Learners construct understanding by making links between their existing conceptual frameworks and new information or experience;
3. The process of learning in science is continuous. Ongoing and continuous evaluation of meaning takes place, and learners modify conceptual frameworks to take account of information or experience which ‘makes better sense’ to them;
4. Ultimately, learners are responsible for their own learning. ‘Ownership’ of the learning process is critical to successful learning, and the learner achieves this by engaging with the key ideas underpinning what is being learnt, whilst using their existing knowledge to construct meaning. (from Driver and Bell, 1986)

Such perspectives offer considerable challenge to more traditional views of the way in which science is perceived, taught, and learnt. Historically, science has been seen as the pursuit of “specific knowledge which is assembled by specialist observers using specialised techniques and equipment” (Olorundare, 1992, p.3). This perspective tends to position science as something of an elitist activity, which is ‘done’ by scientists in the pursuit of pure and non-contestable science understanding, which may have limited obvious relevance to ‘real world’ contexts. This view has undoubtedly influenced the nature of traditional science teaching, where there has for many years been a strong emphasis on the application of the methods and discipline of science to investigations, in pursuit of demonstrating or revealing the ‘discovered’ science knowledge to students. This has often been aligned with teaching approaches which have emphasised transmissive, teacher dominated pedagogies, by which teachers presented what was viewed as non-contestable science knowledge to students through strategies ranging from direct recording from the black (or white) board, textbook investigations, or in some cases, predesigned experiments to demonstrate known scientific principles. Typically, this view of learning in science was consistent with the nature of science knowledge development generally, where scientific knowledge was generated by scientists (the ‘experts’) and made available to others (the ‘non-experts’) to learn and, in the case of most school experiences, be examined or tested.
However, as Olorundare (1992) points out, science endeavour when viewed through the lense of constructivist learning theory offers up a quite different perspective which “emphasises more the craft and community aspects of science” (p.3). While developing accurate science understanding is still at the core of constructivist views of science learning, the methods of learning science, and the view of science knowledge as being ‘absolute and uncontested’ and the sole domain of scientific experts, is challenged. According to Olorundare (2002), constructivist views of science see science knowledge as “tentative, integrative, humanly created, social and crafted” (p.4). It views science understandings as not being absolute and uncontestable, but rather subject to change in response to “new information and more productive theory” (Olorundare, 2002, p.4). It also conceives science knowledge to be a humanly created and social endeavour, and the result of the interpretation of observation and experience – and therefore being open to reconstruction and reorganisation. Constructivist perspectives also encourage learning in science to be an active rather than a passive endeavour, with a far greater role and level of responsibility being identified for the learner in developing personal science knowledge. This factor is often reflected in the methods used in the teaching of science, with a greater emphasis being placed on the social construction of science knowledge through the use of collaborative and cooperative learning strategies, group work, and inquiry approaches.

As introduced briefly earlier, the adoption of constructivist approaches to teaching and learning in science should not be confused in any way with a ‘dilution’ or lessening in the rigor of science inquiry, and while science understandings are seen as personally constructed, they should not be confused with a view of science knowledge as ‘anything goes’. The critical consideration in constructivist-informed approaches to learning in science relate to an acknowledgement that students often bring to a learning situation their own preconceived notions of science concepts and phenomenon, and that these may or may not be consistent with commonly held scientific understandings, but will act as a ‘baseline’ against which new or alternative concepts will be compared. It is the role of the teacher therefore, to reveal such understandings and take these into account, acting accordingly in making decisions about what needs to be learnt (or what existing understandings need to be challenged), and setting learning goals and selecting teaching and assessment strategies as appropriate (Scott, Asoko & Driver, 1992).

The 1980’s work of researchers such as Bell, Tasker, Gilbert, Osborne and Fensham during the Learning in Science Project (LISP) coined the term ‘children’s science’ to describe the early science ideas held by young people. Authors such as Scott (1987) and Schulte (1996) comment on the difficulties these early notions can hold for learning ‘real science’ in that such a process involves “not only adopting new ideas, but also modifying or abandoning pre-existing ones” (Scott, 1987, p.25). Seatter (2003) argues that despite children’s innate curiosity, this is often not consistent or indicative of being a “junior scientist” (p.67) in that often the ideas they hold are based more on common sense thinking than science reasoning. Driver (1989) claims that this can be a barrier to learning in science, as often their common sense notions make more sense to them than those supported by science reasoning, and that the challenge lies in “initiating the individual into the ‘ways of seeing’ of the scientific community” (p.482).
In many cases as Stewart (1993) points out, this process becomes even more difficult due to the “enormously complex conceptual structures (of science) which are not immediately or directly accessible to young learners” (p.9). To many students, learning science requires that they set aside their “common sense language and thought” (Seatter, 2003, p.68) and adopt what to many would seem a new set of complex and often difficult to grasp conceptual tools in trying to view existing and often highly resilient knowledge structures in a new light. Seatter (2003, p.68) sums it up nicely in her comment that “learning in science is not quite as straightforward as Hirst’s notion of ‘sticking to the rules’ – there is no one scientific method, but rather numerous approaches to scientific inquiry”.

The implications from ‘overlaying’ constructivist learning theory on teaching and learning in science are considerable. Central to this lies the challenge that must be made to children’s ‘common sense’ science knowledge by what is often seen by them to be ‘counter intuitive’ scientific knowledge which is based on what Seatter (2003) calls the unobservables of science – that is, abstract notions of “reversibility, modelling, change and probability” (p.70). In discussion of this issue, Seatter (2003) comments that many of the early science ideas children form are based on “perceptual or practical concepts” (p.73), rather than any evolving theoretical understanding of science or scientific reasoning. She comments that this can prove to be a challenge for science teachers, in that understanding of theoretical frameworks is crucial to learning science concepts, as they “organise in highly systematic ways, our ordinary, ‘common sense’ experience and in so doing, greatly increase our intellectual understanding of it” (Dearden, 1968, p.116).

While practical observations are useful in terms of allowing us to witness events, theoretical concepts are not concerned with events, but rather with ideas. As Seatter (2003) observes, understanding science demands not simply an observation of events, but also “an awareness and understanding of a possible reason for the recurrent event” (p.74). For this to occur, she comments students of science eventually need to grasp conceptual theories which can act as frameworks upon which ‘sense’ can be made of new or unexpected science phenomena. Seatter (1993) further contends that while the majority of science teaching at a primary and early secondary level is concerned with the “practical and perceptual… within the concrete realm of understanding natural phenomena” (p.74), this does not mean that teachers do not have responsibility to offer up answers and explanations to help students grasp the theoretical basis for observations. In fact, she comments that although a lot of what happens in science classrooms may be viewed as essentially ‘practical and commonsense’, they still have strong links to theoretical science which teachers should explore with their students. In order to do this however, teachers need to know the science behind what is being observed, and be able to describe and explain this in a way which effectively ‘bridges’ (or in some instances replaces) students’ existing theoretical perspectives with what are viewed as scientifically accepted understandings.

The challenge for teachers is to develop strategies for achieving this which “seek harmony between scientific and children’s conceptions, but only up to the point where continued teaching bears adversely
Upon a child’s self esteem” (Osborne & Freyberg, cited in Matthews, 1994, p.144). Matthews (1994) claims that to adopt an ‘at any cost’ approach to this, risks alienating students even further from engagement in science, destroying their curiosity, enthusiasm and self confidence for science investigation. However, as Seatter (1994) points out, 

…it is difficult to imagine two explanations – one intuitive and the other counter intuitive – culminating in a harmonious understanding. In most cases, in order to resolve the conflict and eliminate the discrepancy, one or the other needs to be set aside.

(Seatter, 2003, p.77)

Seatter (2003) further comments that if the rightful goal of learning in science is the development of accurate scientific knowledge, then only working within what a child considers as sensible explanation and adopting what she views as “avoidance strategies” (Seatter, 2003, p.77) is not going to prove productive in delivering that. In her view, science teachers must be prepared to engage actively in the process of teaching science, and that recent moves towards viewing teaching more as facilitation, devalues a more direct and active role for the teacher in the learning process.

Whilst acknowledging that facilitation may involve more than merely strategic teaching acts, in that it encourages greater levels of student involvement in learning things for themselves through the manipulation of objects and materials and thinking about personal science explanations, it runs the risk of “stranding students in their own world” (Halliday & Martin, 1993, p.170). That is, as the process of facilitation is largely a strategic act, the broader purpose of which is to make learning easier for the learner, Seatter (2003) contends that if applied within a constructivist framework in which student ideas “are held as a substitute for science ideas, the advent of this focus provides the opportunity for the rift between strategic and intellectual acts to widen” (p.79). Driver (1983) adopts a similar perspective in commenting that the popular representation of the child as a young scientist allows for the potential domination of children’s science theories over those of known science, in that if teachers adopt a minimal-intervention facilitatory approach and use children’s existing science ideas as the primary basis for learning science, the potential exists for a ‘deintellectualisation’ of science learning.

Matthews (1994) further comments that the more radical interpretations of constructivist learning theory enacted through popular late 1980s –early 1990s ‘discovery learning’ pedagogies, contributed to significant “errors in intellectual foundation” (p.146) – or the learning of ‘wrong science’. However, Solomon (1994) takes a more measured approach in her discussion of the place of constructivist learning theories in the teaching of science by claiming that the use of students’ ideas as the basis for teaching and learning is nothing new, and that there exists a level of confusion between doing this and the adoption of a specific method of instruction – in her words, understanding student thinking is not “synonymous with having a particular method of instruction which will change them” (Solomon, 1994, p.11). She comments that it is not so much an issue of flawed theory, but rather equating theory with a
particular way of teaching – that is, interpreting it at a pedagogical or method level, rather than at the level of learning theory.

Seatter (2003) comments that despite a level of criticism being levelled at constructivism in science, it still offers the greatest potential for enhancing science learning for students, in that it “places student engagement at the centre of learning” (p.83), and it positions student knowledge and understanding at the centre of learning. In her view, one of its most significant strengths of constructivist learning theory when it is applied to learning in science is that it offers students greater and less threatening access to the ‘world of science’ and science thinking. She claims that in place of “immutable, fixed and final right answers about how the world works” (Seatter, 2003, p.83) is a set of science theories which can act as tools through which one is able to “relate one set of observable states with others” (p.83). In this way, instead of viewing science as a set of true, absolute, and uncontestable views of natural phenomena, it acknowledges the ‘human element’ in positioning scientific theories as human constructs which have been developed to help us make sense of the world. Constructivist learning theories allow us to ‘open up’ science as an accessible discipline in which knowledge development is seen as a human endeavour and in a constant state of change and evolution. It offers an opportunity for greater student engagement in learning science, but also recognises that teachers need to be active participants in the learning process, rather than adopting a ‘hands off’ non-interventionist stance akin to the earlier failed approaches of discovery learning.

The next section of this review examines a range of pedagogical strategies underpinned by constructivist learning theories which are available to teachers in supporting effective teaching and learning in science.
Chapter 5. What pedagogical approaches and teaching and planning strategies inform and contribute to effective school science programmes?

The early Learning in Science Projects (LISP) work at Waikato University identified seven essential elements of effective pedagogies in teaching and learning in science. These were the result of nearly eight years of research into student learning in science, which sought to identify how a broader constructivist perspective on teaching could be applied to improve student ‘access’ to science, and their understanding of science concepts.

These outcomes are summarised briefly below.

Effective pedagogies

1. Take into account student thinking. Eliciting the existing ideas held by students at the beginning of a topic in relation to the science knowledge or concepts to be explored, and the subsequent use of this in the formation of teaching plans and selection of teaching strategies, is essential. Understanding the alternative (to ‘known science’) perspectives students hold can provide teachers with valuable starting points for knowledge transformation;

2. Take into account and build on students’ experiences, cultures and values. This relates specifically to an acknowledgement that not all students hold identical values and world views, or exist within or come from a single cultural setting. Science programme design should as much as possible be of an inclusive nature;

3. Focus on learning activities and strategies that celebrate and promote thinking. As introduced in the previous section, learning in science is an intellectual activity which requires learners to think about science and the purpose of science. Learning strategies which encourage higher level thinking such as creating, evaluating and analysing should be included;

4. Position science within relevant contexts. Effective pedagogies for learning in science utilise contexts which are relevant to students, and allow them to make links between their existing understandings and experiences, and the science to be learnt;

5. Provide students with high quality formative feedback. In order to provide this to students, teachers need to have sound understanding of the underpinning science knowledge and appropriate ways of progressing student understanding towards this;

6. Recognise the importance of science content. Effective pedagogies recognise the extent to which the content of science shapes the manner in which teaching and learning occurs, and that there exists a convergence between teachers’, students’ and scientists’ views of concepts in arriving at specific outcomes;
7. Encourage classroom discussion and communication about science. A variety of techniques to encourage students to communicate their ideas about science both with each other and with the teacher, should be encouraged.

(from NZCER, 2002)

Although distinctly student-centred, the LISP studies also allude to a highly active role for the teacher in the design and implementation of effective science learning experiences. While it is important for students to have significant opportunities to “reflect on and discuss their understanding of science concepts as they are developing them... using strategies such as group work and peer discussion...” (NZCER, 2002, P.147), this does not mean a diminished role for the teacher. The importance of strong formative teacher input into the structuring and content of science learning experiences is still seen as vital, particularly where the intention is to strengthen students’ conceptual knowledge and higher order thinking capabilities...

...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...

(NZCER, 2002, p.147)

Furthermore, the LISP studies point to a range of teaching ‘tools’ which have been found to be effective in helping students to reflect upon and review their personal science knowledge and models, and those of scientists. These include the use of mental models, physical models, metaphors, and analogies which were determined to assist students “not only in learning the content of a particular science concept, but also in the uses and limitations of models as representational tools” (NZCER, 2002, p.147).

According to NZCER (2002), a significant challenge exists in secondary science education to implementing approaches not only based on constructivist-informed pedagogy, but at the very least, represent a departure from the “recipe practical” (NZCER, 2002, p.167) emphasis which currently typifies existing practice. Literature suggests that when such approaches dominate learning in science, students experience difficulty in that they “misinterpret the activities they carry out and do not develop the content outcomes intended. Nor do they link the ‘evidence’ that the practical displays the ‘theory’ that is purportedly being illustrated and endorsed” (NZCER, 2002, p.176). The replacement of a pedagogy based on a ‘formulaic’ approach to teaching science to one in which students have the opportunity to carry out open investigative work, is seen as essential.

Whilst literature suggests that in the initial stages of establishing a more open and investigative approach students needed greater levels of support and guidance in developing the appropriate skills and capabilities (eg: hypothesising, processing and explaining data), the adoption of such an approach allows for a greater sense of student ownership of the learning process, and identification with activities
of ‘real’ science. According to NZCER (2002) the use of student generated open investigations “provide more opportunities for students to pursue their own questions, to bring their own ideas to the learning, and to widen their understanding of both appropriate procedure and the relative flexibility and recursive nature of ‘real science’” (NZCER, 2002, p.167). Furthermore, literature suggests that the adoption of an investigative project-based approach to learning science represents an effective pedagogical model in that it presents a useful ‘vehicle’ through which constructivist approaches to teaching science are able to be enacted. That is, it supports the basic tenets of constructivist-informed pedagogy, in particular:

- the notions of accommodation of existing student views and perspectives;
- the learning of science in contexts which allow the linking of existing understandings and experiences with the science to be learnt;
- the learning is sufficiently challenging;
- the purpose of the learning is clear to students;
- students are engaged in ‘thinking science’ during science tasks;
- students develop content, procedural and nature of science knowledge together, not separately;
- it allows the teacher to model processes which link theory to practice in developing conceptual, procedural and nature of science outcomes;
- it enables students to identify more easily differences between personal science theories and those held by the science community;
- it supports a student-centred approach to learning, and enables the teacher to more readily scaffold student learning across a range of different contexts, better meeting individual student learning needs and preferences

(summarised from NZCER, 2002)

Bell (2005) summarises a range of pedagogical approaches which teachers may adopt which she states meet the key constructivist component of taking into account student views. She comments that these approaches represent student-centred learning models which provide opportunities for students to explore the validity of their existing science ideas, “testing them out, resulting in the creation of cognitive dissonance... from which the construction of new concepts and/or the restructuring of existing conceptions” (Bell, 2005, p.62) can occur. These will now be summarised.

5.1. The Generative Learning Model

The Generative model of science inquiry arose from the early work of Cosgrove and Osborne (1985) on the LISP project. It is based upon a three stage approach and can be described as a conceptual change model, which features problem solving and addresses existing student ideas (Bell, 2005). The three ‘teaching’ stages are preceded by an additional phase which could be termed ‘information gathering’,
which is designed to determine existing student perceptions of the concept being explored, and the identification of historical and scientific perspectives.

The first phase of the Generative model is known as the focus stage, during which the teacher establishes the learning context and provides engaging initial experiences for students designed to both gauge their existing views of the concept, and to stimulate interest in the concepts being investigated. Typically during this stage, teachers will use a range of open ended questions to elicit student thinking and to help students describe and clarify their own views of the concept. During this stage, students are invited to contribute their present understandings of the concept based on both school and out of school experience, and pose questions relating to the concept through group and whole class discussion.

The second stage, known as the challenge stage, centres on the teacher presenting “evidence for the scientists’ view” (Bell, 2005, p.71) whilst also maintaining an open and active dialogue with the students in which their reactions to this view are accepted and appraised, and efforts made to allow students to compare their views with others, including their classmates. Demonstrations or investigations may be structured during this stage to allow students the opportunity to test the validity of their views through seeking evidence.

The final stage of the Generative model known as the application stage, focuses on student engagement with problems which can be solved quickly and effectively by using the generally accepted scientific explanation. During this stage, the role of the teacher concentrates on assisting students to clarify their understanding of the alternative perspective, and encouraging students to discuss and explain their thinking while generating solutions to problems. Much student work during this stage takes the form of practical activity, often with other students, through which the merits of the proposed solutions are debated and appraised. Extension or enrichment activity may also be undertaken, during which time teachers and students may collaboratively engage in solving more advanced problems to which the concept is applicable.

In limited research undertaken during the LISP project, the Generative model was seen to be a reasonably effective teaching model when applied to the development of student understanding of electrical current. However, in the case of the LISP study, the most significant changes in understandings came when students were able to “invent analogies and explore the implications of these analogies” (Bell, 2005, p.73) as a component of the act of understanding the science ideas. It was determined that sufficient time needs to be allocated to such activities so that opportunity for views to be challenged and critically reviewed is made available.
5.2. The Interactive Teaching Model

The interactive teaching model is again underpinned by constructivist theories of learning, but is differentiated from more generative approaches by a greater weighting and emphasis being placed on the role of student questioning. In the interactive science teaching model, student questions are used as the basis for investigation, as it was argued by Biddulph (1989) that these provide teachers with perhaps the most accurate insights into student thinking and ideas about concepts, and can provide teachers with “the ability to start where the children are at” (Bell, 2005, p.74). Literature also indicates a pivotal role for questioning in the interactive model, and in some ways it advocates a departure from the more traditional emphasis of “teacher ask-student answer-teacher respond” (Bell, 2005, p.74) questioning, in favour of an approach in which question asking and answering are the joint responsibility of both the teacher and students. That is, the process of knowledge creation and clarification is the result of a highly interactive and engaging process in which “students and teachers were interacting in talking with each other... in other words, students’ and teachers’ minds were interacting” (Bell, 2005, p.74).

Like the generative learning model, the interactive model adopts a loosely linear approach in which both the teacher and the students were actively involved in the selection of the topic to be explored, and the specific aspects of the topic to be investigated. The key stages of the interactive model are:

- **Preparation** – during this stage the teacher and class collaboratively select a topic to be investigated and research background information;
- **Determining initial student understandings** – the students describe their present knowledge of the topic. This may be carried out as a whole class, in groups, or individually and recorded in some way (eg: charts, via postbox type exercises, through discussion etc);
- **Exploratory activities** are set up to introduce children to the topic and to stimulate interest;
- **Children’s questions** – children are invited to ask questions about the topic or the science ideas contained in it;
- **Investigation** – teacher and students select a range of questions to explore during the course of the topic. These are progressively implemented;
- **After views gauged** – students’ views of science ideas are compared with before views. Recording of these in some way is often an integral component of activities within the unit of learning;
- **Reflection** – establishment of areas of misunderstanding still existing, and restatement of new questions to guide subsequent activities.

(adapted from Bell, 2005, p.75)

While research by Biddulph (1985, 1990) and Osborne and Biddulph (1985) into the use of the interactive approach to teaching science indicated increased student involvement, interest and
enthusiasm for learning science, along with sound development of intellectual skills and science understandings, it was also found to be a demanding process for the teacher, and required a range of new approaches and strategies. According to Biddulph (1990), while the Interactive approach effectively made the teaching of science easier and more accessible for primary teachers who generally were not science content experts, and whose pedagogical alignment was more consistent with the requirements of the approach, it did pose some issues relating to its investigative focus. These issues mainly related to the development of units of learning which were based on student questions, in particular ensuring that the questions posed were not superficial and would provide a solid basis for investigation, and ensuring that children had the level of investigative skills and capabilities to undertake independent research work based on their questions. There were also more logistical issues such as dealing with the diversity of questions, working out those which reasonably were able to be investigated, and sourcing and arranging access to resources to enable the investigations to take place. In addition, Biddulph’s studies also indicated that teachers who were not already pedagogically aligned with constructivist learning theory were unable to implement an Interactive teaching model without significant professional development and support, and even then, in most cases, they found the transition to a more student centred learning model a difficult experience. Those teachers who lacked a depth of science content knowledge also found the transition to an Interactive approach problematic, in that...

...an ongoing concern was that of keeping the focus on the science to be learnt... 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 and metals...

(Bell, 2005, p.78)

While research did not indicate any significant increase in the learning outcomes for students from the use of Interactive teaching strategies, most of the reported benefit seemed to exist in the development of positive student attitudes to learning science – as Bell and Pearson (1992) termed it – ‘better learning conditions’ were established, where teachers considered better learning outcomes were likely to be attained.

5.3. The Importance of Content

The Learning in Science Project studies identified some significant issues around the importance of science content knowledge, and the relevance of the learning context with regard to how effectively students were able to develop accurate and robust science knowledge. The research indicated that not only do students and teachers existing understandings of the science concepts to be taught impact upon the nature and extent of science learning ‘accuracy’, but to an extent these are reflected and communicated both through the planning of science lessons, and also in the way these ideas are
communicated during teaching. As Bell (2005) comments, “the content to be learnt is not unproblematic, nor is it a generic, neutral aspect of learning science” (Bell, 2005, p.78). That is, what is taught may not be strongly representative of scientists’ views of the science concepts, and that these cannot “be expected to remain unchanged from sender (teacher) to receiver (learner)” (Bell, 2005, p.78).

Therefore during the process of teaching and learning science, unintended or inaccurate learning outcomes can inadvertently be generated, through the miscommunication or inaccurate interpretation or understanding of the science ideas being presented. According to the LISP findings, this issue was particularly prevalent in the case of primary science, where due to a lack of specialist science knowledge, teachers often struggled in researching and developing accurate personal understandings of science concepts. It was also considered a contributing factor in the ‘dilution’ of the science content in units, in favour of subject content which was more familiar or comfortable for teachers, resulting, for example, in science units which focused primarily on Living World contexts, and which emphasised a strong language base. As Bell (2005) summed up, “the influence of the content on the pedagogy was strongly acknowledged. The way the content was structured and conceptualised was seen as determining the pedagogy” (p.80).

In the case of one of the LISP projects which focused on the development of concepts related to energy, it was found that teaching did little to transform students’ understandings of energy concepts towards more accurate scientific understandings, and that this issue was compounded further by differing teacher interpretations of what energy was, depending upon their ‘area’ of science. For example, biology teachers tended to interpret energy as a requirement for life within an ecosystem, while chemistry teachers associated it with reorganisation of bonds within matter, and physics teachers with the ability to do work (Bell, 2005). The research indicated that student exposure to often confusing and conflicting definitions of such concepts, combined with a lack of teacher-student dialogue and discussion in helping to clarify and construct common understandings of such concepts, contributed to inaccurate conceptual development. It is clear from these studies and others accessed (for example, Kirkwood and Carr, 1988; Osborne and Wittrock, 1985; Stead, 1980) that teachers of science need an accurate grasp of the science to be taught, need to keep their focus firmly on the science to be learnt, and take into account prior student understandings in developing unit content and selecting pedagogical strategies.

5.4. The Importance of Context

Both the LISP research and work undertaken by the Cognition and Technology group at Venderbilt (1990) in their exploration of constructivism, highlighted the relevance of context to successful learning. This acknowledgement relates not solely to motivational or affective benefits, but also recognises that learning is socially embedded and takes place in a variety of social and cultural contexts. In short,
acknowledgement of context is an important part of the learning process. As introduced earlier, constructivist theory is based on a view of learning as being socially constructed, and that “learners must make links between their existing knowledge and the new knowledge being taught in the classroom” (Bell, 2005, p.83). In order to optimise the possibility that such links will be effectively made, research points to the need to select science learning contexts “which students find interesting and relevant, can relate to, ask questions about, and develop and use to explore their own ideas and make sense of their world” (Bell, 2005, p.83).

It is suggested that the selection of such contexts better enable students to link new science ideas to their existing understandings - that is, between the unfamiliar and the familiar – and have been proven to result in higher science learning outcomes (Bell, 2005).

However, later studies into context-based learning in science (for example, Porteous, 1997) indicate that adopting such an approach, while desirable and beneficial from a student learning perspective, could pose some implementation issues for teachers. While research indicates that teachers were very positive in their overall view of context-based learning (for example, Mohamed, 1995; Rodrigues, 1993), there was not always an alignment of learning context between the students and the teachers. Where this process was largely teacher led, the selection of context was often based on teacher interest and preference, and did not hold great appeal or relevance for students, and visa versa. Conversely, where the process of learning context selection emphasised negotiation and dialogue between the students and the teacher, greater and more effective engagement was noted. Additionally, teachers reported concerns relating to the need for, and availability of, a wider range of resource materials, issues developing contexts that appealed to both genders, the requirement for changed assessment practices, and the need for additional professional development to support more differentiated programmes. Some studies also indicated that an over-emphasis on context could contribute to a ‘watering down’ of the science to be learnt (Hipkins and Arcus, 1997). As mentioned in the previous section, a critical component of effective science teaching is the teacher’s ability to maintain a tight focus on the underpinning science knowledge, and to ensure that this remains at the forefront of their teaching.

Acknowledging the findings of the early LISP studies, more recent approaches to teaching and learning science have adopted an inquiry-based approach, which in many ways combines features of both the generative and interactive learning models, within an investigate approach to science. A more detailed examination of inquiry science will now be presented.

5.5. Science Learning as Inquiry

While inquiry-based approaches to teaching and learning (in science and other curriculum areas) have gained considerable traction in more recent times, the concept of inquiry is not new. In fact, the early work of Dewey (1910) alluded to the basics of inquiry-based learning in science in his address to the American Association for the Advancement of Science. He commented in the presentation that...
...science teaching has suffered because science has been so frequently presented just as so much ready made knowledge, so much subject-matter of fact and law, rather than as the effective method of inquiry into any subject matter...

(Dewey, 1910, p.124)

In this early commentary, Dewey introduces the basis of inquiry learning in science, and alerts us to three of its main thrusts – namely an ability in science inquiry, an understanding of the nature of science, and a knowledge of science as a subject. Dewey further identified what he saw as the critical objectives for science teaching, namely “developing thinking and reasoning capabilities, formulating habits of mind, learning science subjects, and understanding the processes of science” (cited in Bybee, 2000, p.26). Dewey’s early work was further developed by Schwab in the 1950s-60s and James Rutherford in the mid 1960s, who both recognised the changing nature of science, and the implications this held for science education. Schwab in particular noted that traditional interpretations of science as a ‘fixed and stable’ endeavour were being severely tested, and that a new view of science was emerging in which “scientists no longer conceived science as stable truths to be verified, (but as) conceptual structures revisable in response to new evidence” (Bybee, 2000, p.27). Rutherford took these ideas further in 1985 in the American Association for the Advancement of Science’s Project 2061 from which developed the Science for all Americans initiative, aimed at developing a baseline level of science literacy in all students by the end of the 12th grade.

An outcome from this initiative was a series of science standards based on an inquiry approach, which identified inquiry learning in science as

...a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyse and interpret data; proposing the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations...

(National Research Council, 1996, p.23)

It is pertinent to note that this definition of inquiry identifies the importance of knowledge of the content of science, the processes of undertaking science investigation, and the abilities students should develop within science inquiry. The NRC standards elaborate on these by identifying specific Abilities and Nature of Science understandings which they assert underpin an inquiry approach to learning in science. These are summarised below.
5.5.1. Science as Inquiry: Abilities

- Ability to formulate questions that guide science explorations. Students should be able to formulate a hypothesis which demonstrates a link between the hypothesis and an investigation design;
- Ability to design and carry out science explorations. This involves students designing and carrying out science investigations, selecting and using appropriate equipment in safety (including technologies), reflecting on outcomes, and using logic and evidence to construct and share explanations for outcomes;
- Ability to use technology and mathematics to improve science investigations. Using tools such as computers and other devices to improve the accuracy and efficiency of science investigations;
- Ability to develop and revise scientific explanations and models using evidence and logic. Engagement in arguments and discussions in formulating science explanations and models;
- Ability to recognise alternative science explanations. Weighing and analysis of evidence presented by alternative views, and using logic and reason to decide which explanations are best;
- Ability to communicate and defend scientific explanations. Communicating science outcomes and ideas using appropriate means.

5.5.2. Science as Inquiry: Understandings (Nature of Science)

- Historical and current science principles and knowledge guide inquiry, and inform the design and evaluation of science investigations;
- Scientists carry out investigations for a variety of purposes and reasons;
- Scientists use technology to enhance science inquiry, particularly in the areas of data gathering and manipulation;
- Mathematics and mathematical models are used in science inquiry;
- Science explanations are based on evidence, are logical, and open to modification and change based on new evidence;
- Scientists communicate and defend their results in the formation of new knowledge and methods.

(summarised from National Research Council, 1996, p.176)

As can be seen by the above summary, inquiry approaches to learning in science demands a two-pronged approach, which involves both developing knowledge of the nature of science and scientific endeavour, and abilities in doing science.
Although inquiry-based learning is not new to science education, according to Bybee (2000) there is little evidence to suggest that its use is widespread or mainstream in school science. Furthermore, numerous studies indicate that students do not develop understandings of science which are useful in their everyday lives, and that there is little or no incorporation of science thinking in their daily activities (for example, Cobiern, Gibson & Underwood, 1999; Lederman, 1999; Linn, 1998; Rutherford & Ahlgren, 1989). According to Claxton (1991), “schools are still reinforcing the message that science education is about remembering the results of other’s (scientists) research, rather than developing an ability to conduct one’s own” (p.28). Kubicek (2005) comments that effective inquiry-based learning engages students in the process of self-directed science inquiry, in learning to think and act in a scientific manner, and developing understanding between evidence and theory. The emphasis therefore in science learning is both developing accuracy in science understandings, and learning the process of science inquiry.

When reflected at a classroom level, inquiry in science demands a different approach to more traditional science teaching. As Kubicek (2005) observes, the benefits of adopting an inquiry approach can be mitigated if they are not supported by appropriate transitions to student centred learning pedagogies. That is, if inquiry approaches are simple ‘overlaid’ across prevailing and often more teacher-directed learning models, little benefit will accrue in terms of enhanced student outcomes. The essence of inquiry approaches, in keeping with constructivist learning theory as introduced earlier, is allowing students to “choose their own question or problem to investigate, and be able to steer their inquiry in directions of their own choosing” (Kubicek, 2005, p.2). According to Kubicek (2005) while such an approach places additional management and organisational demands on the teacher, it leads to increased student engagement and is a more accurate representation of scientific inquiry, helping students build better understandings of the nature of science as a discipline. Huber and Moore (2001) elaborate on this by commenting that when the more traditional emphasis on worksheets and books is maintained within a so-called inquiry approach, it “presents science as a process of following step by step instructions and filling in the blanks on worksheets (which) promotes erroneous and impoverished concepts regarding the nature of science” (Huber and Moore, 2001, p.33).

Vasquez (2008) in a useful discussion of the nature of classroom science inquiry, maps out how such a transition might be reflected in the practices of the teacher (and related student activities) as supporting pedagogies move from teacher-aligned to student oriented within an inquiry model. According to Vasquez (2008), it is the role of the teacher to manage learning according to the needs of their students and the demands of the task at hand, and while within an inquiry model the emphasis should be on students assuming significant responsibility for, and contributing to this process, it does not mean diminished teacher role or responsibility. Jarrett (1997) views the teacher’s role at any point in time as existing on a continuum from structured at one end, to guided in the middle, through to open (student-initiated) at the other end. Vasquez (2008) comments that it is the role of “a skilled teacher to be able to move between the different variations in the amount of structure, guidance and coaching.
they give their students” (p.16) in response to the demands of the learning situation. She comments that a combination of these approaches is required at various times within an inquiry model, and has identified their characteristics as:

- Structured inquiry – teacher directs or models to ensure a specific focus or outcome critical to the inquiry is gained;
- Guided inquiry – teacher facilitates learning experience, but greater responsibility is vested in students for determining the procedures of the investigation;
- Open or student initiated inquiry – students hold most responsibility for the design and conduct of investigations, based on answering their own questions.

(adapted from Vasquez, 2008, p.16)

Thus while inquiry-oriented approaches generally emphasise a more student centred learning approach, at various stages within any unit of learning different teaching strategies may be required to ensure learning goals are met and accurate science understandings generated. While the ultimate goal for learning science is the development of a level of science literacy in students, the demands on the teacher to support student inquiry from structured through to open are considerable. Teachers who are able to achieve this successfully, according to Vasquez (2008) are those who have “deeper understanding of the content, know how to ask effective questions to promote higher-level thinking, and feel comfortable facilitating and entertaining student questions” (p.16). While on the surface this may appear to be a relatively straightforward process, in reality it is far from it. Such a transition demands significant changes not only pedagogically, but also philosophically in terms of how teachers view their role, and the way this is reflected in their practice.

In summarising the features of inquiry approaches to science, Vasquez (2008) provides a very useful analysis of how such a transition may ‘look’, based around the essential elements of inquiry practice. This is encapsulated in the diagram on the next page. As can be seen in the diagram, there is a progressive transition from teacher responsibility to student responsibility for learning from left to right, and that it is the role of the skilful teacher to manage and support this transition along with the student, developing the necessary cognitive and practical capabilities in developing a level of learner independence and scientific literacy. Consistent with a constructivist approach to learning, there is a requirement on the teacher to preface any investigation with an appraisal of the students’ existing scientific understandings, to ensure they have a solid grasp of the useable knowledge in the content and processes of the science involved, and to help them master necessary metacognitive capacities so they are able to monitor their own learning goals, and the progress they are making towards achieving them.
Figure 1 Elements of inquiry

<table>
<thead>
<tr>
<th>Element of Inquiry</th>
<th>Structured (teacher-led)</th>
<th>Open (student-led)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learner engagement in scientifically oriented questioning</td>
<td>Learner engages with questions, materials etc provided by the teacher or other source</td>
<td>Learner poses their own questions</td>
</tr>
<tr>
<td>Learner participation in the design of procedures for evidence gathering</td>
<td>Learner follows set procedures</td>
<td>Learner designs and implements their own procedures</td>
</tr>
<tr>
<td>Learner recognises importance of evidence in responding to questions</td>
<td>Learner is given data and shown how to analyse it</td>
<td>Learner determines what comprises evidence and collects and analyses accordingly</td>
</tr>
<tr>
<td>Learner develops explanations using evidence</td>
<td>Learner is provided with an explanation</td>
<td>Learner formulates explanation based on evidence</td>
</tr>
<tr>
<td>Learner makes connections between explanations and scientific understandings</td>
<td>Learner does not connect explanations with science understanding</td>
<td>Learner independently connects explanations with science knowledge</td>
</tr>
<tr>
<td>Learner communicates and justifies explanations</td>
<td>Learner is given steps and procedures to follow for communication</td>
<td>Learner forms reasoned and logical arguments and communicates own explanations</td>
</tr>
</tbody>
</table>

In illustrating a classroom process for inquiry approaches to science, Vasquez (2008) also presents a model through which she claims inquiry-based learning is able to be implemented and developed. This model is based on the National Science Education standards (NRC, 2000) and is reflected through a cyclic, five stage process. She comments that within such a process there is an argument for a range of pedagogical strategies to be used, from teacher-led to student-led as described above, and that the combination and balance of these within any unit of learning will be determined by the needs and capabilities of the students. However, she comments that the ultimate goal of science education should be to facilitate a general ‘movement’ from left to right, indicating greater levels of learner independence and increased scientific literacy.
The diagram below maps out key stages and transition points in this five-stage process, based on the 5E Instructional Model for Inquiry Science (NRC, 2000).

![Diagram 2: The process of inquiry in science teaching](image)

As introduced earlier in this section, the transition to student-led inquiry approaches to science demands a significantly different skill set and pedagogical and philosophical stances to more traditional approaches. In analysing the role of the teacher in an inquiry-oriented classroom, Crawford (2000) has identified ten characteristics which she claims differentiates the role of the teacher in an inquiry science classroom. These are consistent with early perspectives presented by Osborne and Freyberg (1983) in their analysis of constructivist-informed approaches to teaching science, which emphasise a changed role for the teacher from the deliverer of knowledge, to one where they are more concerned with establishing environments to enable student construction of knowledge. These ten characteristics are summarised in bullet point format below:
• The teacher as **motivator**. In this role, the teacher encourages students to take responsibility for their learning through encouragement and enthusiasm for both the subject area, and student performance;

• The teacher as **diagnostician**. The teacher should structure activities and provide opportunities to allow students to express their ideas to determine existing understandings;

• The teacher as **guide**. The teacher should provide and if necessary structure activities to assist students in developing strategies to carry out science explorations;

• The teacher as **innovator**. New science–related ideas and strategies are actively pursued to enhance and improve teaching performance;

• The teacher as **experimenter**. This involves the teacher in trying out new ways of teaching and assessing to improve student learning;

• The teacher as **researcher**. The teacher is reflective of their practice and is able to self-review to improve performance. Self-reliant in solving problems and addressing issues;

• The teacher as a **modeller**. The teacher models and promotes the attitudes and attributes of scientists;

• The teacher as a **mentor**. The teacher actively supports students to learn, and is knowledgeable about scientific work, the nature of science, and undertaking science explorations;

• The teacher as **collaborator**. In this role the teacher facilitates a free exchange of ideas and thinking, and allows students to assume a level of leadership (as ‘teacher’) in constructing new knowledge;

• The teacher as a **learner**. Actively models the process of continuous learning by being responsive to learning new concepts.

(summarised from Crawford, 2000, p.932)

While Crawford alerts us to a very different capability-set for teachers under an inquiry framework, she does not confuse this in any way with a diminished role for the teacher. In fact, in her discussion of the demands of inquiry approaches she comments that both “teacher and student roles are complex and changing, and greater levels of involvement are required by teachers than in traditional teaching” (Crawford, 2000, p.933). She warns of the dangers in interpreting the role of the teacher as ‘facilitator’ as an oversimplification, and comments that in reality the role “is more expansive... necessitating more active and complex participation than that of a facilitator or a guide” (p.934).

In support of this, Crawford (2000) cites from the American Association for the Advancement of Science (1993) document, Science as Inquiry, the complexities involved from the teacher’s perspective in engaging students in inquiry-based learning. According to this document, inquiry science involves teachers in encouraging students to “use the kinds of cognitive processes used by scientists when asking questions, making hypotheses, designing investigations, grappling with data, drawing inferences, redesigning investigations, and building and revising theories” (Crawford, 2000, p.934). Such activities are inherently complex, and requires of the teacher substantial engagement in the learning processes
and activities of the students. Far from being seen as an ‘easy solution’ to teaching science, Crawford (2000) comments that inquiry approaches demand greater and more diverse teacher input and capabilities than traditional teaching methods, and higher levels of subject and content expertise and knowledge. In summarising this role, Crawford comments,

...a model of collaborative inquiry requires the teacher to take on more active and demanding roles than traditionally depicted. The changing teacher roles demand more active and complex participation than that suggested by the commonly used metaphor, teacher as facilitator...

(Crawford, 2000, p.935)

In summarising this section, it is apparent that Inquiry-based learning in science can be a highly effective approach in supporting scientific literacy and an understanding of science processes. Research (for example, Glasson, 1989; Lindberg, 1990; Lloyd & Contreas, 1985; Rakow, 1986; and Staver, 1986) also indicates inquiry approaches to be valuable in extending scientific vocabulary knowledge and conceptual understanding, critical thinking, science procedural knowledge, logico-mathematical knowledge, and enhancing positive attitudes towards science inquiry. However, studies also indicate that in order to achieve such outcomes, teachers need to be actively engaged with students at all stages of the learning process, be knowledgeable subject experts, and be pedagogically-aligned with constructivist learning theories. While within any specific Inquiry unit of learning the role of the teacher may vary from highly instructional (teacher-led) to student-led collaborations or independent investigations, research indicates that where Inquiry models are simply ‘overlaid’ across traditional, teacher-dominated pedagogies and instructional approaches, few benefits for student learning are apparent. The successful implementation of Inquiry approaches for many teachers requires a rethink at a philosophical level, a reinterpretation of their role as a teacher of science and how this is reflected through their practice. It also demands a new approach to learning science, one that acknowledges the existence of student prior concepts and ideas, and uses these as the basis or ‘starting point’ from which to develop teaching programmes and sequences. Inquiry approaches require high levels of expertise and knowledge, both in the content and processes of science, and in managing classrooms supporting diverse investigative activities. There is little doubt that making such transitions within the constraints of rigid school structures and assessment schemes is a challenging prospect for most teachers.
Chapter 6. What issues impact upon school science teaching and learning?

While the previous section outlined the potential of inquiry approaches for enhancing student learning in science, as already alluded to, implementation of such approaches based on constructivist learning theories, particularly in secondary schools, is far from straightforward. This section provides a discussion of some of the significant influences on teaching and learning in science, with specific reference to the New Zealand secondary school context.

As previously introduced, one of the critical issues impacting upon teachers’ practices in science relates to philosophical and pedagogical alignment with constructivist views of learning. The studies clearly indicate a level of ‘philosophical tension’ is generated through traditional science teaching approaches which have generally emphasised higher levels of teacher direction and the presentation of science knowledge as ‘external to the knower’, able to be ‘learnt’ essentially through a process of transmission from the teacher to the learner. This is representative of an epistemological view of science knowledge as being absolute and irrefutable, and largely the outcome of science activities undertaken by specialists using robust techniques and methods to gather data and draw conclusions, which are subsequently confirmed by repeated trials and peer review. In the eyes of those who hold this epistemological view of science as the ‘revealor of truth’, the matter of teaching and learning in science can be interpreted as an act of merely making available to students the opportunity to prove this knowledge, often through the provision of investigations or explorations which allow the concepts or knowledge to be demonstrated. In such cases, there is generally little emphasis on developing understanding of the nature of science, or on student engagement in science investigative processes. Instead, teaching practices are geared towards student acquisition of science knowledge through largely teacher designed and directed activities, and often in response to the requirements of assessment regimes. It would be fair to state that such ‘front loading’ methods of science teaching have dominated pedagogical approaches for many years (Hipkins & Neill, 2006), but that they do little to support the overall goals of science education – namely, the development of scientific literacy, and an understanding and valuing of scientific endeavour.

In stating this, it needs to be acknowledged that education as an activity does not take place in a vacuum, and that, like most other ‘public’ activities, it is subjected to an array of influences which, to a greater or lesser extent, dictate or at the very least, influence what is to be done and how it is to be carried out. Insofar as secondary education goes, one of the most significant of these relates to the nature of assessment, and how the outcomes from a course of learning in science are measured and reported. According to Hipkins and Neill (2006), “there has long been critical comment that assessment can be the tail that wags the curriculum dog” (p.49). That is, due to the requirement on secondary schools to prepare students for successful participation in credentialing examinations and assessments,
there has been a tendency for teachers to design their classroom curriculum according to what is needed to get as many students successfully ‘past the finishing post’ as possible.

Prior to the advent of the standards-based National Certificate of Educational Achievement (NCEA) in 2002, students sat a range of external norm referenced assessments under the School Certificate and University Entrance banners. While elements of University Entrance were internally assessed, in both cases there was a heavy emphasis on the use of ‘one off’ examinations in order to ascertain the level of knowledge students held in relation to subjects being studied, so an objective determination could be made as to the 50% who ‘passed’ and the 50% who did not, under the norm referenced model. Examinations in science during this era generally emphasised students’ abilities to recount science knowledge through the recall of science ‘facts’, or the retrieval and application of science ideas and concepts to solving particular problems or responding to scenarios presented in the test. There was a general deemphasising of student capability in applying science processes or understanding of the nature of science, in favour of an ability to recall and reproduce science knowledge created by others. In response to this assessment approach, and acknowledging that in a competitive environment for students it was in a school’s best interest to get as many of their students ‘past the post’ as possible, models of instruction were adopted which were geared towards optimising test results, rather than developing true capabilities in investigating science, science literacy, or knowledge of the nature of science. It was common practice during this time for teachers to use the content of previous University Entrance or School Certificate examination papers as the basis, or at the very least, to inform their classroom curriculum in a model of instruction which became known as ‘teaching to the test’. Such an approach sat very comfortably with the epistemological view of science as described in the introduction to this discussion, but is fundamentally at odds with constructivist-informed pedagogies such as the Inquiry or Interactive approaches detailed in the previous section.

Since 2002, the standards-based NCEA has replaced the older norm referenced School Certificate and University Entrance systems, combining a range of internal and external assessments in the reporting of student Achievement Standards. While it is not the purpose of this review to detail the specifics of NCEA, standards-based assessment is summarised by Peddie (1992) as...

...the term used when the measurement or outcome is assessed, in other words, analysed, against some fixed criterion of level of achievement, known as the standard. A whole set of standards may be involved. These standards should be set in advance, so they are well-known to both

\[\text{http://www.nzqa.govt.nz/ncea/about/index.html}\]

\[\text{http://www.nzqa.govt.nz/ncea/about/index.html}\]
In theory, each learner gets exactly what they achieve, so that it is possible again in theory, for all learners to achieve the particular standard desired.

(Peddie, 1992, p.23)

The fundamental shift from norm-referenced to standards-based assessment methodology, in theory at least, should allow teachers greater freedom to interpret science curriculum in a more constructivist-aligned manner, which is more responsive to students’ existing science ideas, and incorporates greater elements of investigative processes and nature of science understandings. In 2003, Hipkins and Neill undertook a small scale study on behalf of the Ministry of Education, one of the goals of which was to determine if indeed the advent of NCEA did support such a transition within the context of science teaching. The relevant findings of this study will now be briefly discussed. The Hipkins and Neill 2003 study involved 18 case study secondary schools in responding to a range of questions examining the impact of NCEA level 1 on...

…the content, structure, and balance within programmes for Maths and Science, (and determining) if there are identifiable changes in teaching and learning styles used within Maths and Science programmes that support the development of practical skills, or that allow teachers to address students’ attitudes and values relevant to the subject area.

(Hipkins, 2006)

Findings of this study indicated something of a ‘mixed bag’ of outcomes in terms of the impact that the standards-based framework had on science teaching and learning. While some of this can be attributed to the newness of the framework at the time the study was undertaken, and teething problems relating to the manner in which it was implemented, some interesting insights have been revealed which are influencing the uptake of more student-oriented pedagogies. Firstly, while teachers in the study commented that the ‘levelling’ of the achievement standards (credit, merit and excellence) encouraged them to “spend more time on ensuring that assessment incorporates a range of levels and/or types of thinking” (Hipkins, etal, 2006), they appeared to be less than happy with this, and viewed it as a “narrowing of the curriculum” (Hipkins, etal, 2006). This comment specifically related to the perception held by the science teachers that they were spending more time “teaching for understanding than for content coverage” (Hipkins, etal, 2006) and that this demanded of them new capabilities such as being able to ‘embed’ skills such as problem solving and critical thinking into classroom science activities, as these were required in order to help students attain the higher levels of merit and excellence. The move towards more holistic assessment, away from the defined measurement of discrete skills which could be recorded using competency-based ‘checklist’ approaches, proved challenging for some teachers, while others saw it as a unique opportunity to move towards approaches to teaching more aligned with investigative science. As one teacher commented, “…it (NCEA) gets away from nebulous concepts of facts and compartmentalised learning, and moves towards a more holistic/process focused approach”
It was apparent from comments made by teachers in this study that there was something of a ‘hang over’ from earlier thinking with regard to the breadth of ‘content’ needing to be covered, and that the need to teach new skills and approach learning in different ways detracted from their ability to ensure that sufficient breadth was delivered.

Associated with this, while some teachers in the Hipkins (et al, 2006) study saw the advent of NCEA as an opportunity to develop student capability in a more holistic manner, this also became an issue in terms of the amount of curriculum ‘space’ required to achieve this, in what they already perceived to be a crowded programme. Once again this appeared to be linked to the previous notions of breadth of ‘content coverage’ for examination recall being paramount, and the extra time needed to teach and provide opportunity for the exercise of investigative skills, required teachers to rebalance priorities. As the study pointed out, “students need time to learn to think more critically and independently, making connections to other parts of their learning and/or application to related issues and contexts” (Hipkins, et al, 2006, p.58). In addition to the need to realign priorities such as time allocation, Hipkins (et al, 2006) comments that the transition from breadth of content coverage to a recognition of the need to develop skills and understandings of the nature of science, also tugs at many teachers’ ideas of what it means to ‘do science’. In order to support their students to the higher levels of merit and excellence within the NCEA framework, teachers must allow them opportunities to develop higher order thinking capabilities and have greater levels of learner independence by engagement in student directed investigations, which in many instances demands an uneasy shift from teacher to student centred learning. The nature of assessment requirements in the upper levels of NCEA also require students to “develop the skills to transfer learning flexibly and confidently... and to be able to embed such learning within ‘real’ contexts and integrated topics” (Hipkins, et al, 2006, p.59). However, according to the Hipkins (etal, 2006) study, there is little evidence of teaching in context occurring in practice, and few examples of teachers actively supporting the development of the higher order thinking capabilities through the design of rich investigative tasks.

Although at the time of this study it was apparent that there had been few ‘universal’ changes to practice in response to the advent of NCEA, Hipkins (etal, 2006) did note that there was significant cause for optimism going forward. The study revealed that there was greater levels of understanding developing of the fundamental differences between the requirements of NCEA and the older norm-referenced system, and that “teachers were spending time preparing students to recognise the different types of answers now required to achieve merit and excellence levels” (Hipkins, et al, 2006, p.60). This specifically related to the quality of responses required for the higher levels of NCEA, and the depth of thinking that needed to be apparent in answers. Comments from teachers also indicated that greater thought was being put into meeting the needs of more capable students, whereas in the past “the needs of average learners took precedence” (Hipkins, et al, 2006, p.60). Other teachers commented that assessment expectations are far clearer under NCEA, and that communicating these to students and parents was easier than it had been under the older regime. One teacher even went as far as
stating that he does not see the merit and excellence levels of NCEA in terms of assessment, but rather as a tool to “help students see the logic and structure of knowledge” (Hipkins, etal, 2006, p.62) within science topics.

While this early research indicates that potential at least exists under the NCEA assessment system for teachers to engage students in more student-centred inquiry approaches to science learning, movement in this direction at the time of the writing of the report appears to have been limited. Significant challenges exist around ‘dismantling’ the legacy of past assessment systems which have effectively prioritised content coverage over the development of skills and capabilities, and have recognised and rewarded the recall of factual science knowledge over the demonstration of capabilities in science processes. To an extent this issue is interwoven with the conceptual view teachers hold about what it means to ‘do science’ – and that notions of rigor in this are tied to one’s ability to ‘master’ the knowledge of others in the field. There appears to be something of a ‘catch-22’ situation apparent, where teachers acknowledge the need for students to develop both science process skills and higher order thinking skills in order to meet requirements at merit and excellence levels, but are constrained by the notion of needing the time taken to teach these at the expense of ensuring adequate ‘coverage’.

While many science teachers are working towards a ‘depth in favour of breadth’ model, they appear uneasy in doing so, seeing this as a narrowing of the curriculum (Hipkins, 2006).

The perception of the need for subject ‘coverage’ appears also to be reinforced by central agencies, which seem to be actively reinforcing the notion that ‘more is good’. In commenting on the mixed messages around NCEA, the Principal of Wellington Girl’s College commented,

...we were talking about dropping the number of credits that we set so that we are not being driven by assessment. On the one hand, the Ministry is saying we should be assessing less, on the other hand the Minister is congratulating those students who have gained the most Achievement Standards – who have got the most credits – and in that way is going to set up a new league table, which is really difficult.

(McLeod, 2003, cited in Welsh, 2003, p.20)

It may well be that with time these issue will diminish in significance in terms of impacting upon the development of more student-centred approaches to science, but indications are that any widespread transformation will take considerable time.

In addition to the impact of assessment regimes, studies indicate the success of constructivist-informed pedagogies for learning in science can be strongly influenced by student capabilities, and a lack of these, at least in the initial stages, can act as a significant disincentive for teachers to adopt constructivist models. In a study of the implementation of Inquiry approaches in middle school students (12-13 year olds), Krajcik, Blumenfield, Marx, Bass and Fredricks (1998) revealed a number of issues with Inquiry models in the initial stages. The first of these issues related to students’ abilities in generating
appropriate questions for investigation, in particular, the extent to which questions are meaningful and authentic. In the Krajcik (etal, 1998) study, initial student questions emphasised the identification of low level, factual responses, and that significant teacher input was required to form questions into ones which were able to be researched, and were “meaningful and related to their lives” (Krajcik, etal, 1998, p.342). This finding was consistent with earlier studies by Roth and Roychoudhury (1993) and Scardamalia and Bereiter (1992), who determined that although this was the case initially, the level of students’ questions improved over time, and became more specific and required greater depth of exploration and analysis, the more experience they had in constructing them. All studies allude to a vital role for the teacher in this phase, in terms of their willingness to appropriate and timely feedback from teachers and peers, in modelling good question-forming techniques, and allowing students the opportunity to “revise questions and generate new ones” (Krajcik, etal, 1998, p.342).

While some authors advocate that Inquiry models should be implemented only after students have ‘mastered’ the necessary prerequisite skills such as questioning, even if this requires ‘direct’ teaching – others comment that the learning of such skills must be part of the process of learning inquiry. Krajcik, (etal, 1998) claim that “learning inquiry and content should be closely intertwined rather than separated, and, like other forms of learning, students’ abilities to generate questions are fostered through active engagement” (p.342). In stating this, Krajcik (etal, 1998) indicates the need for significant teacher input to this process, pointing to the critical importance of appropriate and timely feedback from teachers and peers, in modelling good question-forming techniques, and allowing students the opportunity to “revise questions and generate new ones” (Krajcik, etal, 1998, p.342).

Part of this process involves teaching students how to generate appropriate questions from personal experience or interests, in a way that the scientific integrity is maintained without compromising the question’s authenticity, whilst maintaining manageability insofar as the students’ investigative abilities are concerned. Challenges also exist in developing single ‘bigger picture’ questions under which the student-led investigations can be framed. Krajcik (etal, 1998) claims it is often difficult to identify ‘macro level’ questions which can act as unifying frameworks for Inquiry-based investigations, while at the same time students often experience difficulty in defining their inquiries to within the boundaries of particular science ideas or concepts, especially when their existing understandings of these may be inaccurate or unclear. However, the study indicates that where teachers are prepared to provide quality feedback, model appropriate question-forming strategies, and engage students directly in the critique of questions posed, then students are quickly able to improve the quality of their questioning and gain greater independence in utilising Inquiry methods in science.

The second issue revealed by the Krajcik (etal, 1998) study, relates to initial limitations in student capability in being able to design and implement appropriate procedures for the collection and analysis of data from investigations. In this study, students did not grasp the importance of matching the data procedures to the research question, and “were not proficient at eliminating uninformative measures
and did not realize the importance of being clear about the purposes of the measures” (Krajcik et al., 1998, p.344). Associated with this, while students were found to be generally proficient in carrying out investigative procedures, this study indicated that many experienced issues in managing time and struggled to maintain consistency in making measurements or experimental controls, particularly where, as is the case in many inquiry-based approaches, investigations spanned over prolonged periods, and often demand the establishment and monitoring of simultaneous investigations.

Krajcik (etal, 1998) attributed some of this to the legacy of ‘cookbook science’, where effectively students have been given worksheet-type formats to follow, which have indicated both the nature of investigative procedures to be carried out, the equipment and process through which they are to be carried out, and how and when results are to be recorded and communicated. To help students in these processes, teachers need to assist students in developing self-reflective skills, so that they can “keep track of their progress and maintain a focus on the problem, rather than getting confused by its elements” (Krajcik etal, 1998, p.346). According to Blumenfield, Soloway, Marx, Krajcik, Guzdial & Palinesar (1991) two specific elements need to be developed – the first which they term tactical control, is a reflective skill which “enables students to monitor and fine tune thought as they work through the details of tasks” (ibid, p.372). The second element Blumenfield (etal, 1991) identifies as strategic control, which relates to the capability of students to make sense of, and develop unity within, what may seem to be disconnected elements of projects. That is, strategic control enables students to “focus on the substance and driving question and organise their efforts in the service of longer-term purposes” (Krajcik etal, 1998, p.346). Krajcik (1998) views metacognitive capabilities such as these as essential to inquiry models in science, if students are to be in a position to make modifications during the course of an investigation, and combine outcomes from multiple explorations in making sense of and responding to research questions. As within Inquiry approaches to science a lot of this responsibility is handed over to the students, teachers need to take the time to ensure such capabilities in designing and carrying out valid and robust science investigations are developed.

The final issue in implementing Inquiry models apparent in the Krajcik (etal, 1998) study, centred on the manner in which outcomes from investigations were communicated, and students’ capabilities in linking their data and findings with their conclusions in terms of being able to “develop logical arguments to support their claims” (Krajcik, etal, 1998, p.347). While students generally were competent in carrying out investigative procedures, the development of valid and robust conclusions from data requires higher levels of sophistication of thought. As the study discovered, students embarking on Inquiry approaches in the initial stages had limited experience in organising and gaining patterns of meaning from data, and above all, appeared unable to construct robust justification for what they claimed their data indicated. Presentations of outcomes generally took the form of “what they did and what they found out” (Krajcik etal, 1998, p348), rather than any substantial engagement in discussion of the data or the validity of conclusions reached. Although, as Krajcik (etal, 1998) points out, such phenomenon is not unique to school science as they have observed similar happenings at higher levels of the education
system, an essential aspect of science learning is being able to explain and justify scientifically robust conclusions in terms of procedures used and data gathered. They comment that teachers may need some assistance themselves in developing such capabilities, as in their study...

*...although teachers attempted to foster discussion, there was little examination or discussion about either the data or the validity of the conclusions, nor was there any conversations about how the combined findings from each of their investigations related to the overall driving question or to what additional questions emerged.*

(Krajcik, et al., 1998, p.347.)

While the literature supports the use of constructivist-aligned instructional models such as Inquiry learning to significantly enhance science learning, it is apparent that in order to successfully implement these there are significant implications for teachers in managing the transition to student-centred, question-based, multiple inquiry learning environments. These implications relate to such things as assessment regimes, teacher philosophical alignment and role definition, student capabilities, curriculum design considerations, and investigation task management. While project-based science inquiries offer a workable structure to facilitate such transitions, the practical management of these within school systems governed by timetabled blocks and departmental divides remains a substantial challenge. As with all innovations, there will be some teachers who will attempt to initiate such approaches despite the constraints of environments in which they operate. Likewise, there will be school leaders and managers who understand the benefits of such approaches for student learning, and will actively seek to remove as many barriers as possible to the uptake of the innovation. It remains a fact, however, that such instances will remain the exception rather than the rule for sometime to come – at least until new assessment structures become embedded and better understood, the residual influence of past assessment systems diminish, and there is a general move to more modular, process-oriented curriculum and programme organisational structures. With the advent of the new national curriculum framework (Ministry of Education, 2007) and its emphasis on Key Competency development, it may be that a window of opportunity exists by which constructivist-informed models such as Inquiry science could become more ‘mainstream’. The next section of this review examines the potential for this to occur.
Chapter 7. The Present Position - How are we Going?

This section provides a brief overview of the results of international surveys of the achievement of students in science in New Zealand as compared with a range of other countries, and speculates on the potential that now exists for a more general movement towards methodologies aligned with enhancing science teaching and learning, as introduced in the previous sections. An examination of the international TIMSS (Trends in International Mathematics and Science Study) and PISA (Programme for International Student Assessment) data was considered relevant for this review, as it helped to identify how New Zealand rated across a range of indicators relative to other countries, and, to an extent, provides a level of support for some of the changes to science teaching approaches advocated in this review.

The TIMSS survey is undertaken by the International Association for the Evaluation of Educational Achievement (IEA), and involves surveying year 5 and year 9 students from 46 countries in key curriculum areas including science, using as its basis,

...science curricular goals regarded as important in most participating countries, and therefore, representing a consensus among participating countries about the mathematics and science students at these educational levels should be expected to have learned...

(Ministry of Education, 2004, p.2)

For the purposes of this review, only an overview of the outcomes from the TIMSS year 9 students will be provided, as these are the most relevant in terms of their ‘location’ relative to the target group for the Science for Life initiative. Additionally, only data from the 2004 survey will be discussed, this being the most recently published summary available.

While the TIMSS (2004) survey positioned New Zealand favourably in terms of overall science achievement - a mean of 520 as compared with an international mean of 474, placing it 13th of the 46 countries surveyed, two significant outcomes are worthy of note. Firstly, while the overall result was generally favourable, unlike a number of other countries the mean achievement level had not improved significantly from the time of the first survey in 1994. From examining the data, this appeared to be due in part to a ‘flattening’ in the levels achieved by New Zealand students in the assessment, with fewer students reaching the highest (Advanced - above 625) and second (High - above 550) benchmarks, despite relatively more reaching the Intermediate- above 475 and Low – above 400 levels. Data also indicated that fewer students were ‘kicking on’ to achieve at higher levels, and achievement at those levels was generally more modest.

Secondly and perhaps more importantly, the survey revealed New Zealand students’ self confidence in science (SSC) as being considerably less than most other developed countries. In comparison with
countries that included integrated science in their curriculum (27), “48% of students had a high level of self confidence in science; this compared with 41% of New Zealand students, 49% in Australia, 56% of students in the United States, and 59% in Scotland and Israel” (MOE, 2004, p.17). Furthermore, a positive correlation was evident between the achievement and confidence indices, with those scoring highly in confidence also scoring highly in achievement.

This relative lack of self confidence in science also correlates with significantly lower than average scores in the SVS (Students Valuing Science) index. This index gauged student attitudes towards science, in particular how positively they perceived science as a discipline. In this survey, while 40% of New Zealand students held positive attitudes towards science and 40% held relatively moderate views, this fell well short of the international average of 57% of students holding positive attitudes. In addition, 21% of students held negative attitudes towards science, as compared with the international mean of just 12%. As was the case with the SSC index, the SVS index correlated positively with the data on student achievement – that is, students with the most positive attitude towards science achieved higher scores than those who held poorer attitudes who tended to scored lower (MOE, 2004, p.18).

Additionally, while just over 30% of the surveyed students indicated high levels of enjoyment of learning science, nearly the same percentage indicated the opposite, and almost 40% indicated only ‘marginal’ enjoyment of the subject. The study also revealed that while New Zealand students engaged in more group activities, they were less likely to “watch their teacher undertake experiments/investigations, and plan or design their own experiments/investigations compared with students in many other countries” (MOE, 2004, p.30).

The Programme for International Student Assessment (PISA)\(^1\) assesses students’ capabilities “to perform scientific tasks in a variety of situations, ranging from those that affect their personal lives to wider issues for the community or the world” (OECD, 2007, p.12). It assesses three broad areas of science competence: Identifying scientific issues (recognising scientific issues and the key features of scientific investigation); Explaining phenomenon scientifically (application of the knowledge of science to solve scientific problems); and Using scientific evidence (interpreting evidence to draw conclusions, identifying assumptions, presenting evidence and reasoning).

In the 2006 PISA survey of nearly 400,000 students from 57 nations, data revealed that the highest achieving New Zealand students in science were comparable with the best in the world; in fact the number of New Zealand participants reaching the highest achievement level 6 (3.9%), was three times greater than the OECD average. This was also the case for students achieving at level 5, with only

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\(^1\) Further detail on the content and focuses of PISA can be found at [http://www.pisa.oecd.org/pages/0,2987,en_32252351_32235731_1_1_1_1_1,00.html](http://www.pisa.oecd.org/pages/0,2987,en_32252351_32235731_1_1_1_1_1,00.html)
Finland bettering New Zealand’s figure of 18% achievement at this level. However, while at the top end of the scale achievement was generally very good, it is pertinent to note that New Zealand’s underachieving ‘tail’ was disproportionately long – with nearly 15% of participants achieving only, or failing to reach, the most basic first level. In addition, New Zealand also rated as having the least level of equity, with achievement in science being impacted upon significantly by the socio-economic background of the students. That is, while achievement levels were high, so was the level of impact on these outcomes of student socio-economic background. When data relating to the consistency of performance within and between participating schools is examined, this inequity becomes even more apparent. PISA data indicates significant variations in the New Zealand results both between and within participating schools, with between school variations appearing also to be linked closely with socio-economic factors.

The survey also profiled the nature of student engagement with science in each participating country. This section examined student attitudes towards science, the level of support displayed for scientific inquiry, student self efficacy as science learners, and their sense of responsibility towards resources and environment. This component was seen to be important as it explores student motivation and attitudes towards science, “which plays a key part in today’s societies and economies, but appears not to be taken up enthusiastically by young people at school” (OECD, 2007, p.26). The report commented that gaining such understandings were vital as...

...continued investment in scientific endeavours relies on broad public support, which is influenced by citizens’ responses to science and technology; scientific and technological advances are important influences on nearly everyone’s life; and a continued supply of scientific personnel requires a proportion of the population to take a close interest in science...

(OECD, 2007, p.26)

Whilst overall the survey indicated students considered science as being important in helping them understand the natural and physical world around them, only slightly more than half saw science as being personally relevant, and only 37% indicated that they would consider working in a career involving science while less than 21% commented they would be interested in doing advanced science study. While no direct causal relationship with overall science performance can be drawn, self-efficacy (one’s belief in being able to ‘do’ science) appeared generally to be linked to levels of science achievement, but in the New Zealand case, the relatively high levels of achievement did not correlate with high levels of self-efficacy. In fact, when compared with other countries at a similar achievement level, only students from Japan, Korea, Slovenia and Liechtenstein held poorer levels of self-efficacy. Of those higher achieving nations, New Zealand students also held significantly less than average awareness of environmental issues, with significant variations being apparent on an issue by issue basis.
It would be fair to state that while both the TIMSS and PISA reports paint a generally positive picture of science achievement by New Zealand students, they also indicate some areas which are worthy of attention. These include:

- The low interest in higher-level science study by New Zealand students;
- The low level of interest held by New Zealand students in science-related careers or work;
- The less than average sense of self-efficacy held by New Zealand students towards their capabilities in science;
- The significantly lower than average number of New Zealand students holding positive attitudes towards science;
- The long achievement tail. A proportionately high percentage of New Zealand students only achieve at, or fail to meet, the first PISA achievement level;
- Significant inequity- high between school and within school result variations, and their relationship with student socio-economic backgrounds.

It needs to be acknowledged that such concerns are not unique to the New Zealand context⁴, and while achieving a ‘pass’ mark in international surveys in terms of overall achievement, there can be little doubt that science teaching and learning in this country can and should aim to improve in certain areas. While there is no ‘magic bullet’ in this respect, the following discussion explores how the revised curriculum framework (MOE, 2007) may offer opportunities to make science learning more relevant and motivating, thereby helping to address engagement and self-efficacy concerns.

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Chapter 8. Learning Science for the 21st Century

During the period 2001 - 2002, the Ministry of Education undertook a review of the National Curriculum Framework (MOE, 1993) in response to calls from a range of stakeholders to examine the form and relevance of the framework in terms of the knowledge and competencies required of students entering the 21st century. The purpose of the review was to determine the appropriate ‘shape’ of the school curriculum in terms of delivering the type of outcomes needed for, amongst other things, a high-knowledge, high-skill economy, where both physical and social environments were dynamic and rapidly changing. In addition, the curriculum stocktake as it became known, aimed to assist teachers by making more precise and ‘honing in’ on the essential content to be taught and suitable contexts for teaching it, through a rationalisation of the achievement objective structure, a clarification of essential subject aims and goals, and a stronger focus on overarching key competencies for living and learning in the new century.

As summarised in the final Ministry report (MOE, 2002),

...the curriculum stocktake report analyses the recent New Zealand curriculum reform experience in terms of: the appropriateness of the New Zealand Curriculum and Te Marautanga o Aotearoa in the current educational, social and economic climate; the purposes of these curricula; and the quality of these curricula in contributing to improved student outcomes, meeting the expectations of a range of stakeholders, and against comparable international curricula.

(Ministry of Education, 2002, p.1)

The curriculum review process led to the development of a much tighter and less prescriptive revised National Curriculum (MOE, 2007), which outlined for teachers essential concepts within each subject area to be taught at various levels of the school system, as well as defining a range of Key Competencies and Values which were to serve as an overarching framework to guide planning and teaching across the curriculum. The Key Competencies originated from the work of Rychen and Salganik (2003) and the OECD, who sought to identify the nature of core competencies students will need as they enter the rapidly changing world of the 21st Century. The reports generated from their research defined competence as more than simply the acquisition of specific knowledge and skill, but rather they “involve(s) the ability to meet complex demands, by drawing on and mobilising psychosocial resources (including skills and attitudes) in a particular context” (Rychen & Salganik, 2001, p.6). The research identified three broad areas where it was considered such competencies should exist, and further defined these into subcategories which provided greater levels of description of what these might ‘look like’ in practice. The three primary categorisations were:
Using tools interactivity (competence to use technological and socio-cultural tools including language and ICT);

Acting in heterogeneous groups (competence to act effectively as part of a group);

Acting autonomously (competence to take responsibility for their own lives within wider social contexts).

(OECD, 2001, p.5)

The OECD Key Competencies are interpreted within the revised New Zealand Curriculum Framework under “five capabilities for living and lifelong learning” (MOE, 2007, p.12). These are:

- Thinking – using creative, critical and metacognitive processes to make sense of information, experiences and ideas;
- Using language symbols and texts – working with and making meaning of the codes through which knowledge is expressed;
- Managing self – self motivation, and students seeing themselves as capable learners;
- Relating to others – interacting effectively with a diverse range of people in a variety of contexts;
- Participating and contributing – being actively involved in communities.

(MOE, 2007, pp.12-13)

According to the curriculum framework, the Key Competences are not intended to be viewed as standalone entities, but rather they are viewed as key to learning in all areas, and combine “knowledge, attitudes and values in ways that lead to action” (MOE, 2007, p.12). This perspective is compatible with overseas literature such as that produced by the European Commission (2002, p.12) in their discussion of the nature of curriculum under the Key Competency model for knowledge economies. Within the context of science education, they comment that four types of understandings are critical - Knowing what (transferable knowledge); Knowing why (science understanding and the impact of science on human-kind); Know how (the capability to perform certain scientific tasks); and Know who (knowing who to access to find out if you don’t know why, how or what).

Within the wider purpose of the development of a level of universal scientific literacy, the Commission report comments that science inquiry provides an ideal platform for the development of a range of personal competencies. These include an “ability to understand and apply scientific concepts and the development of generic competencies of problem solving, reasoning and analysis” (Eurydice, 2002, p.16). The report further comments, however, that one of the main obstacles to achieving this goal is the traditional tendency to teach science within what they term a “disconnected curriculum model” (ibid, p.17), where “subject matters are taught in ways encapsulated from one another and sealed off from the lives students outside of school, not to mention the lives they will lead after they have completed their schooling” (Eurydice, 2002, p.17). They identify a significant challenge in this respect as being...
...to organise curricula in such a way as to demonstrate the interrelationship between the substance of different subjects and topics... demonstrating to students the relation between teaching and real life, showing that learning is a worthwhile exercise.


When these perspectives are applied to teaching and learning in science, arguments could be made for changes not so much to what is taught, but the manner in which it is taught and the underpinning ‘big ideas’ which guide teaching decisions and processes. As Barker, Hipkins and Bartholomew comment

Science competencies now need to address not just questions of thinking, but also questions of being – issues of belonging, ownership, cultural identify, and questions about the kind of world one wants to live in, and ultimately the kind of person one wants to be.

(Barker, etal, 2004, p.8).

When exploring the strands of the new curriculum statement (MOE, 2007), it is apparent that the opportunity exists for more student-centred approaches to teaching science, such as those aligned with Inquiry and project-based learning, to be implemented within topics embedded in the contextual strands (Living World, Planet Earth and Beyond, Physical World, and Material World). A combination of the advent of the Key Competency framework as described above, and the overarching Nature of Science strand, encourages teachers to adopt approaches to teaching science which are more accessible, more relevant, and link more closely with the day to day activities of both students and society as a whole. The Nature of Science strand in particular advocates that students should “learn how scientists carry out investigations” (MOE, 2007, p.28) and that they are encouraged to “see science as a socially valuable knowledge system. They learn how science ideas are communicated and make links between scientific knowledge and everyday decisions and actions” (ibid, p.28). The Nature of Science strand is further defined at each curriculum level into a series of descriptors which aim to develop in students a greater understanding of the purposes and processes of scientific endeavour, what it means to be a scientist and ‘do’ science, how science impacts upon, and in turn is impacted upon, by society, and how science ideas are validated and communicated. These descriptors and a short summary of their general focuses are:

- Understanding about science – developing understanding of the nature of science knowledge, the role of theory in developing scientific knowledge, and how scientific knowledge is validated through evidence and peer review;
- Investigating in science – developing understanding of, and capability in carrying out increasingly complex scientific investigations, including the identification and control of variables, and the selection of scientific methods and models appropriate for purpose;
- Communicating in science—increasing accuracy in the use of appropriate and correct scientific symbols, texts and conventions in communicating outcomes from scientific investigations, and in reviewing and evaluating scientific accounts;
- Participating and contributing—increasing awareness of socio-scientific issues by gathering and reviewing relevant scientific information, and using evidence to draw conclusions and make decisions about appropriate action.

(from MOE, 2007, curriculum inserts)

While these descriptors do not define and are not reliant upon the use of a specific pedagogical approach to teaching science, a significant emphasis exists relating to students developing capability in undertaking scientific investigation through the use of appropriate scientific methods and models, and being able to link these with ‘real world’ contexts through authentic projects which consider a range of socio-scientific issues.
Chapter 9. Summary

It is apparent from literature accessed for this review that project-based, inquiry models offer considerable potential to operationalise the Nature of Science objectives through authentic, student-centred investigations within the four contextual strands. However, it is also apparent that while the curriculum allows for and even encourages this, there exists other significant barriers – perceived or real – to this taking place. Amongst these are:

- Teachers’ views of science knowledge and how this is ‘delivered to’ students. While there appears to be isolated movement towards more constructivist-referred pedagogies which acknowledge initial student ideas and concepts, and recognise knowledge as being contextually-based and personally and socially constructed, the general adoption of such a theoretical stance is the exception rather than the rule. Significant research exists which supports the efficacy of approaches to teaching science in which initial student ideas are used as starting points to planning, and where strategies are developed and implemented which ‘move’ students from their current understandings towards those generally considered to be more scientifically accurate;

- A continued (and highly resistant) emphasis on ‘knowing science’ rather than on ‘knowing science through doing science’. That is, a de-emphasising of student engagement in the processes and challenges of authentic scientific inquiry, in favour of pedagogies which are more concerned with learning (and reproducing) the outcomes of others’ inquiries. This manifests itself in the adoption of teaching approaches and strategies in which students reproduce, usually devoid of an authentic context, previously discovered science knowledge through predesigned experiments and investigations;

- The ‘legacy effect’ of earlier norm-referenced assessment systems which, principally through the design of assessment tasks, valued more highly students’ mastery of science ‘facts’, than their capacity to design and undertake science investigations, or analyse socio-scientific problems, dilemmas, or issues;

- The organisational structure of secondary schools generally does not support the adoption of integrated, inquiry-based, project-oriented approaches to curriculum design. The structural impediments referred to include subject-based departmental or faculty systems which tend to create working ‘silos’ which discourage between-subject cooperation and integration, the existence of difficult to change timetable arrangements which do not allow for time blocking or the flexibility needed for project-based work, and in some cases, management, logistical and compliance difficulties related to students working away from the classroom;

- The limited capabilities of students, at least initially, in the skills needed for independent scientific inquiry. Teachers often viewed students as lacking in the investigative, analytical, conclusion-forming, and communication skills needed to undertake and review outcomes from
quality scientific investigations. This was seen as something of a ‘catch 22’ situation, where
teachers saw the investment of additional time in developing student investigative capacity as
being difficult to justify in what they viewed as an already crowded curriculum, when more
traditional methods usually aligned with teacher demonstration and/or teacher-prescribed
investigation would suffice;

- Traditional views of what it means to be a teacher of science, and how this ‘looks’ in practice.
The reviewed literature suggests that in order for teachers to implement inquiry-based practice
models, there needs to be a significant rethink of the nature of their role and how this is carried
out. While the literature does not accept or advocate more extreme interpretations of the
teacher as a ‘hands off’ facilitator or ‘guide on the side’, it does suggest that teachers need to
adopt a range of different roles and hand over greater levels of responsibility for learning to
their students, by helping empower them in decision-making, and allowing them greater input
into the identification, execution, and communication of the outputs from science activities.
Teacher knowledge, both in terms of content and pedagogical content knowledge are viewed
critical elements in achieving this goal.

In reviewing the above summary, it is apparent that the challenge for science education to become
more universally authentic, accessible, relevant, and meaningful is considerable. While, as is the case
with almost any innovation, there are pioneers who make it their business to ‘push the envelope’ and
try such alternative strategies, they are few and far between and sometimes have to be almost
subversive in their approaches to doing so, in the face of often strongly compliant subcultures existing
in their school. However, the literature reviewed indicates there is a strong argument for adopting
alternative Inquiry-oriented approaches in terms of enhancing student attitudes towards, and
performance in science, but that systemic change is needed to facilitate this on a wider scale. The
following quote from Edgar Jenkins (2000) summarises well the nature of this challenge...

...science aims will need to become more student-centred, reflecting what studying science can do
for the student rather than what the student may eventually be able to contribute to science. The
challenge to much of the traditional pedagogy of school science is likely to be no less severe.
Science teaching is dominated by work in the laboratory and characterised by an emphasis upon
secure and known outcomes. In addition, there is some evidence that, while science teachers do
not use a narrower range of pedagogical techniques than some of their colleagues teaching other
subjects, the approach to teaching individual science topics is often remarkably standardised...
much repetition (and often outdated) laboratory work will need to be abandoned to make room
for genuine collaborative scientific investigation, perhaps extending over several months...

(Jenkins, 2000, p.223)
Chapter 10.  References


