LITERATURE REVIEW

Quality Learning and Teaching in Primary Science and Technology

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This study was commissioned by

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EXECUTIVE SUMMARY

Experts in science and technology education, together with generalist primary school teachers, express concerns about the teaching and learning of primary science and technology. There is general agreement on the types of approaches to teaching primary science and technology that would contribute to productive learning, but implementing these approaches remains challenging in many school settings.

There is considerable variation in the quality of teaching in primary science and technology. In some instances little science and technology is taught; in others it is taught in limited ways; in others rich learning experiences are provided by teachers for students. Key questions that arise from this literature review include: What influences this variation in the learning and teaching of primary science and technology? What choices are made that impact on the science and technology experiences that are provided for students? And, how might these decisions be influenced to enhance primary science and technology?

The summary reports findings under themes that emerged from this literature review.

1. Problems with Performance in Science and Technology

National and international studies over the last decade show that, although the attitudes and interest of primary students toward science and technology have remained consistently high, problems persist with primary science and technology teaching and learning as evidenced by continuing poor performances in national and international measures.

2. School Capability and Teacher Capability

Reports on primary school science and technology capability suggest that, in some schools, there is a need to ensure greater support for teachers, including:

- additional professional learning opportunities
- an emphasis on science and technology in school programming and assessment
- more time for science and technology planning and preparation
- well organised and sufficient resources for planned and potential activities.

The literature is unclear on the minimum level of resourcing required for effective science and technology education. In studies conducted with teachers, teachers typically report that additional and well-organised resources and materials are required to facilitate the teaching of science and technology.

Many primary science and technology teachers themselves have reservations about whether they have the knowledge, pedagogical skills and pedagogical content knowledge (PCK) that is required to teach primary science and technology effectively.

3. The Relationship between Science and Technology is Complex

Science and technology differ in their goals in that science is concerned with the need to know and technology is concerned with the need to do. However, in terms of teaching and learning, both enable hands-on learning, support problem solving and offer authentic learning where students are able to see the links between science and technology learning and relevant aspects of their everyday lives.

4. Teacher Know-how

There is evidence that teachers with strong PCK tend to be able to teach science and technology effectively. There are also examples from the literature where, in collegially supportive environments, teachers with modest science and technology PCK have implemented productive science and technology activities.

The following attributes of teachers' knowledge appear important for quality science and technology teaching to occur:

- knowledge of the curriculum, including purposes and learning outcomes, and content to be taught

- knowledge of pedagogy, including the management of the classroom learning; environment to best deliver the teaching strategies for successful learning
- knowledge of how to assess knowledge production and capabilities in science and technology
- knowledge of how students learn in science and technology
- understanding of context and authentic learning activities
- positive attitudes and beliefs, and confidence to teach science and technology.

5. Student Inquiry

Student inquiry is central to effective teaching models and approaches for primary science and technology. Many models are broadly consistent with this pedagogical framework. Five models are presented in this review:

- 5Es Instructional Model, based on teaching and learning proceeding through five phases
- Generative Learning Model, based on the premise that perceptions and meanings are generated by students
- Learners' Questions Model, based on promoting and researching students' questions
- Science in Schools (SIS) Model, which stresses context and relevance, and adds relationships with communities to the models above
- Representational Intensive Pedagogy, based on students producing and learning through and about multimodal representations.

6. Characteristics of Quality Science and Technology Teaching and Learning

The review indicates that the following features characterise quality science and technology teaching and learning:

- emphasis on student inquiry
- ue of starter activities that arouse and engage students in investigations
- identification of real needs or problems and investigations of ways of resolving these problems
- promotion of student questioning
- exploration of ideas, development of designs and creation of products
- the sharing and subjecting of designs and ideas to scrutiny through evidence based discussions and in trials using experiments
- opportunities to fail and try again
- support of ways to search for information and find out what is already known
- engagement in authentic activities
- connections to students' life experiences
- display and presentation of products of learning and design
- use of formative assessment to diagnose needs and inform iterative changes to planned learning sequences
- students creating and analysing their own representations and analysing standard technological and scientific representations
- exploitation of teachable moments for explicit teaching of science and technology principles, skills and processes
- employment of summative assessment to gather evidence of learning achievements
- use of a variety of strategies to communicate ideas with a range of audiences
- use of digital technologies to enhance learning
- opportunities to connect learning experiences with local communities.

These elements are most likely to be effective when applied by a teacher with sound science and technology PCK, including strong knowledge of science and technology content. They are more likely to occur when promoted by effective school leadership that places an emphasis on collaborative teams to build capacity throughout a primary school to improve science and technology teaching and learning.

INTRODUCTION

The aim of this literature review is to address the broad research question: What characterises quality teaching and learning in primary science and technology? Effective teaching that engages students to learn successfully indicates quality.

The document first sets the context of the literature review by providing a broad overview of science and technology education in Australia. It then evaluates the status of science and technology education in Australia, and internationally. Expectations, barriers and challenges that schools and primary teachers experience in implementing quality science and technology programs in the classroom are highlighted.

Second, the literature review briefly describes science and technology and discusses the relationship between these two constructs within the context of the New South Wales New South Wales Science K–10 (incorporating Science and Technology K–6) Syllabus. This situates the literature review within the parameters of the curriculum context and clarifies the relationship between science and technology. An understanding of the nature of science and technology and their relationship should inform stakeholders of the types of knowledge, skills and practices that are required to teach science and technology effectively.

The NSW syllabus brought together science and technology learning as a major key learning area in primary education about two decades ago. Indeed, during these two decades in Australia and internationally, many primary school teachers may not have viewed technology — and in particular, design technology — as intended by the New South Wales Science K–10 (incorporating Science and Technology K–6) Syllabus in their teaching programs (Fensham, 2008; McRobbie, Ginns, & Stein, 2000; Rohaan, Taconis, & Jochems, 2010). Many teachers have seen technology education as related to the use of computers only (ATSE, 2002; Benson, 2011). The interest in technology research in the literature often appears to be related to digital technology use in primary students' learning in science and other disciplines (e.g. Hall & Higgins, 2005; Jane, Fleer, & Gipps, 2009; Murphy, 2003; Rodrigues & Williamson, 2010; van Braak, Tondeur & Valcke, 2004).

As digital technology is a supporting tool to enhance the teaching and learning of science and technology, it is not the focus of this literature review.

Third, factors that influence the effective teaching and learning of science and technology in primary education are identified. This review considers what it means to be an effective teacher of primary science and technology and then outlines proposed pedagogical approaches. It then elaborates on the complex science and technology pedagogical knowledge system on which effective teachers draw. It highlights the role played by teacher efficacy in limiting or expanding the scope of science and technology teaching and learning. Then, it considers the ways in which school capability can impede or facilitate effective teaching and learning before elaborating on a selection of specific teaching models and approaches.

METHODOLOGY

The research literature on primary science and technology is dominated by studies in primary science education, rather than in technology education or science and technology education (Lewis, 2006). For example, Potvin and Hasni's (2014) review of 228 papers for the analysis of interest, motivation and attitude towards science and technology at K–12 levels contained predominantly science education papers. The availability of a more extensive science education literature is understandable as science has been a central and often mandatory element of the primary curriculum for many years in many countries. By contrast, the presence of technology or design in the primary curriculum is relatively new outside the UK and Australia. In Australia, it has only been required in NSW recently, where it is not a separate key learning area but is combined with science.

As a result, this literature review will target resources predominantly in science education and/or technology education at the primary school level but, where appropriate, may include general science education and technology education resources.

Procedure

The research for this review was conducted in three phases. These phases comprised a discussion with experts to identify themes, database searches and a review of reference lists in relevant papers.

The first phase comprised a discussion held with primary science teacher experts within the research team to determine the key themes to be researched. A list of search terms was created from the resultant list of key themes. These search terms were then used as keywords in the second stage of the research.

The second stage of research involved database searches. Three primary databases were searched for literature relating to primary science teaching. These were Thomson Reuters Web of Science, the National Library of Australia TROVE database and Google Scholar. Web of Science is an extensive subscription based search engine. TROVE is a source of Australian and online resources in a variety of media and was included for its broad database, which includes doctoral theses. Google Scholar was searched to identify literature from unusual sources that may not be represented in Web of Science or TROVE.

The initial search terms of "effective" with "teaching" and "primary" or "elementary" revealed that there is a large number of papers relating to effective science teaching in primary school. The search was narrowed by including the names of a number of key Australian authors in this field — for example, Fleer and Tytler. These authors have written key papers in the field of primary science education, and therefore it was considered that any subsequent works on the topic would be likely to mention one or more of these authors in their literature reviews. These searches resulted in many hundreds of papers and so the terms were further refined.

Given the large body of literature on teaching practices in science in past decades, the searches were further refined to limit results (predominantly) to those papers published in the period 2000–2015. However, examples from a selection of some earlier works are also reported. Further, a large number of papers were directed at teacher education and so the search terms of "novice" and "pre-service" were used to deselect papers. Within the resulting search results, individual searches were then conducted on terms relating to the key themes — for example, "multimodal" and "technology".

The third stage of the research was to review the reference lists of the papers resulting from database searches. Papers within these reference lists that had not appeared in the database searches were reviewed for relevance.

Papers resulting from this three-stage research approach were read. Themes were identified and summarised. The literature review was then compiled from these summaries and reviewed by the research team.

PRIMARY SCIENCE AND TECHNOLOGY EDUCATION IN AUSTRALIA

CURRENT STATUS

National and international studies over the last decade indicate that the teaching of science and technology remains challenging.

For decades, there has been a steady stream of calls in Australia for reform and improvement in school science and technology education (Aubusson, 2011; Tytler, 2007). Similar calls for change and improvement in science, technology, engineering and mathematics (STEM) education in schools are also evident internationally, with successions of reports commissioned by government departments and scientific bodies published in countries such as the United States, United Kingdom and across Europe (Epstein & Miller, 2011; Millar, 2012; Rocard, Csermely, Jorde, Lenzen, Walberg-Henriksson, & Hemmo, 2007).

For the purposes of this literature review, a number of reports are particularly relevant and include:

- The teaching of science and technology in Australian primary schools: A cause for concern (ATSE, 2002)
- The status and quality of teaching and learning of science in Australian schools (Goodrum, Hackling, & Rennie, 2001)
- Re-imagining science education: Engaging students in science for Australia's future (Tytler, 2007)
- Science and mathematics participation rates and initiatives (Victorian Auditor-General, 2012)
- Science, technology, engineering and mathematics: Australia's future (Office of the Chief Scientist, 2014)

Spanning more than a decade, these Australian reports collectively present a view of a persistent crisis in science and technology education in schools. Major matters regarding primary science and technology teaching and learning are the following.

Student Performance

Student performance in science has fallen over the past decade, as evidenced by the most recent results from The Trends in International Mathematics and Science Study (TIMSS). This is an international study conducted every four years to assess and compare Year 4 and Year 8 performance in mathematics and science (ACER, 2012). Australia's average Year 4 science score in TIMSS 2011 was significantly lower than the 2007 TIMSS score. Although Australia's achievement score on TIMSS 2011 was significantly higher than that of 23 countries, including New Zealand, it was below that of 18 countries, including many Asian countries, England and the United States of America. (Australian and international research on student achievement in technology education has not been conducted.)

Teaching Quality

The national Australian study conducted by Goodrum et al. (2001) reported systematic problems with the science curriculum, pedagogical approaches and quality of teaching and learning experiences in primary science education. Furthermore, there is a concern that pre-service teachers have been inadequately prepared to teach science and technology (ATSE, 2002). A lack of adequate professional development opportunities for in-service teachers in this area of the curriculum has been reported across the education sector.

Teacher Capability

It has long been acknowledged that many primary school teachers lack confidence and expertise in teaching science and technology. Most recently, survey responses of 108 teachers across eight primary schools in Victoria showed that the primary school teachers rated their knowledge in mathematics teaching much higher than in science teaching (Victorian Auditor-General, 2012). The data in Table 1 shows that knowledge levels in science teaching are about half of that in mathematics teaching (Victorian Auditor-General, 2012, p.29). A survey of NSW primary school teachers raised similar concerns, with teachers voicing

opinions about their own skills and knowledge with respect to being able to teach primary science and technology adequately (Aubusson & Griffin, 2011; Aubusson, Griffin & Palmer, 2015). These studies highlight the perceived lack of skills and understanding of key pedagogical constructs, which makes the teaching of science and technology difficult.

Table 1: Teachers stating that their knowledge of science and mathematics teaching is good or very good

Teaching (per cent)	Science	Maths
Content	47.5	90.0
Pedagogy/Instruction	38.6	86.3
Curriculum	40.0	85.3
Integrating ICT	38.0	74.3
Assessing Students	39.0	84.3

Victorian Auditor-General (2012)

School Capability

School based factors, operating as barriers to effective science and technology teaching, have been reported in many studies (ATSE, 2002; Goodrum et al., 2001; NRC, 2011; Rennie, Goodrum, & Hackling, 2001; Victorian Auditor-General, 2012). These barriers include inadequate resources, a lack of time for teacher preparation, poor access to science and technology specific professional development, and school cultures that prefer to avoid activities associated with messiness and noise. A survey of 173 NSW primary science and technology teachers found that primary teachers themselves reported low levels of science and technology capability in their schools (Aubusson & Griffin, 2011).

Student Attitudes towards Science and Technology

Despite perceived inadequacies and concerns, the attitudes of primary school students to science appear to have remained resilient. The Victorian Auditor-General's (2012) report showed that 93 per cent of Year 6 students said they strongly agreed or agreed with the statement "the (science) subject is fun and interesting". In an earlier survey of more than 1,200 upper primary students across Australia, Goodrum et al. (2001) reported that more than 80 per cent of the students indicated that they enjoyed science lessons and were curious about science at least some of the time, with 62 per cent and 43 per cent indicating "often" and "always" for these items respectively. In addition, the primary students perceived science to be generally easy rather than hard, although not too easy. Similar attitudinal data was obtained in the 2012 Victorian Auditor-General's audit of science and mathematics, with 72 per cent of students indicating that learning in science was easy. Despite data suggesting positive student attitudes to learning about science, achievement data and self-reported teacher capability suggest that this is a complex situation and indicate a need for improvement and change. (Research assessing primary school students' attitudes towards technology in Australia was not found in the literature search.)

Reports on the status of science and technology have identified a range of concerns about primary science and technology regarding student learning, teaching quality, teacher knowledge and school capability. It has consistently been argued that, in order to improve the performance of the nation in STEM, children's education in science and technology should be encouraged from the earliest years of schooling (ATSE, 2002; Fitzgerald, 2013; Harlen & Qualter, 2014). This view has been adopted and supported by the Australian Curriculum (ACARA, 2014) and BOSTES which requires all primary students to be taught science and technology from Kindergarten to Year 6. It is clear that learning in science and technology K–6 has attracted renewed attention as the subject forms a critical foundation for national science and technology capability, as well as for the production of a scientifically literate citizenry. This does, and will, continue to place new and greater demands on the teaching and learning of science and technology in primary schools.

Wonder, Curiosity, Creativity, Working Scientifically, Working Technologically, Inquiry, Design, Skills, Knowing, Understanding and Dispositions

The Australian Curriculum (Science) provides a framework for science learning from Foundation to Year 10. In New South Wales, BOSTES is responsible for the development of all syllabus documents for schools and includes the content and achievement standards as described in the Australian Curriculum. Figure 1 visualises the organisation of the K–6 science and technology content taught by primary teachers in NSW.

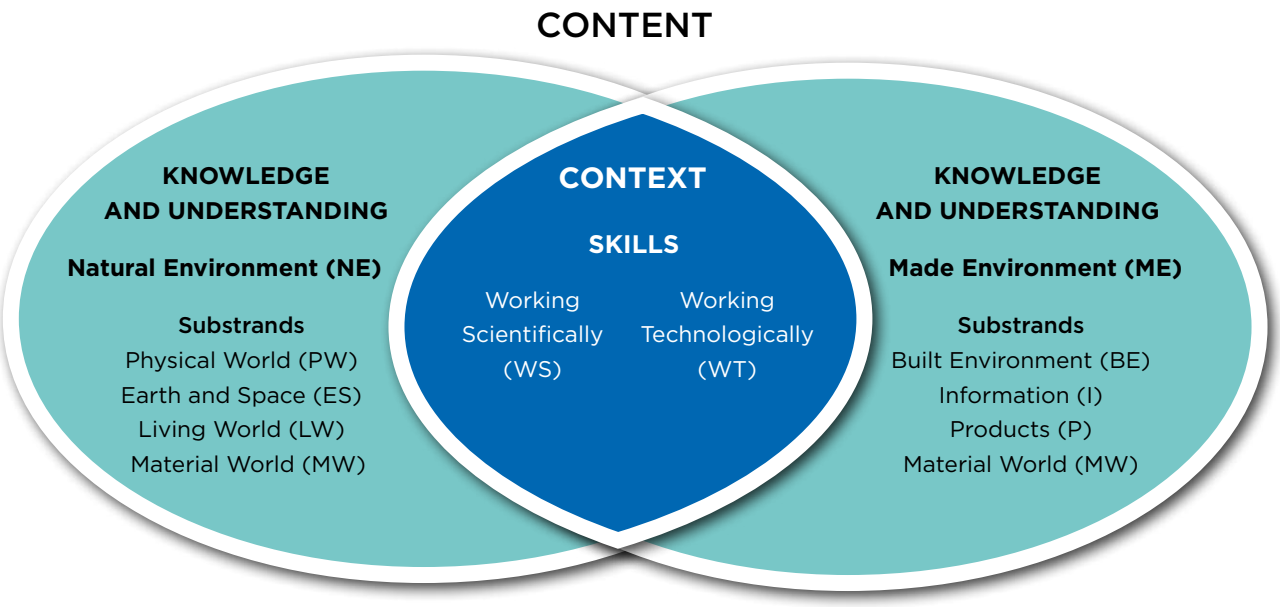


Figure 1: Organisation of Content — Science and Technology K–6 Syllabus BOSTES (2012, p.30).

The aim of the Science K–10 (incorporating Science and Technology K–6) Syllabus (BOSTES, 2012, p.16), is to:

- foster students' sense of wonder and expand their natural curiosity about the world around them in order to develop their understanding of, interest in and enthusiasm for science and technology
- develop students' competence and creativity in applying the processes of Working Scientifically and Working Technologically to appreciate and understand the Natural Environment and Made Environment
- enhance students' confidence in making evidence-based decisions about the influences of science and technology in their lives
- enable students to confidently respond to needs and opportunities when designing solutions relevant to science and technology in their lives.

The changes to the curriculum for primary students are directed at creating a continuum of dispositions, skills, knowledge and understanding from science and technology K–10. The outcomes and content integrate understanding about the development, uses and influence of science and technology on students' lives now and into the future. Finally, the skills, knowledge and understanding content provides specific guidance about the scope of student learning and how the outcomes may be interpreted.

RELATIONSHIP BETWEEN SCIENCE AND TECHNOLOGY

Science and technology are different but pedagogically and intellectually connected endeavours. Science and technology both enable hands-on learning, support problem solving and offer authentic learning opportunities whereby students are able to see the links between science and technology learning and relevant aspects of their everyday lives.

The existence of an important relationship between science and technology is universally agreed but there are manifest differences in understandings of the nature of this relationship. There are a number of prominent views on this:

- the central difference between science and technology lies in their goals — the need to know for science and the need to do for technology (Lewis, 2006)
- science and technology can exist independently but need to be combined in order to produce functional results (Brook, 1994)
- scientific knowledge discovered by scientists can be used by technologists for the design and production of products for use — technology is applied science (Léna, 2011).

All agree that there are distinctive differences in the types of knowledge and processes between the two constructs, making the relationship between science and technology complex. Almutairi, Everatt, Snape and Fox-Turnbull (2014, p.55, citing Sparkes) summarised differences between science and technology against a set of dimensions ranging across goals, the nature of knowledge, products, values and processes. Table 2 summarises these differences.

Table 2: Summary of the differences between science and technology

Criteria of differences	Science	Technology
Goals	To pursue knowledge and understanding for its own sake	To create technological artefacts and systems to meet people's wants and needs
Knowledge introduced	Scientific	Technological
Way of processing knowledge	Through experimentation and theory creation	Through design, invention and production as implementation of theory in science
Reductionism & holism	Breaking and isolation of materials to explain the phenomenon	Integrating theory, ideas and data for the design purpose
Value judgement	Value-free	Value-laden
Conclusion & decision	Takes time to obtain more data if the current data is insufficient	Product has a deadline and technologists can make a decision based on incomplete data
Research	Search for new knowledge and understanding through controlled experiments	Search for development of products by searching for the principles underlying better processes

Almutairi et al. (2014)

By contrast, Gardner (1994) emphasised the connectedness of science and technology and summarised four possible relationships between them.

1. *Technology as applied science:* where science precedes technology and technological capability growth is through applied science, hence scientific knowledge expansion is accompanied by technological expansion.

2. *The demarcationist view:* where science and technology are based on different approaches to knowledge and use and can exist as independent disciplines with different goals, methods and outcomes. This view proposes that science and technology be taught separately in the school curriculum.

3. *The materialist view:* where technology precedes science and where scientists cannot advance conceptual knowledge without the technological instruments created by technologists.

4. *The interactionist view:* where science and technology are intertwined, with neither science nor technology being seen as the dominant contributor. This view acknowledges the differences between science and technology but sees them informing and challenging one another — that is, they are productively complementary (ATSE, 2002).

In NSW, the primary science and technology curriculum acknowledges these differences but also emphasises the connectedness for the learning in K–6. ATSE (2002) advocated an integrated approach in primary schools (i.e. the interactionist view) because "science at this level is useful only if it intersects the lives of students" (p.5). McCormick and Banks (2006) also argue for an interactionist approach because science and technology share broadly similar pedagogical principles: both enable hands-on learning, both support problem solving and both offer authentic learning where students are able to see the link between science and technology learning and relevant aspects of their everyday lives.

Lewis (2006) asserted that within the context of science and technology, design and inquiry are conceptual parallels. The goal of science is to understand the natural world while the goal of technology is to make modifications in the world to meet human needs. Based on this central difference in goals between science and technology, it is reasoned that technology as design is parallel to science as inquiry. Lewis identifies similarities and convergence between inquiry and design, and these similarities enable effective integration of science and technology education into the primary science and technology curriculum. This integrated approach in primary education is supported by others including Beven and Raudebaugh (2004), Davies et al. (2014), Rennie, Venville, and Wallace (2012), and Todd (1999). Although alternative curriculum arrangements have been suggested, particularly in the secondary school, the case for an integrated science and technology curriculum in the primary school is reasonable as it enables teaching and learning to benefit from both the connectedness of these intellectual endeavors and their pedagogical relationships.

SCIENCE AND TECHNOLOGY TEACHING

Science and technology experts pose great questions and find solutions to real needs. So, too can children. "Why does the Sun follow me?" "How can I make a chair for my teddy bear?"

Defining effective teaching of science and technology is difficult as our understanding of effectiveness is based on the experiences and opinions of various stakeholders and hampered by the lack of a clear definition of what a good teacher is (Fitzgerald, Dawson, & Hackling, 2013). Determining what is effective teaching requires a consideration of what is to be taught and what learning is worthwhile for the students.

Science and technology education encompasses the development of the understanding of scientific processes and technological procedures, as well as the theories, principles and concepts underpinning the respective disciplines that students are required to learn.

Working Technologically is about designing, building and evaluating, matching materials to purpose. The ATSE (2002, p.5) defines technology as:

Technology is about the synthesis of knowledge, ideas and skills in the solution of identified problems and the development of innovative capabilities. In its focus on synthesis, design and invention, it embraces creativity across the full spectrum of a student's learning. In a real sense, this synthesis places technology education as a significant integrating force within schooling. It is learning through practice. It is often practised through group or team activities with the objective of finding solutions that are culturally and environmentally informed.

In technology education, Rohaan et al. (2010) state that conceptual knowledge, metacognitive strategies and procedural knowledge are important. Conceptual knowledge requires thorough knowledge of the subject matter. Metacognitive strategies, such as reflection and generalisation, are crucial for developing technological literacy and problem solving skills. Procedural knowledge is necessary to successfully solve design problems within technology education (Garmire & Pearson, 2006).

In science education, according to Rennie et al. (2001), outcomes that focus on scientific literacy are of greatest value to the learner. The Organisation for Economic Cooperation and Developments (OECD) Programme for International Student Assessment (2013, p.127) defines scientific literacy as:

An individual's scientific knowledge and use of that knowledge to identify questions, to acquire new knowledge, to explain scientific phenomena and to draw evidence based conclusions about science-related issues, understanding of the characteristic features of science as a form of human knowledge and enquiry, awareness of how ***science and technology*** *shape our material, intellectual, and cultural environments, and willingness to engage in science-related issues, and with the ideas of science, as a reflective citizen. (emphasis added).*

Stating scientific literacy in this way — targeting it as central to science and technology and seeking to assess learning outcomes for international benchmarking — has implications for the directions education should take. Table 3 outlines a shift in directions for teaching and learning by identifying changes in emphasis in Australian schools, as recommended by Rennie et al. (2001).

Table 3: Scientific literacy teaching requirements

Teaching for Scientific Literacy Requires:

Less emphasis on	More emphasis on
Memorising the name and definitions of scientific terms	Learning broader concepts than can be applied in new situations
Covering many science topics	Studying a few fundamental concepts
theoretical, abstract topics	Content that is meaningful to the student's experience and interest
Presenting science by talk, text and demonstration	Guiding students in active and extended student inquiry
Asking for recitation of acquired knowledge	Providing opportunities for scientific discussion among students
Individuals completing routine assignments	Groups working cooperatively to investigate problems or issues
Activities that demonstrate and verify science content	Open-ended activities that investigate relevant science questions
Providing answers to teacher's questions about content	Communicating the findings of student investigations
Science being interesting for only some students	Science being interesting for all students
Assessing what is easily measured	Assessing learning outcomes that are most valued
Assessing recall of scientific terms and facts	Assessing understanding and its application to new situations, and skills of investigation, data analysis and communication
End-of-topic multiple choice tests for grading and reporting	Ongoing assessment of work and the provision of feedback that assists learning
Learning science mainly from textbooks provided to students.	Learning science actively by seeking understanding from multiple sources of information, including books, the Internet, media reports, discussion and hands-on investigations.

Rennie et al. (2001), p.487

This proposed change in emphasis is broadly consistent with seminal work in primary science education conducted in the New Zealand Learning in Science Project. Drawing on this research, Faire and Cosgrove (1988, p.28) posit that students learn successfully in primary science when they offer their own ideas and can:

- back up those views with evidence
- listen to and consider others' ideas
- seek clarification by probing, challenging or investigating others' viewpoints
- extend, modify or change their views when emerging evidence suggests a need
- ask questions about things that are puzzling
- ask further questions that suggest the development of important ideas and attitudes
- have ideas to assist in investigation
- devise their own investigations
- look for patterns, similarities and differences that may exist in observations
- identify ideas held before and after topics
- give reasons for a change in views or for continuing to hold a view
- explore and investigate beyond the topic and school program
- understand important ideas about their world.

Cumulatively these definitions and factors provide teachers with guidance and focuses, which may be instructive for improving their science and technology teaching practices.

Effective Teachers and Effective Teaching

Although research on effective teachers is contentious, a number of Australian studies have sought to investigate the practices of teachers who are identified as being effective. Practices for identifying effective teachers include identification by colleagues, teachers who are recipients of teaching awards, and/or from analyses indicating that their students are high achieving. The reasoning is that if the teacher is effective then the teaching practices they employ may be effective and worthy of studying. Tobin and Fraser (1990) identify key factors contributing to effective teaching practice in science: the use of efficient management strategies in the classroom, utilisation of strategies and activities that allow the monitoring of student understanding throughout lessons, and encouragement of students to be engaged in their learning.

Only a few studies have focused on effective science teaching practices of primary school teachers. Tytler, Waldrip and Griffiths (2002) examine effective science teaching in a study of 19 primary school teachers. They suggest that effective teachers have strong notions of how and what their students should learn and what their attitudes towards learning should be. These teachers also recognise the individual learning needs of students.

A study conducted by Fitzgerald et al. (2013) suggests six themes representing effective primary science teaching practices. Table 4 presents the six themes together with the factors that characterise teachers' beliefs and practices.

Studies of effective teachers of primary technology in Australia are rare. In their study of primary school teachers, McRobbie et al. (2000) reported that opportunities within the classroom to teach technology were often missed by teachers. This may be related to the newness of the learning area in Australia, which may result in teachers being less expert and adept at its teaching. They also reported that where teachers have deep knowledge of technical concepts and procedures,

Table 4: Effective teaching of science

Theme	Factors for effective practices
Classroom environment	Creating a science-rich/science-friendly environment Creating a positive classroom environment Fostering positive classroom interactions and relationships
Conceptual knowledge and procedural skills	The explicit teaching of science skills and concepts Building students' science knowledge and skills
Teaching strategies and approaches	Using a variety of classroom activities and pedagogies Using hands-on activities Linking science with information and communication technologies (ICT) Using a thematic and/or integrated teaching approach Discussion and questioning as teaching and learning tools Investigations as a teaching and learning tool
Student-specific considerations	Fostering student interest and curiosity in science Understanding and catering for students' needs and interests
Teacher-specific considerations	Developing personal science knowledge Planning and preparation Having confidence in personal science knowledge
Context-specific considerations	Preparing students for future science learning Developing independent learning skills

Fitzgerald et al. (2013)

student learning is likely to be evident (Stein, Ginns & McRobbie, 2000). This finding is supported by Jones and Moreland (2004) who identified that in order to plan, implement and assess quality programs in technology education, teachers need to have specific knowledge of technological practice and of how it is applied. Teacher knowledge of technology in association with appropriate pedagogical approaches is central to enhancing and sustaining learning in technology (Jones & Moreland, 2004).

According to Webster, Campbell and Jane (2006), effective teaching of technology that provides children with opportunities to create solutions requires an interactive process that may involve designing, creating, questioning, discussing, and sharing and testing ideas through hands-on activities and reflection on learning. Fleer and Jane (2011) suggest that pedagogical diversity is important in approaches to design technology education, including emphases or points of entry such as:

- discrete technology using a tightly framed design brief with a teacher-centred perspective
- interactive simulation technology with a child-centred perspective
- values-based technology that is purpose-oriented using a community-centred perspective
- culturally framed technology focusing on cultural aspects of the design, construction, use and analysis of technology.

Effective teaching of technology requires teachers to understand and communicate clear technological learning paths and goals to students. Even with experienced teachers of technology, children can be confused as to what they are supposed to learn (Moreland & Jones, 2000). Consequently, teachers need to understand the technological concepts and procedures and how these are used by society, as well as have practical technology skills (Jones, Milne, Chambers & Forret, 2001).

It is clear from these studies that there is a distinct set of effective practices associated with the teaching of science and technology. A key finding is that teacher effectiveness is underpinned by teacher knowledge of science and technology and pedagogical knowledge. In the next section, we consider what forms this knowledge takes and its implications for teaching and learning.

Teacher Knowledge

Research has shown that the quality of teaching is a key determinant of students' interest in learning and achievement (Darling-Hammond, 2000; Osborne, Simon & Collins, 2003; Pressick-Kilborn, 2015; Rowe, 2003). In science education, the strength of teachers' content knowledge is shown to impact their classroom practices. Teachers with weak content knowledge have been found to teach less science and teach in more traditional ways instead of teaching science that is open-ended and inquiry based (Alake-Tuenter, Biemans, Tobi & Mulder, 2013). A literature review by Rohaan et al. (2010) shows that teacher knowledge of technology affects teaching and subsequent students attitudes and concept development in primary technology education.

However, while teacher knowledge of science and technology, per se, is important, it is not sufficient to ensure quality science and technology education. In order to teach primary science and technology successfully, teachers also require knowledge about the students they teach and an awareness of the students' concepts of science and technology (Appleton, 2013; Davis, Ginns & McRobbie, 2002; Jarvis & Rennie, 1996; Lange, Kleickmann & Moeller, 2010; Mulhall, Berry, & Loughran, 2003). Furthermore, teachers need to be aware of their students' alternative (mis) conceptions pertaining to the particular content being taught.

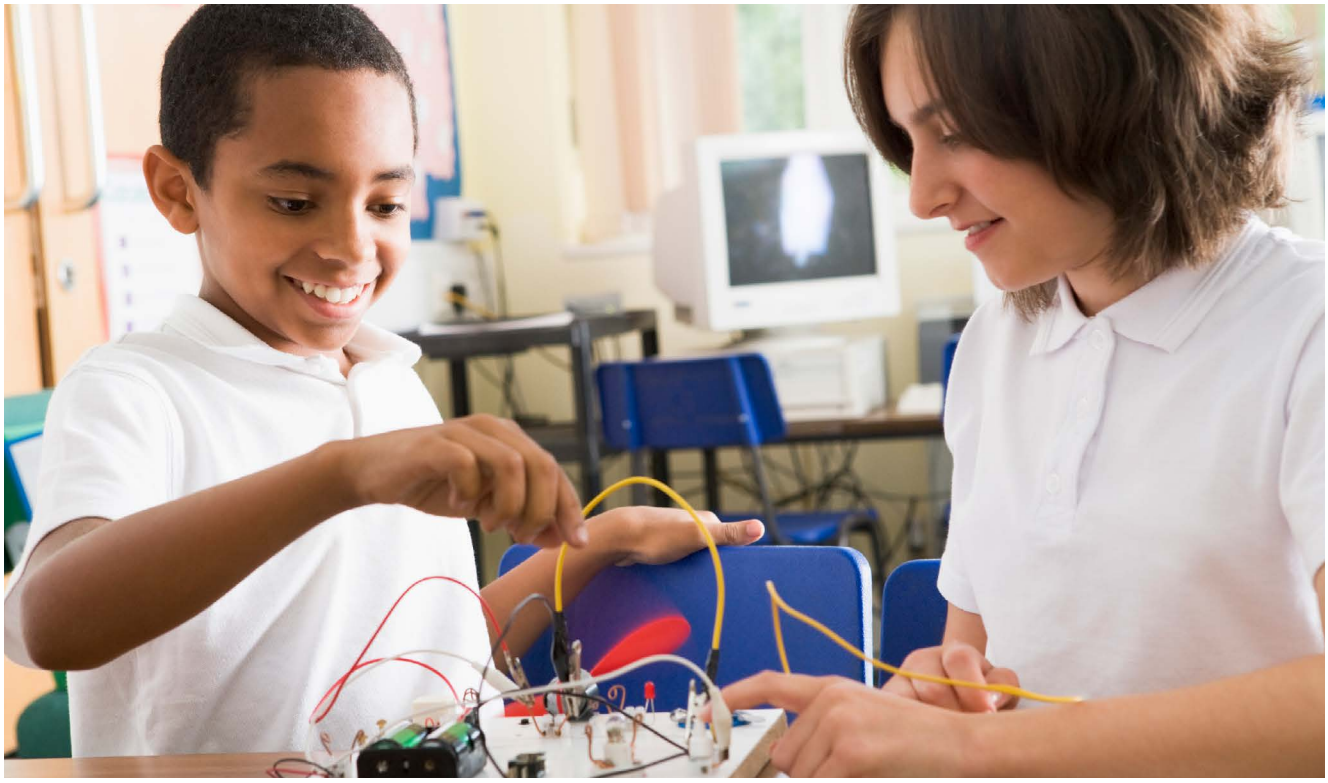
Constructivist learning theory posits that children come into the classroom with worldviews (also called prior knowledge) that they have already constructed in order to make sense of the world around them. When these constructions conflict with the accepted body of scientific knowledge, they are often described as misconceptions or alternative conceptions. Misconceptions have long been considered to be both bridges and barriers to successful learning (Allen, 2014; Pines & West, 1986). They may function as bridges

because they provide a starting point for new learning enabling a connection between what the learner knows and might come to know. However, they can also operate as barriers because students tend not to give up their worldviews easily (Allen, 2014). One means of reconstructing students' misconceptions is through externalising their worldviews, (e.g. through discussion with their teacher and peers). A variety of approaches to science and technology education, derived from social-constructivism (Vygotsky, 1978) depend on making misconceptions explicit in order to render them open to scrutiny through investigation and discussion.

Pedagogical content knowledge (PCK) has become a useful construct to inform analyses of the knowledge required for effective teaching. Literature on science education and technology education indicates that primary teachers' pedagogical content knowledge influences their teaching. Shulman (1986, p.9) describes PCK as embodying:

> *. . . the aspects of content most germane to its teachability. Within the category of pedagogical content knowledge I include, for the most regularly taught topics in one's subject area, the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations — in a word, the ways of representing and formulating the subject that make it comprehensible to others . . . [It] also includes an understanding of what makes the learning of specific concepts easy or difficult: the conceptions and preconceptions that students of different ages and backgrounds bring with them to the learning.*

The concept of PCK embraces the idea that successful teachers have good content knowledge and possess a repertoire of pedagogical strategies that they draw on to teach that content. In science and technology education, for example, these may include the use of inquiry based learning, practical work, group work, cross-curricular activities and appropriate representations of concepts to facilitate learning for students (Prain & Waldrip, 2006; Rohaan et al., 2010; van Driel, Verloop & de Vos, 1998; Wilson & Harris, 2003).



As PCK is unique to each discipline, researchers have built on Shulman's (1986) definition of this to identify components that are discipline specific. Table 5 shows the PCK components identified in the literature for science (Magnusson, Krajcik & Borko, 1999; Park & Oliver, 2008) and the PCK components for technology (Jones & Moreland, 2004; Verloop, Van Driel & Meijer, 2001).

Although worded differently, the components of science PCK and technology PCK correspond with a focus on teachers having:

- knowledge of the curriculum, including purposes and learning outcomes, and content to be taught
- knowledge of pedagogy, including management of the classroom learning environment to best provide for successful learning
- knowledge of assessment of concepts learned or products constructed
- knowledge of students' learning of science and technology
- an understanding of the role of context in the learning activities
- positive attitudes and beliefs, and confidence to teach science and technology.

Table 5: Corresponding components of science PCK and technology PCK

Science PCK	Technology PCK
Knowledge of science curricular	Nature of technology and its characteristics Conceptual, procedural and technical aspects of technology Knowledge of the relevant technology curriculum including goals and objectives as well as specific programs
Knowledge of instructional strategies Knowledge of assessment	Specific teaching and assessment practices of technology (e.g. authentic, holistic, construct reference) Classroom environment and management in relation to technology (e.g. groupings, managing resources, equipment and technical management)
Knowledge of students' understanding of science	Knowledge of student learning in technology including existing technological knowledge, processes, strengths and weaknesses, and progression of student learning
Understanding of the contextual, cultural and social limitations in the learning environment	Understanding the role and place of context in technological problem solving
Attitudes and beliefs about science teaching	Attitudes and confidence in technology teaching
References: Magnusson et al. (1999); Park and Oliver (2008)	References: Jones and Moreland (2004); Verloop et al. (2001)

Attitude and confidence in teaching technology are considered part of the general construct of teacher knowledge (Verloop et al., 2001). Teachers' attitudes towards technology and confidence in teaching it are believed to influence attitudes of their students towards technology. Jones and Moreland (2004) found that enhanced teacher technology PCK was associated with increased student interest and motivation, and improved learning in primary technology education. They noted that teachers' knowledge of the nature and purpose of technology education influenced what teachers highlight to students as important.

A similar assertion, with respect to the effect of teacher's attitude towards science on students' attitudes has also been reported (for example, AAS, 2012; Pell & Jarvis, 2003). A study of pre-service teachers teaching physics in primary schools resulted in the recommendation that teacher education should first focus on forming positive attitudes and then on increasing pre-service teachers' subject knowledge and PCK (Johnston & Ahtee, 2006).

The development of PCK in science and technology is dynamic, where the interaction between content knowledge and pedagogical knowledge is a function of experience (Davis, 2004; Van Driel, Verloop & de Vos, 1998). It means that as teachers learn to teach, they build a PCK that will support their students' learning. Hence mentoring of novice teachers by experienced teachers will assist the novice teachers to develop their PCK for effective science teaching (Hudson, 2004, 2005). Science teachers can construct discipline-specific PCK (e.g. biology or physics), topic-specific PCK (e.g. electricity, energy or food webs) or general PCK that address several content areas in general science. There is evidence to show that novice science teachers tend to build discipline or topic-specific PCK while experienced teachers are able to hold a more general view of PCK (Luft, Firestone, Wong, Ortega, Adams & Bang, 2011). Schneider and Plasman's (2011) literature review on science teachers' learning progression of PCK indicated that it is helpful for teachers to think about their students first and then to focus on teaching — reflection plays an essential role for teachers to rearrange their ideas in ways that develop their PCK effectively.

This overview of PCK serves to highlight that the knowledge needed to teach primary science and technology effectively is complex — it includes discipline-specific PCK and an understanding that teacher PCK influences student learning. While it is clear that science and technology PCK is essential, the extent of, or the minimum, PCK required is not clear.

Studies show that productive science and technology teaching and learning is associated with teachers who have rich science and technology PCK. However, there are cases reported in the literature where teachers have engaged productively in science and technology teaching despite appearing to have modest levels of science and technology PCK (Aubusson, 2001; Hackling & Prain, 2008). Notably, in these instances there have often been highly collaborative colleagues and well-structured resources to support the teaching. While it is clear that PCK is essential, the extent to which this is required by an individual teacher to engage in effective science and technology teaching is context specific. It seems likely that PCK among primary school teachers develops together with their attempts to improve teaching practices. Where primary science and technology teachers collaborate, there may be a collective or team PCK that compensates for relatively low individual PCK. In these circumstances, the collective PCK may facilitate the development of PCK among team members. Thus, an individual teacher's PCK acts as a co-requisite rather than a pre-requisite for initiating improvements in science and technology teaching and learning.

Teacher Self-efficacy

The literature suggests that there are a number of challenges facing primary science and technology teachers. It is therefore not surprising that some may have reservations about how well they are equipped to teach this subject.

Low self-efficacy of teachers in primary school science has been a topic of research for twenty years (Mansfield & Woods McConney, 2012; Palmer, 2011). Teacher self-efficacy is defined as the beliefs teachers' have in their skills to successfully teach students what they are required to learn and that students learn

from their teaching (Tschannen-Moran & Woolfolk Hoy, 2007). Teachers with high self-efficacy are more likely to try new methods in their teaching (Guskey, 1988; Ross, Cousins, & Gadalla, 1996). Teacher self-efficacy influences teachers' motivation, behaviour and practices, and facilitates positive student motivation and achievement (Ashton & Webb, 1986; Bruce, Esmonde, Ross, Dookie & Beatty, 2010; Caprara, Barbaranelli, Steca & Malone, 2006; Skaalvik & Skaalvik, 2007; Wheatley, 2005; Woolfolk & Hoy, 1990).

Teachers do not feel efficacious for all the subjects they teach (Tschannen-Moran & Woolfolk Hoy, 2007). Science teaching in primary school is a particular area in which teachers may feel less capable (Howitt, 2007; Mansfield & Woods McConney, 2012). Many primary teachers in Australia have reported that they lack confidence in teaching primary science (Mulholland, 1999; National Science Standard Committee/Australian Science Teachers' Association, 2002; Rennie et al., 2001).

Identifying the sources of teachers' self-efficacy for teaching science in primary schools is important in understanding how to improve student outcomes in science (Mansfield & Woods McConney, 2012). Four sources of self-efficacy for science teaching have been identified: mastery experiences (or performance attainments), vicarious experiences (comparison with the attainments of others), physiological and affective (emotional) states, and social persuasion. *Mastery experiences* are successful experiences and are arguably the most influential source of self-efficacy. They are indicators of capabilities. *Vicarious experiences* contribute to self-efficacy by positioning teachers to learn from other teachers' accomplishments and demonstrated skills. For example, observing how other teachers teach could influence a teacher's perception of their own competency by comparing skills, knowledge, teaching, and personal attributes. *Social persuasion* influences self-efficacy whereby others can encourage and persuade teachers that they can perform their tasks successfully. Social persuasion influences motivation and persistence, which increases successful teaching outcomes, leading to greater perceptions of capability. *Physiological and affective states* contribute positively to self-efficacy when the individual experiences positive emotions (e.g. joy and increased energy) following a teaching experience. The emotional states reinforce positive views of capabilities. More research, however, is required on these four sources of teacher self-efficacy (e.g. the ways teachers acquire or improve them) (Carleton, Fitch, & Krockover, 2008) and how these sources operate in practice (Klassen, Tze, Betts & Gordon, 2011).

CONTEXTUAL FACTORS

In addition to teacher quality, the literature suggests that that the capacity to provide effective science and technology education is also influenced by the school environment. School based factors such as inadequate resources and time may operate as barriers to effective science and technology teaching (ATSE, 2002; Goodrum et al., 2001; NRC, 2011; Victorian Auditor-General, 2012). Factors most frequently cited as limiting the quality of science teaching in primary schools include: a lack of resources and equipment, inadequate time for preparing to teach science, the teacher's lack of background knowledge in science, time constraints resulting from a crowded curriculum, and lack of, or poor access to, science professional development (Rennie, Goodrum, & Hackling, 2001).

Similar school based barriers were reported in a study of primary teaching of technology in the Netherlands, where teachers cited a lack of materials, the time and effort required, a lack of support and inadequate availability of ICT in their classrooms (van Cuijck, van Keulen, & Jochems, n.d.). In Britain, where design and technology has been a part of primary education for many years, some schools have attempted to eliminate the challenges presented by design tasks through integration with other subjects, such as visual arts. This has resulted in the scope of design opportunities being limited (Barnes, Sayers, & Morley, 2002). According to Tytler (2010), there are factors that exist within schools that are associated with a reluctance to support primary science and technology including: an aversion to the mess associated with many activities, lacking the time required to prepare science and technology activities, and school cultures that frown upon noise and disruption associated with practical investigations.

Aubusson and Griffin (2011) found that teachers themselves report low levels of science and technology capability in their schools on eight measures as outlined in Table 6.

The implication of findings from these studies is that if schools are seeking to promote effective science and technology teaching, then a whole school approach is required. Investing in whole school change requires leadership to promote science and technology within the school and to effectively manage cultural change.

This may require:

- emphasising the importance of science and technology education in the school program
- promoting more positive perceptions of messy and noisy activities
- ensuring adequate organisation and availability of materials for science and technology activities
- promoting collegial networks to support primary science and technology teaching
- making time or additional support staff available to plan and prepare for science and technology.

The role of school leadership in promoting school improvement, school change management and approaches to teacher professional learning are beyond the scope of this literature review. These factors are an integral part of a coherent process to enhance primary science and technology education.

Table 6: School science and technology capability

Percentage of teachers agreeing that teachers in their school:	
Have the opportunity to do professional learning in science and technology	58%
Have collegial support for science and technology	56%
Do good activities in science and technology	46%
Understand the Science and Technology syllabus	43%
Have knowledge of effective strategies in science and technology	33%
Have a good background in science and technology	30%

Percentage of teachers agreeing that their school:	
Has facilities and resources to promote teaching of science and technology	45%
Regards science and technology as important	53%

Aubusson & Griffin (2011)

MODELS AND APPROACHES FOR TEACHING AND LEARNING FOR SCIENCE AND TECHNOLOGY

INQUIRY BASED LEARNING

Science and technology knowledge is embedded in the representations it uses and develops. Science and technology teaching and learning engages with and uses and builds capacity with, and through, representations.

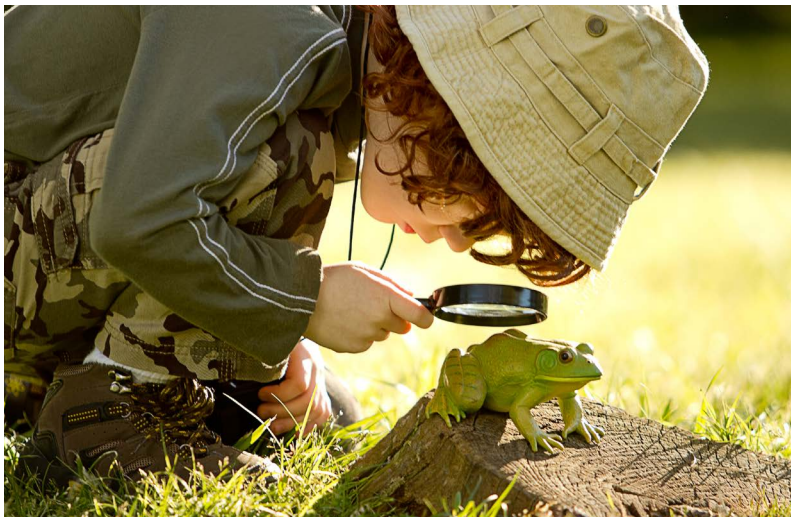
Research literature on effective pedagogy in technology education at the primary school level is less comprehensive than that for science education. This section will discuss models and approaches appropriated for teaching and learning in an integrated primary science and technology curriculum.

It has been argued that the teaching and learning of science must centre on inquiry. Inquiry based learning requires students to be provided with meaningful learning opportunities that are challenging and authentic. These allow students to develop a deep understanding and ownership of their understandings (Fitzgerald, 2013). Goodrum et al. (2001, p.467) describe inquiry as:

Students investigate, construct and test ideas and explanations about the natural world. Inquiry approaches expose students to the nature of science and the scientific enterprise, and provide an effective approach to meaningful learning, which is grounded in personal experience of natural phenomena and engagement in the learning process. Experimental investigation is central to the pursuit of science and the learning of science. Minds-on, as well as hands-on, practical work is an essential component of the science curriculum.

Inquiry based learning focuses on questioning, critical thinking and problem solving where evidence from investigative questioning is gathered and possible explanations considered (Marshall, Horton, Igo & Switzer, 2009; Savery, 2006; Supovitz, Mayer, & Kahle, 2000). Processes that involve inquiry pedagogy are observing, posing questions, researching for information to see what is already known and what evidence exists to support it, designing and planning investigations, using appropriate equipment to gather evidence and interpret data, and explaining and communicating results. In design based learning, skills and processes parallel to inquiry based learning are also essential.

According to Fleer and Jane (2011), inquiry in design and technology teaching has been found to support student creativity, allowing for a diversity of artefacts to be produced and creating a high level of technological learning. However, they argue that the nature of teacher interactions required to support this learning is not clear and further research is suggested. McCormick and Banks (2006) propose that the methods of best practice for science and technology are similar. Both enable hands-on learning, support problem solving and project based learning, and offer authentic learning enabling students to see relevant aspects of their lives connected with science and technology learning. Inquiry based teaching and learning recognises that knowledge construction is complex and interconnected. It permits teachers and students to collaboratively build a deep understanding of science and technology concepts and techniques.



TEACHING MODELS AND APPROACHES

Five models1 or approaches for primary science and technology teaching and learning are outlined below. An explanation as to why these particular models have been selected, as well as general comments about their orientation and use, are provided.

According to Dawson and Venville (2007), there have been a number of teaching models used in Australia to organise science lessons effectively. They suggest three models that have influenced science teaching in Australia: the 5Es Instructional Model, the Generative Learning Model and the Learners' Questions Model (also known as the Interactive Model). They are pedagogical models rather than detailed models of science processes (outlining for example, planning, investigating, experimenting, generalising) or technology processes (outlining for example, identifying need, clarifying task, creating solutions).

These models have been selected because they have the potential to inform the design of effective learning programs and lesson sequences in science and technology. They provide a set of teaching/learning phases that is not necessarily intended to be completed in a single lesson.

A fourth model, a description of effective science and technology teaching, was developed through the Science in School (SIS) Project (Tytler, 2001). The SIS model is arguably a next-generation approach in that it builds on the three models identified above but extends them by stressing the connections with communities, relevant contexts and the use of digital technologies. The SIS model differs from earlier models in that it moves away from an emphasis on individual teachers towards an emphasis on the whole school (or at least groups of teachers) in promoting effective teaching and learning.

A fifth, more recent, model, Representational Intensive Pedagogy, is also included. It has recently been shown to contribute to student learning in science (Tytler, Prain, Hubber & Waldrip, 2013) but is less demonstrably adaptable than the other models to the teaching of technology. It is included because it is a recent culmination of much research into many teaching approaches, including studies in primary schools. It represents a significant shift in thinking about learning and teaching in science with its emphasis on multimodality.

All models are consistent with the inquiry approach, although they vary markedly in their philosophical and theoretical underpinnings. All models selected have been the subject of research in primary schools. For each model, we have chosen to draw predominantly on the work of those who originally proposed each model.

The models are usually associated with different degrees of structure in the learning sequence and different degrees of predictability in terms of the learning outcomes. Effective teaching is related to the effective framing of questions as either open (unspecified) or closed (well specified). Fleer and Jane (2011) report that when students were involved in open-ended technology projects, there were evident conceptual and procedural knowledge gains. Although open questions may lead to more creative outcomes for children, both question types are important (Järvinen & Twyford, 2000). Questioning must be appropriately challenging, engaging and stimulating peer discussion while encouraging students to explore and refine their understandings.

The five models outlined promote questioning and discussion and it is worth noting that the types of questions asked is important in the effective teaching of science and technology. Given the need for both open and closed learning experiences, models that promote both open and closed inquiry have been selected. For example, the 5Es Instructional Model is often manifested as a set of teaching learning activities that have been designed and set out in advance. It is a relatively closed and predictable form of inquiry. By contrast, the Learners' Questions Model is more open-ended and responsive to the varied questions that students might raise and requires the overarching lesson sequence to be modified iteratively in response to students' needs.

None of the models presented here supposes that learners will discover science and technology principles,

1 For ease of communication, the general term model will be used when both models and approaches are being referred to in this section.

concepts, practices, skills or processes that have taken the best minds in the world hundreds or even thousands of years to work out. All require explicit explanation at different stages of the teaching and learning process and require the teacher to either possess necessary knowledge to facilitate explanation in advance (e.g. 5Es) or to develop knowledge as the teaching and learning sequence progresses (e.g. Learners' Questions).

These models should not always be routinely followed in all teaching of primary science and technology. Teachers make professional judgements about which model to use, when to use it, and how to modify it according to the context. Using the same model repeatedly may be less productive than drawing on different models for different topics across different grades. Finally, each of the models provides extensive cycles of learning. While each is applicable across all levels of primary school, the extent to which teaching progresses through phases of the inquiry model may vary according to grade, topic and students' engagement in learning.

5Es Instructional Model

The 5Es Instructional Model is a widely applied research based learning cycle based on learning progression through five phases: Engage, Explore, Explain, Elaborate and Evaluate (Bybee, 2014). Each phase has specific purposes. The 5Es model of inquiry based learning recognises that students need time and opportunities to develop concepts and abilities. Table 7 shows the summary of the 5Es Instructional Model presented in Bybee (2014) and appropriate activities for each stage as outlined by Fitzgerald (2013).

According to Bybee (2014), the 5Es model is most effective if used for a two to three week unit of learning where one or more lessons are based on each phase. The exception is the engage phase, which could be less than one lesson. Using the 5Es model as the basis for a single lesson is not recommended as it shortens the time for effective learning. There are insufficient opportunities for challenging and restructuring the concepts and abilities developed. It is also not recommended to use the model over an extended period as each phase loses its effectiveness if prolonged.

Bybee (2014) suggests that formative assessment should be utilised continuously during the implementation of the 5Es but stresses that there is a need for summative evaluation at the end of the unit. The 5Es model informed the design of Primary Investigations and Primary Connections. Studies of these programs have indicated that the approach may contribute positively to primary science and technology teaching and learning (e.g. Aubusson & Steele, 2002; Hackling & Prain, 2008).

Table 7: 5Es Instructional Model summary and activities

Objective	Appropriate Activities
Engagement The teacher or a curriculum task helps students become engaged in a new concept through the use of short activities that promote curiosity and elicit prior knowledge. The activity should enable students to make connections between past and present learning experiences, expose prior conceptions and organise thinking toward the learning outcomes of current activities.	Student representations Concept maps and cartoons Discussions POE (Predict, Observe, Explain) Word wall (word display)
Exploration Exploration experiences provide students with a common base of activities within which current concepts (i.e. misconceptions), processes and skills are identified and conceptual change is facilitated. Learners may complete activities that help them use prior knowledge to generate new ideas, explore questions, and design and conduct an investigation.	Investigations Research Field trips Collecting samples
Explanation This phase focuses students' attention on a particular aspect of their engagement and exploration experiences and provides opportunities to demonstrate their conceptual understanding, process skills or behaviours. In this phase, teachers directly introduce a concept, process or skill. An explanation from the teacher or other resources may guide learners toward a deeper understanding, which is a critical part of this phase.	Teacher explanation Peer explanation Role plays Presentation by expert
Elaboration Teachers challenge and extend students' conceptual understanding and skills. Through new experiences, the students develop deeper and broader understandings, more information and adequate skills. Students apply their understanding of the concept and develop abilities by conducting additional activities.	Open-ended discussions Data analysis to find patterns Research Create models
Evaluation The evaluation phase encourages students to assess their understanding and abilities and allows teachers to evaluate student progress toward achieving the learning outcomes.	Science journal entries Posters Presentations Tests

Bybee (2014); Fitzgerald (2013)

Generative Learning Model

According to Osborne and Wittrock (1985), the fundamental premise of generative learning is that perceptions and meanings consistent with their prior learning are generated by students. This means that teaching needs to encourage learners to generate firm links between constructed meanings and their existing knowledge. Such links allow students to be able to retain ideas in memory more successfully.

This model proposes three distinct teaching phases as outlined by Osborne and Freberg (1985):

1. *Focus:* the teacher establishes a context within which the new concept is to be explored. This phase creates student motivation and interest. Students' ideas are clarified.
2. *Challenge:* students' ideas are challenged and compared with scientific viewpoints.
3. *Application:* student discussion and analysis allows the ideas generated to be applied to new situations and problems.

The generative learning model is relatively general in its description. More detailed teaching approaches with similar philosophical positions and research bases have been developed. These are sometimes collectively called interactive models or interactive teaching approaches. One such approach is the Learners' Questions Model.

Learners' Questions[2] Model (also known as the Interactive Model)

Effective science and technology teaching also involves providing learning conditions that encourage children to ask and investigate questions (Faire & Cosgrove, 1988). The Learners' Questions Model is an amplification of interactive teaching that involves a series of connected steps within which the teachers' roles are as a resource person, motivator, challenger and developer of the learners' ideas, and a communicator of different ideas. Most importantly, the teacher is a model learner. Variations on the Learners' Questions Model are available. The version presented in Figure 2 is in its original form (Faire & Cosgrove, 1988, p.16).

2 The term 'Learners' Questions Model' is used here because it is the term Cosgrove preferred to use to describe this approach.

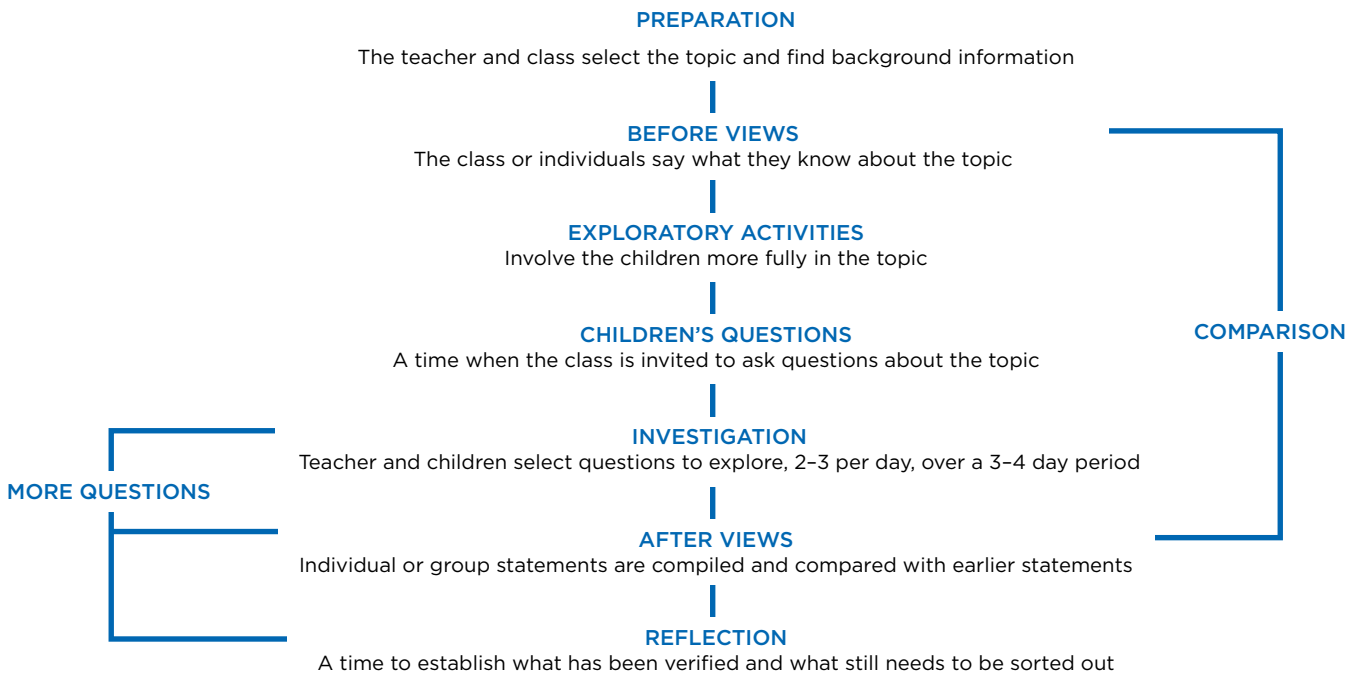


Figure 2: A sequence for interactive learning

Assessment in the Learners' Questions Model is aimed at helping teachers decide whether a student has progressed intellectually, not that the student has reached a pre-determined level of knowledge. Student evaluation should therefore be developmental in that the criteria evaluated represent an ideal but attainable state towards which students will move at different rates. The assessment within this model should be continuous, observation based, reflective of the program offered, occurring during learning activities and based on criteria (Faire & Cosgrove, 1988).

Schaverien and Cosgrove (1997) reported that teachers using the Learners' Questions Model were able to shift from more didactic to more generative approaches to teaching science and technology. Students learned as they proposed, tested and modified ideas in an ongoing cycle where each new idea was subjected to further scrutiny until a defensible explanation for phenomena under study was established. Schaverien and Cosgrove (1997) argued that the Learners' Questions Model assisted teachers to teach in in ways they had previously felt ill equipped to adopt. They also reasoned that the Learners' Questions Model aligned teaching with children's natural ways of learning (Schaverien & Cosgrove, 2000). Consequently, the Learners' Questions Model is particularly well suited to facilitating learning among primary school children. It is noteworthy that in studies of teachers employing this approach, teachers have typically been extensively supported by researchers as part of intervention studies. Less is known about the use of the Learners' Questions Model in less highly supported circumstances.

Science in Schools (SIS) Model

As part of a large Victorian Government funded project to improve science education, Tytler (2001) developed and validated a description of the characteristics of effective science teaching. Tytler (2010) noted implications of the model specifically for the development of primary science teaching and learning. As noted previously, this model extends and builds on the other models described by foregrounding contexts and connecting teaching and learning authentically to local communities.

The SIS components of effective teaching and learning in science are the following:

1. *Students are encouraged to actively engage with ideas and evidence.* Students express their ideas and question evidence in investigations and in public science issues. Their input influences the course of lessons. They are encouraged and supported to take responsibility for science investigations and their own learning.

2. *Students are challenged to develop meaningful understandings.* Students are supported to develop deeper understandings of major science ideas and to connect and extend ideas across lessons and contexts. They are challenged to develop higher order thinking in solving science based problems.

3. *Science is linked with students' lives and interests.* Student interests and concerns are acknowledged in framing learning sequences. Links between students' interests, science knowledge and the real world are constantly emphasised.

4. *Students' individual learning needs and preferences are catered for.* Strategies are used to monitor and respond to students' different learning needs and preferences and their social and personal needs. There is a focused and sympathetic response to the range of ideas, interests and abilities of students.

5. *Assessment is embedded.* Monitoring of student learning is varied and continuous, focuses on significant science understandings and contributes to planning at a number of levels. Various types of assessment tasks are used to reflect different aspects of science and understanding.

6. *The nature of science is represented in its different aspects.* Science is presented as a significant human enterprise with varied investigative traditions and constantly evolving understandings that also has important social, personal and technological dimensions. The successes and limitations of science are acknowledged and discussed.

7. *The classroom is linked with the broader community.* A variety of links are made between the classroom program and the local and broader community. These links emphasise the broad relevance and social and cultural implications of science, and frame the learning of science within a wider setting.

8. *Learning technologies are exploited for their learning potentialities.* Learning technologies are used strategically for increasing the effectiveness of, and student control over, learning in science. Students use information and communications technology in a variety of ways that reflect their use by professional scientists (Tytler, 2001, 2011).

The SIS project included both primary and secondary schools. Key developments in primary schools resulting from the Science in Schools project, reported by Tytler (2009), included that schools reviewed their school science curriculum, wrote new science based units and embedded SIS components into science activities. Schools built up and provided better access to resources to support activities and initiated special events, such as family science nights or science clubs or camps. According to Tytler (2009), outcomes for primary schools included an increased profile for science in the school, a more coherent presentation of the nature of science, improved attitudes towards and confidence to teach science among teachers, and the use of more exploratory approaches to teaching and learning.

Representational Intensive Pedagogy

There is growing evidence that encouraging students to demonstrate their understanding using multiple modes of representation assists with conceptual development (AAS, 2012; Aubusson, Treagust, & Harrison, 2009; Prain, Tytler, & Peterson, 2007; Tytler, 2010). Teachers can scaffold learning by using multiple modes of representation, and students learn when they are encouraged to create and defend their own representations of ideas. Modes are generally classified, for the purposes of learning science, as descriptive (written, verbal, graphic, tabular), experimental (demonstration, fair test investigation), mathematical, figurative (symbolic, pictorial, analogous, metaphoric) and kinaesthetic (gesture, physical action) (Tytler, Prain & Peterson, 2007). Given that students require three or four experiences with a concept to establish long-term knowledge, recoding representations in multiple modes allows students to refine their ideas and make them more explicit (Prain & Waldrip, 2006). In order to develop an understanding of science, students need to learn how to interpret, integrate and reproduce multi-modal representations both within and across topics (Tytler et al., 2007). Different modalities (e.g. text, tables and diagrams) can be used within a representation to explain the concept being studied. The same modality can also be used in multiple representations (e.g. written text or an illustration) or a role play may be used in re-representing a concept of interest. Such expressions of meaning in different modes are distinct from simply replicating or illustrating concepts and help students create meanings (Kress, 2009) that are deeper.

Tytler et al. (2013) suggest that the principles that underpin a representational approach to teaching and learning are the following.

1. ***Teaching sequences are based on sequences of representational challenges:*** students construct representations to actively explore and make claims about phenomena.

    a. *Teachers clarify the representational resources underpinning key concepts:* teachers need to clearly identify big ideas, key concepts and their representations at the planning stage of a topic in order to guide refinement of representational work.

    b. *A representational need is established:* students are supported, through exploration, to identify the problematic nature of phenomena and the need for explanatory representation before the introduction of recognised forms.

    c. *Students are supported to coordinate representations:* students are challenged and supported to coordinate representations across modes to develop explanations and solve problems.

d. *There is a process of alignment of student constructed and recognised representations:* there is interplay between teacher-introduced and student-constructed representations where students are challenged and supported to refine, extend and coordinate their understandings.

2. ***Representations are explicitly discussed:*** The teacher plays multiple roles, scaffolding the discussion to critique and support student representation construction in a shared classroom process. Features of this meta-representational discussion includes the following.

   a. *The selective purpose of any representation:* students need to understand that multiple representations are needed to work with aspects of a concept.

   b. *Group agreement on generative representations:* students critique representations for their clarity, comprehensiveness and explanatory persuasiveness to aim at a resolution, in a guided process.

   c. *Form and function:* there is explicit focus on representational function and form, with timely clarification of parts and their purposes.

   d. *The adequacy of representations:* students and teachers engage in a process of ongoing assessment of the coherence and persuasiveness of student representations.

3. ***Meaningful learning involves representational/ perceptual mapping:*** students experience strong perceptual/experiential contexts, encouraging constant two-way mapping/reasoning between observable features of objects, potential inferences and representations.

4. ***Formative and summative assessment is ongoing:*** students and teachers are involved in a continuous, embedded process of assessing the adequacy, and their coordination, in explanatory accounts.

When considering enabling students to construct their own representations, it is important to provide children with a range of resources to enable them to make appropriate choices (Davies et al., 2014). Fleer (2000), for example, found that children as young as three years old were able to use verbal (oral) and visual representations for planning as part of the process of making things in technology learning. Furthermore, as children become increasingly familiar with digital technologies, it is useful to facilitate their use for creative generative purposes, including students constructing their own representations. Brown, Mercia and Hackling (2013) suggest that in order for these technology based modalities to be successful, four principles of practice are required in the classroom:

1. intentional pedagogy that purposefully uses the technologies
2. collaborative learning
3. discussion supported by clear ground rules
4. teachers identifying and exploiting teachable moments that allow the explicit teaching of science principles.

A discussion of the role of digital technologies is beyond the scope of this review, but we note that as digital technology is an integral part of children's lives, using digital technology to communicate meaning is a valuable mode of expression that contributes to learning (Davies et al., 2014; Ng, 2012). Rich learning experiences can be afforded by using contemporary technologies such as interactive whiteboards, slowmation, graphic tables and mobile phones to create multimodal representations (Brown et al., 2013; Hoban & Nielsen, 2012; Kearney, Pressick-Kilborn, & Aubusson, 2015).

CONCLUSION

The question is not so much what might good science and technology learning look like ... but rather, how might we achieve it?

In conclusion, it is accepted that the teacher's influence on students' learning is critical (AAS, 2012; Darling-Hammond, 2000; Osborne et al., 2003; Pressick-Kilborn, 2015; Rowe, 2003; Tytler, 2007). However, it is difficult to describe the nature of effective teaching in a few sentences (AAS, 2012). This is due, in part, to the fact that describing quality teaching is dependent on its context, and context has "multifarious interpretations" (AAS, 2012, p.144). Context characteristics, some of which have been discussed to varying degrees in this literature review, include the nature of the curriculum to be taught, teacher pedagogical content knowledge, teacher self-efficacy and students' prior knowledge and contexts, as well as school support and general science and technology capability (such as availability of resources, amount of dedicated science and technology time and professional development opportunities).

Recent research has indicated that particular pedagogical content knowledge is required to teach science and technology effectively. This includes:

- knowledge of the curriculum, including purposes and learning outcomes, and content to be taught
- knowledge of pedagogy, including management of the classroom learning environment to best provide for successful learning
- knowledge of assessment of concepts learned or products constructed
- knowledge of students' learning of science and technology
- an understanding of the role of context in the learning activities
- positive attitudes and beliefs, and confidence to teach science and technology.

High levels of science and technology pedagogical knowledge are associated with effective teachers of science and technology, but an essential or minimum required pedagogical content knowledge has not been empirically determined.

Research investigating effective primary science and technology has taken four general forms: observational studies of primary classes, targeted observation of teachers who have been identified in some way as being effective, intervention studies trialling specific strategies and approaches, and studies with teachers to validate components of effective teaching based on literature. A fifth form of study involving meta analysis of many data sets has also been used to identify effective teaching practice (e.g. Hattie, 2012) but no such study of primary science and technology was found during the undertaking of this literature review.

A number of well researched models have been presented in this review including the 5Es Instructional Model, the Generative Learning Model, the Learners' Questions Model, the Science in Schools (SIS) Model and the Representational Intensive Pedagogy. These models should not necessarily be combined nor any of them be used exclusively as they vary in the extent to which they promote open and closed inquiry and design. Effective teaching would ensure that primary students experience learning with a range of models across the open-closed continuum. Features that characterise quality teaching and learning in primary science, as suggested in this review, are the following.

FEATURES THAT CHARACTERISE QUALITY SCIENCE AND TECHNOLOGY TEACHING AND LEARNING

- foregrounding student inquiry
- finding starter activities that arouse and engage students in investigations
- identifying real needs or problems and seeking or building solutions
- promoting student questioning
- exploring ideas, developing designs, creating products
- sharing and subjecting designs and ideas to scrutiny through evidence based discussions and in trial by experiment
- failing and trying again
- looking up information and finding out what is already known, engaging in authentic activities
- connecting to students' life experiences
- displaying and presenting products of learning and design
- using formative assessment to diagnose needs and inform iterative changes to planned learning sequences
- students creating and analysing their own representations and analysing standard technological and scientific representations
- exploiting teachable moments for explicit teaching of science and technology principles, skills and processes
- employing summative assessment to gather evidence of learning achievements
- using a variety of strategies to communicate ideas with a range of audiences
- using digital technologies to enhance learning and, where possible, connecting learning experiences with local communities
- connecting learning experiences with local communities.

These elements are most likely to be effective when applied by a teacher with sound science and technology pedagogical content knowledge. They are more likely to occur when promoted by effective school leadership that places an emphasis on collaborative teams to build capacity throughout a primary school to improve science and technology teaching and learning.

The list is neither comprehensive nor sequential. It is not intended to be a substitute for the models outlined in this review nor is it suggested that all elements would feature in the teaching of all topics. It is neither a checklist nor a formula for teaching practice. Rather, teachers may draw upon this list of elements of effective science and technology teaching to inform what they do. The decision about what to do should be based on teachers' professional judgement and decisions on what is most worthwhile for their students' learning at a particular time including which elements to employ under particular circumstances to achieve student learning outcomes in particular topics with particular children.

Themes that arise from this review suggest that experts in science and technology education, as well as generalist primary teachers themselves, express concerns about the teaching and learning of primary science and technology. There is general agreement on the types of approaches to teaching primary science and technology that contribute to productive learning. However, implementing these appears to remain challenging in some school settings. There is considerable variation in the quality of teaching in primary science and technology. In some instances little science and technology is taught; in others it is taught in limited ways; in others rich learning experiences are provided by teachers for students.

Key questions that arise from this review include:

- What influences variations in the quality of learning and teaching of primary science and technology?
- What choices do teachers make that impact on the science and technology experiences that are provided for learners?
- How might these decisions be influenced to enhance primary science and technology?

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