

Elementary Science Literature Review

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For:

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This literature and research review was conducted to provide information to guide future work on elementary science in Alberta. Although direction was given to the researchers/writers to establish parameters for the task, the content of this document reflects the writers' perspectives on topics and subjects reviewed and does not necessarily reflect the position of Alberta Education.

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Executive Summary

In this report, we present a literature review of elementary science (see Glossary of Terms) and design technology (see Glossary of Terms) education research. The review is intended to provide direction to the elementary science working groups charged with the responsibility to revise the *Alberta Elementary Science Program* (1996) by reflecting current ideas reported in research literature.

The review included journals (primarily from the years 2000–2006) that contained information about K–6 science education, K–6 design technology education, Aboriginal science education and K–6 French language science education. This range of journals reflected the current *Alberta Elementary Science Program* (1996) emphasis on science inquiry and problem solving through technology and a wish to take an inclusive approach to designing the new program.

Meetings by the Literature Review Team resulted in identifying the research themes listed below. These themes reflected the main strands of research presented in the literature and were subsequently used to provide the framework for the analysis presented in this document.

- The Nature of Science, the Nature of Technology, and Science/Technology/Society (Environment)
- Children’s Learning
- Science as Inquiry
- Design Technology Problem Solving
- Teacher Knowledge
- Teacher Practices: Instruction and Assessment
- Teaching Science in Diverse Contexts, Including Aboriginal Contexts
- Teaching Science in French Language Classrooms
- Integrating Computer Technology
- Research Related to the *Alberta Elementary Science Program* (1996)
- Designing Science Programs

The literature review concludes with a section entitled “A Vision for the Future.” In this section, we provide a summary list of well-supported ideas that have the potential to influence elementary science programs in Alberta for years to come. As with all ideas presented in the literature, complete consensus among researchers does not exist. However, these ideas are those that enjoy considerable support and should be given due consideration by those responsible for the Alberta program revision.

Introduction

An international community of science education leaders and researchers from the United States, Canada, Britain, Australia, New Zealand and other countries actively shares ideas about what science to teach children, how to teach children and any number of other current science issues and trends. Members of this community regularly read each other's books, research reports and curriculum documents and use this information to inform their own science programs. A case in point is the international trend toward formulating national science content standards that can be used to guide the development of school science programs.

In Canada, an important study by the Science Council of Canada (1984) on the state of Canadian science education has influenced the development of a standards document that outlines a common framework of science learning outcomes (Council of Ministers of Education, 1997). Science standards have also been outlined in the National Curriculum in Britain and in curriculum documents in Australia, New Zealand and the United States. American science educators have been particularly active in writing standards documents (e.g., *Science for All Americans*, Rutherford and Ahlgren, 1989; *National Science Education Standards*, National Research Council, 1996; *Standards for Technological Literacy*, International Technology Education Association, 2000) that contain ideas about what science should be taught, how it should be taught, and why ideas about scientific literacy and technological literacy are now seen as important goals for science programs.

The term *scientific literacy* has been subject to various definitions, but the one common thread is that it implies a broad and functional understanding of science for general education purposes rather than preparation for specific scientific and technical careers. Scientific literacy defines what the public should know about science in order to live more effectively with respect to the natural world (DeBoer, 2000).

The term *technological literacy* bears resemblance to scientific literacy in that it involves understanding technology to the extent that people can make informed decisions and live more effectively with respect to the manufactured world (ITEA, 2000).

Researchers recognize that many of the crucial issues that face our society demand solutions that are informed by both science and technology – that is, they require thoughtful debate by people who are both scientifically and technologically literate. As Osborne, Erduran and Simon (2004) observe, we live in a society in which scientific issues are increasingly dominating the cultural landscape. Recognition of the interdependency of science and technology and the inevitable role society plays in influencing and being influenced by science and technology, has led various researchers to speculate about what authentic learning experiences for children might look like, and why programs should feature opportunities for children to understand science/technology/society (STS) interconnections.

Against this background comes the review of literature contained in this report. The review includes six sections. In the first section, we provide a general overview of past trends in science education that have influenced Alberta elementary science programs and briefly discuss guiding ideas that continue in many current programs. Following this, we feature a section that provides a brief discussion of the methodology used to guide the literature review. Literature review outcomes are then organized according to the eleven themes listed in the Executive Summary. The review concludes with a Vision for the Future intended to provide a concise summary of important ideas. We have also included a Glossary of Terms for those interested in how various terms are defined in the literature and a Bibliography listing all extracted documents.

Past Trends

In his review of science curriculum reforms, Hurd (2002) observed that nothing much has changed despite the contexts of science and technology undergoing fundamental change. Science programs continue to feature an inquiry approach to teaching children science; frameworks of concepts (see Glossary of Terms), skills (see Glossary of Terms) and attitudes (see Glossary of Terms); and information about how children learn. These ideas have endured because they are good ideas that provide teachers with guidance about teaching practice.

Science as inquiry has a long history in science education. Here are a few milestones:

1910: John Dewey writes about the importance of inquiry science.

1927: Gerald Craig writes about the importance of teaching science through investigations.

1947: Natural Sciences and Science Education (NSSE) Yearbook endorses science programs based on features that include problem-solving skills.

1960s: Major revision of science education occurs through development of new science curricula that emphasize inquiry approaches (ESS [Elementary Science Study], SAPA [Science–A Process Approach], SCIS [Science Curriculum Improvement Study]).

1970s: Science educators question effectiveness of “extreme” version of discovery science, i.e., minimal teacher intervention.

1980s: Growing interest in the nature of science, including its implications for how authentic inquiry can be carried out in science classrooms.

1990s: Domination of constructivist (see Glossary of Terms) learning theory, including emphasis on importance of children’s existing ideas and how they affect what is learned during scientific inquiry.

2000: Shift in emphasis in classroom scientific inquiry from a focus on “science processes” to a focus on evidence, explanation and current scientific knowledge.

(Note: A more detailed history of the inquiry approach can be found in Pine et al., 2006).

These milestones have had an ongoing impact on Alberta elementary science programs (Kamal, 2006). What program writers need to consider further is the extent to which science and technology are now part of our economic, social and political life (Hurd, 2002). Hurd (2002) suggests that a way to modernize science programs is to think about how we can help students to transform science information into a working knowledge that can be used in personal and civic contexts. What is sought, he argues, is a lived curriculum for all K–12 students.

Methodology

The literature review methodology is based on the best-evidence approach, which provides a balance between haphazard selection and exhaustive inclusion (Alton-Lee, 2004; Slavin, 1986, 1987; Slavin & Letyel, 1995). Use of the best-evidence approach logically points toward a synthesis of design along the following lines:

- Developing valid a priori inclusion criteria (e.g., identifying the leading peer-reviewed science education journals and using these as the main source for the literature review).
- Including references to international standards documents.
- Including research written on the *Alberta Elementary Science Program* (1996) regardless of journal source.
- Keeping full and accurate bibliographic records.
- Classifying findings under key headings.
- Writing up a clear, concise, readable review that allows readers to reach their own conclusions (e.g., introduction, main body consisting of information and discussion about the studies reviewed, and conclusion that brings the findings of the different studies together).

Specific journals were selected through consulting lists of highly regarded journals found in the *Journal Citation Reports* and by the Literature Review Team, using their collective knowledge about the field. A summary of the journals consulted and the number of articles reviewed is located in Appendix A. A list of the 224 articles extracted for this review is found in the Bibliography. In addition, Appendix B includes a supplementary bibliography of articles in French.

Outcomes

The Nature of Science, the Nature of Technology, and Science/Technology/Society (Environment)

Considerable research has been devoted to identifying current ideas about the nature or character of science and exploring how these ideas might best be taught to students (Abd-El-Khalick & Lederman, 2000; Aikenhead & Ryan, 1992; Lederman, 1992; McComas, Clough & Almazroa, 2000 – all in Sadler, 2004). Acting as a catalyst to this research is the view that an individual's understanding of the nature of science inevitably affects his or her interpretation of scientific knowledge and influences the manner in which he or she responds to scientific claims and socio-scientific issues (Sadler, 2004).

Current ideas about the nature of science often presented in research literature include:

- Some scientific knowledge is relatively stable and durable whereas less substantiated scientific knowledge is tentative and subject to change (Hanson & Akerson, 2006; Sadler, 2004).
- Science relies on empirical evidence (Hanson & Akerson, 2006; MacDonald & Gustafson, 2006; Sadler, 2004).

- Scientists employ creativity, imagination and their existing ideas about the question to obtain and interpret evidence (Hanson & Akerson, 2006; Sadler, 2006).
- Scientific research and cultural norms mutually shape one another (Sadler, 2004).
- The pursuit of scientific progress often encounters or creates ethical and moral dilemmas (Sadler, 2004).
- While scientists generally agree on what constitutes a valid investigation, there is no fixed method or set of steps that are always followed (MacDonald & Gustafson, 2006).
- The validity of scientific claims is eventually resolved by referring to observations of phenomena (MacDonald & Gustafson, 2006).

Despite these current (and very common) ideas about the nature of science found in a number of international science standards documents, the nature of science remains a contested domain (Alters, 1997; Labinger & Collins, 2001; Laudan, 1990; Taylor, 1996 – all in Osborne et al., 2003) without complete agreement about what constitutes the nature of science. This is despite the observation that almost everyone agrees that the nature of science should be taught to children (Stanley & Brickhouse, 2001 in Osborne et al., 2003). Osborne, Collins, Ratcliffe, Millar and Duschl (2003) ask a number of critical questions regarding common ideas about the nature of science that are found in a wide range of curriculum documents:

- Do these curriculum documents represent a consensus or, alternatively, the kind of compromise that is often the product of reports produced by committees?
- That is, do they represent the lowest common denominator around which it is possible to achieve agreement rather than any coherent account of the nature of science?

Some researchers have conducted studies into how common, current ideas about the nature of science can best be taught to students (Akerson, Abd-El-Khalick, & Lederman, 2000; Khishfe & Abd-El-Khalick, 2002; Bartholomew, Osborne, & Ratcliffe, 2004). These studies tend to agree that for students to develop an understanding of the nature of science:

- explicit and reflective instruction about the nature of science needs to be incorporated throughout science teaching over an extended period of time (Akerson, Abd-El-Khalick, & Lederman, 2000; Akerson & Volrich, 2006; Bartholomew, Osborne, & Ratcliffe, 2004; Khishfe & Abd-El-Khalick, 2002)
- target ideas about the nature of science should be embedded in and taught within a framework of inquiry activities (Khishfe & Abd-El-Khalick, 2002)
- instruction must be integrated within a conceptual change approach to learning (Akerson, Abd-El-Khalick, & Lederman, 2000)
- effective teaching of ideas about science requires establishing a context where students can engage in reflexive epistemic dialogue (Bartholomew, Osborne, & Ratcliffe, 2004)
- case studies of either a historical or contemporary nature should be explicitly taught (Irwin, 2000; Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003).

One group of researchers used the metaphor that science inquiry can be thought of as a bridge or a base upon which nature of science instruction could be built (Khishfe & Abd-El-Khalick, 2002).

Related to these research projects about the nature of science are those that have discussed the terms “authentic science” (see Glossary of Terms) and “scientific literacy.” These terms have been introduced in an effort to describe ideas that could be used to inform the framework of school science programs.

Buxton (2006) provides an overview of how the term “authentic science” is used in research literature. He reports that authentic science:

- allows children to follow investigative pathways over time
- includes natural problem-solving contexts with high degrees of complexity
- requires the application of many cognitive processes
- includes an accurate view of the nature of science
- models what scientists do
- addresses the culture of children
- involves applying scientific inquiry to public, social and community purposes.

Gentilini adds that authentic science includes historical stories of the human pursuit of scientific knowledge (1999).

Scientific literacy is a term that has been used to describe the desired understanding people should have to live more effectively and thoughtfully with respect to the natural world (DeBoer, 2000). Acquiring scientific literacy is more than just having the skills to decode words and locate information. Rather, reading and writing science text (Norris & Phillips, 2003):

- depends on the background knowledge of the reader
- depends on relevance decisions made by the reader
- requires the active construction of new meanings.

A number of different interpretations and conceptions of scientific literacy have been proposed. The various definitions raise issues of the nature of scientific literacy, the purposes of scientific literacy and how scientific literacy should be measured (Laugksch, 2000). One common distinction is between scientific literacy as a content knowledge store and scientific knowledge as the ability to function effectively within society. From the latter, more recent perspective, being scientifically literate includes:

- understanding the relationship between science and technology (Cajas, 2001)
- recognizing the symbiotic relationships between science and technology and between science, technology and human affairs (Hurd, 1998)
- recognizing that almost every fact of one’s life has been influenced in one way or another by science and technology (Hurd, 1998)
- knowing that science in social contexts has political, judicial, ethical and sometimes moral interpretations (Hurd, 1998)
- using science knowledge where appropriate in making life and social decisions, forming judgments, resolving problems and taking action (Hurd, 1998)

- recognizing that science concepts, laws and theories are not rigid but rather they grow, develop and may change over time (Hurd, 1998)
- distinguishing evidence from propaganda, fact from fiction, sense from nonsense, and knowledge from opinion (Hurd, 1998)
- recognizing that scientific literacy is a process of acquiring, analyzing, synthesizing, evaluating and utilizing science and technology in human and social contexts (Hurd, 1998)
- personalizing the learning by developing an education that looks not only to students' cognitive development but also to their emotional, aesthetic, moral and spiritual needs (Hodson, 1998 in Shapiro, 2004).

With these conceptions of the nature of science, authentic science and scientific literacy comes the view that science education must involve much more than teaching children discrete facts that are narrowly aimed at increasing scores on standardized tests of science knowledge (DeBoer, 2000).

In existing school curricula the greatest emphasis has been on curriculum content – meaning knowledge and skills. It is difficult to anticipate that the acquisition of habits of mind, values and attitudes can effectively take place without the learner being actively engaged in learning specific knowledge and skills in some contexts (Law, 2002).

A broad view of formal science education suggests that it needs to be more integrated with everyday life (Roth & Lee, 2004):

- Science education should allow students to participate in legitimate ways in community life and therefore provide a starting point for uninterrupted lifelong learning across the presently existing boundary separating formal schooling from everyday life outside schools (Roth & Lee, 2004).
- Science and scientific literacy constitute the outcomes of a lived curriculum (Roth & Lee, 2004).
- There is a need to provide more opportunity for students to experience authentic science for themselves and thus to appreciate the importance of tacit knowledge and the affective work of scientists. Too often students believe that doing science is a matter of merely putting together scientific knowledge and scientific skills. We must help them to recognize the importance of the affective, to realize that doing science involves the whole person, their creativity and their imagination, their commitment and their persistence (Woolnough, 2001).
- Science should teach students how to find out about the science underlying current ethical and social issues, and help them establish a strong base for a lifetime of autonomous learning (Solomon, 2002).
- Scientific literacy through schooling is important. It is time to consider life in society itself as the starting point for determining the scientific knowledge that should be given priority in the school science curriculum (Fenshan, 2002a & 2002b).

For some years researchers have reported that a Science/Technology/Society (STS) instructional approach holds the promise of helping children take a much broader view to applying scientific knowledge and using information to resolve local issues (Yager, Nworgu, & Lu, 2003). The following list identifies some of the claims emerging from STS (see Glossary of Terms) research:

- The STS instructional approach is superior to a textbook-oriented approach in terms of facilitating students' application of science concepts to new situations (Yager, Nworgu, & Lu, 2003).
- STS improves student enjoyment of and interest and engagement in science (Hughes, 2000).
- STS helps students understand the interrelationships among science, technology and society (Hughes, 2000).

Research studies on STS have given rise to a closer inspection of the nature of technology and the goals of technology education. The strategies and settings that promote creative thinking in design and technology make the area suitable for addressing ethics and values and may be one of the major reasons for including design and technology programs in school curricula (Middleton, 2005).

Common ideas about the nature of technology include that:

- design is a fundamental element of technology (Cajas, 2002 quoting AAAS, 1993 and ITEA, 2000)
- technology relates to science and society and all are value-laden (Cajas, 2002 quoting ITEA, 2000)
- constraints (physical laws, economic limits, etc.) and failure are parts of technological practice (Cajas, 2002 quoting ITEA, 2000).

Cajas (2002) sums up the connection between technology education and STS when he observes that American technology education has moved from a focus on preparing students for the workplace and assisting them to develop practical skills, to the goal of developing citizens who understand the nature of technology and its interaction with science and society.

Children's Learning

Over the last 25 years, much science education research has been framed by a constructivist view of learning that in recent years has emphasized a social constructivist (see Glossary of Terms) perspective. In these studies, researchers have worked to identify children's alternative conceptions (see Glossary of Terms) of science concepts, understand how children construct an understanding of science in classrooms, study how language shapes children's ideas and understandings, and conceptualize teaching and learning in science from a social perspective (Akerson, Flick, & Lederman, 2000; Crawford, 2005; Hand et al., 2003).

Currently, research on compiling lists of children's alternative conceptions has moved toward asking questions about how knowledge of these alternative conceptions may have implications for teaching practice and science programs. Researchers have reported that teachers should be aware of the following ideas:

Children's Existing Ideas

- Children have many existing ideas about science topics prior to classroom instruction. These existing ideas contain a mixture of scientifically correct and incorrect ideas. Children have difficulty understanding science ideas that are contrary to personal life experiences (Chiu & Lin, 2005; Liu & Lesniak, 2006; Shapiro, 1995).
- A lifetime of learning demonstrates the importance of taking into account and attaching a high value to personal efforts to learn and makes clear how the personal frameworks that learners develop persist and influence learning (Shapiro, 2004).
- Teachers need to develop and use formal assessment tools such as pre-tests and interviews to find out children's existing ideas (Morrison & Lederman, 2003).
- Well-thought out teacher interventions can change children's ideas more toward scientific conceptions (Sharp & Kuerbis, 2006).
- Teaching may promote even more alternative conceptions (Liu & Lesniak, 2006).

Children's Experiences

- A complete explanation of how learning occurs must include a consideration of the experience of the learner, the key participant in learning (Shapiro, 2004).
- Teachers need to focus on children's experience outside the classroom and their engagement with science content (Pugh, 2004).
- Younger students are more interested in the environment than adolescents. This interest can motivate students at an early age to become involved in environmental and scientific issues (Pruneau, 2002).

Children's Understanding

- Children need to go beyond mere observation and description to deeper concepts and authentic explanations (Ford, 2006).
- Children frame their understandings of science investigations with reference to three types of mental contexts: imaginary, experienced and investigative worlds (Shepardson & Britsch, 2001).
- Students understand the same concept in different ways. Their understandings and the ways they construct meaning are rooted in situational contexts and in their own individual contexts. What makes meaning for children is not simply what words are used but how the explanation sits within each child's wider narrative context: the links that are made to events and memories and the personal values that colour and shape understandings (Tytler & Peterson, 2004a & 2004b).
- Children's use of scientific language does not reflect their understanding (Liu & Lesniak, 2006).
- Children have difficulty understanding how macroscopic observations might be related to microscopic explanations (e.g., the particulate model of matter) (Liu & Lesniak, 2006).
- Children should be encouraged to question accepted theories in order to develop deeper understandings of those theories (Freeman & Mrazek, 2001).

- Children need opportunities during design technology activities to develop their physical knowledge and make conceptual meanings simultaneously (Liu, 2000).
- Children may not necessarily use scientific conceptual knowledge developed in science to inform how they work during their design technology activities. Students' technological conceptual knowledge may be highly contextualized and situated (Levinson, Murphy, & McCormick, 1997 in Liu, 2000).
- The passage of time exerts strong influence on children to fall back from scientific to everyday ways of describing concepts. Children tend to avoid using unfamiliar scientific terms and knowledge (Hellden & Solomon, 2004).

Children and Representations

- Using multiple analogies to represent science ideas and helping children understand the constraints of all analogies can assist children to grow in their understanding of science concepts (Chiu & Lin, 2005).
- Students attend to the content domain, local activity and personal preferences when evaluating representations. Student creation of representations is mediated by other students, task constraints, the teacher and local norms for good representation (Danish & Enyedy, 2007).

Implications for Teaching

- Long-term constructivist-oriented instruction helps both high and low achieving students develop more comprehensive and better-integrated cognitive structures, engages them more in metacognition, and helps them more effectively use information processing strategies (Wu & Tsai, 2005).
- Teachers should act as a facilitator and encourage children's participation in ongoing messy open-ended activities (Kelly, Brown, & Crawford, 2000).
- It is important to help children develop language strategies that more clearly share ideas with others by helping them to clarify the reasons and logical arguments for moving in one direction or another (Shapiro, 1995).
- Metacognitive learning, which emphasizes formal opportunities for teachers and students to talk about their science ideas, leads to more permanent restructuring of their ecology understandings (Blank, 2000).

Important among research on children's learning over the past 15 years are research studies that have explored the roles of language, reading and writing in science. Language is viewed as being an integral part of doing science and constructing conceptual understanding (Hand et al., 2003). Language is also linked to scientific literacy in that language is used to communicate understanding to others who may base their opinions and actions on received messages (Hand et al., 2003). Ideas about language, reading, writing and science reported in the literature include:

- Oral and written language is the symbol system used by scientists to interpret and present science evidence and explanations (Locke, 1992 in Hand et al., 2003).
- Language shapes science ideas and the nonlanguage features of science shape scientific discourse (Lock, 1992 in Hand et al., 2003; Laplante, 2000).

- Scientific literacy involves being fluent in language and the communication systems of science, and being knowledgeable and educated in science (Norris and Phillips, 2003 in Hand et al., 2003).
- Reading is an interactive, constructive and transformative process for making meaning (Hand et al., 2003).
- Science is another tool for developing children's literacy skills (Akerson, Flick, & Lederman, 2000).

Studies show that gender plays a role in student science learning.

- The popularity of certain science topics varies with age and gender. Girls generally prefer biological topics (Baram-Tsabari, Sethi, Bry, & Yarden, 2006).
- Girls have access to science books at school and teachers have strategies to encourage reading them. Parents encourage reading at home but are generally less directive than teachers as to what the girls read, and tend to underestimate their daughters' science-related interests (Ford, Brickhouse, Lottero-Perdue, & Kittleson, 2006).
- There continues to be significant gender differences in science experiences, attitudes and perceptions of science courses and careers (Jones, Howe, & Rua, 2000).
- Globally, girls surpass boys in reading, and boys surpass girls in math and science but the gap between boys and girls in scientific subjects has lessened over time. Girls can surpass boys in certain mathematical and scientific disciplines when questions are open-ended and collaborative in nature (Blondin & Lafontaine, 2005)
- Scientific activities designed from a "feminist and socio-constructivist perspective" are much more appealing to girls and motivate girls to continue in the sciences (Lirette-Pitre & Mujawamariya, 2005).

From these studies of children's learning have come some implications for science programs:

- Although the progression implied in science programs is a linear and staircase-like uniform change, children's learning does not evolve in this manner (Liu & Lesniak, 2006).
- Children's understanding of matter varies from substance to substance and there is no universal progression (Liu & Lesniak, 2006).
- Due to time constraints, students are at most "exposed" to program concepts but do not have time to develop an understanding of the concepts (Liu & Lesniak, 2006).
- Program developers should embed well-planned analogies in the text (Chiu & Lin, 2005).

Science as Inquiry

In the last decade, scientific inquiry has remained as an important element in many program standards documents. There are various meanings attributed to the term inquiry. Dichotomies expressed in this range of meanings include (Abd-El-Khalick et al., 2003):

- learning science versus learning about science
- science as a search for truth versus science as a problem-solving activity
- raising and answering questions versus posing explanations

- science as a cognitive activity versus science as a social activity
- demonstrating what we know (concepts) versus how we know and why we believe it
- hypothetico-deductive science versus model-based science
- science as justifying knowledge claims versus science as generating knowledge claims.

Currently, scientific inquiry tends to be described as including the diverse ways in which scientists study the natural world, gather evidence and formulate explanations. Students in inquiry-based classrooms are taught to pose problems, gather data, make observations, evaluate findings, test hypotheses and communicate their results to others (Lewis, 2006).

Reflecting the above conception, the *National Science Education Standards* (NRC, 1996) encompass the following changes in emphases in relation to scientific inquiry (NRC, 1996, p. 113):

Changing Emphases	
Less Emphasis On	More Emphasis On
Knowing scientific facts and information	Understanding scientific concepts and developing abilities of inquiry
Studying subject matter disciplines for their own sake	Learning subject matter disciplines in the context of inquiry, technology, science in personal and social perspectives, and history and nature of science
Separating science knowledge and science process	Integrating all aspects of science content
Covering many science topics	Studying a few fundamental science concepts
Implementing inquiry as a set of processes	Implementing inquiry as instructional strategies, abilities, and ideas to be learned
Changing Emphases to Promote Inquiry	
Less Emphasis on	More Emphasis On
Activities that demonstrate and verify science content	Activities that investigate and analyze science questions
Investigations confined to one class period	Investigations over extended periods of time
Process skills out of context	Process skills in context
Emphasis on individual process skills such as observation and inference	Using multiple process skills: manipulation, cognitive, procedural
Getting an answer	Using evidence and strategies for developing or revising an explanation
Science as exploration and experiment	Science as argument and explanation
Providing answers to questions about science content	Communicating science explanations
Individuals and groups of students analyzing and synthesizing data without defending a conclusion	Groups of students often analyzing and synthesizing data after defending conclusions

Doing few investigations in order to leave time to cover large amounts of content	Doing more investigations in order to develop understanding, ability, values of inquiry, and knowledge of science content
Concluding inquiries with the results of the experiment	Applying the results of experiments to scientific arguments and explanations
Management of materials and equipment	Management of ideas and information
Private communication of student ideas and conclusions to teacher	Public communication of student ideas and work to classmates

A companion document, *Inquiry in the National Science Education Standards* (NRC, 2000), identifies variations in scientific inquiry in regard to the amount of learner self-direction and the amount of direction from teacher or material (NRC, 2000, p. 29):

Essential Feature	Variations			
	More	Amount of Learner Self-direction		Less
	Less	Amount of Direction from Teacher or Material		More
Learner engages in scientifically oriented questions	Learner poses a question	Learner selects among questions, poses new questions	Learner sharpens or clarifies question provided by teacher, materials, or other source	Learner engages in question provided by teacher, materials, or other source
Learner gives priority to evidence in responding to questions	Learner determines what constitutes evidence and collects it	Learner directed to collect certain data	Learner given data and asked to analyze	Learner given data and told how to analyze
Learner formulates explanations from evidence	Learner formulates explanation after summarizing evidence	Learner guided in process of formulating explanation from evidence	Learner given possible ways to use evidence to formulate explanation	Learner provided with evidence
Learner connects explanations to scientific knowledge	Learner independently examines other resources and forms the link to explanations	Learner directed toward areas and sources of scientific knowledge	Learner given possible connections	Learner provided with connections
Learner communicates and justifies explanations	Learner forms reasonable and logical argument to communicate explanations	Learner coached in development of communication	Learner provided broad guidelines to use to sharpen communication	Learner given steps and procedures for communication

With respect to existing teacher beliefs regarding scientific inquiry and the teaching and learning of science, one study found that teachers believe that (Levitt, 2001):

- the teaching and learning of science should be student centered: Students should engage in hands-on activities
- students should be active participants in learning science
- learning of science should be personally meaningful to students
- science education should foster positive attitudes toward science
- the role of the teacher changes to accommodate a focus on students.

Some researchers have studied scientific inquiry in classrooms and have identified fundamental issues relating to inquiry teaching (Lewis, 2006).

- Preservice teachers can improve their classroom practice by receiving instruction on how to carry out scientific inquiry (Schwarz & Gwekwerere, 2007).
- Inquiry should focus students on constructing and evaluating scientific explanations for natural phenomena (Sandoval & Reiser, 2004).
- More emphasis should be placed on an evidence-explanation approach to inquiry in order to effectively address the multiple agendas of science education (Abd-El-Khalick et al., 2003).
- Teachers tend to include a constructivist dimension in the teaching of inquiry (MacKenzie, 2001 in Lewis, 2006).
- Inquiry tasks commonly used in schools evoke reasoning processes that are qualitatively different from the processes employed in real scientific inquiry. School reasoning tasks appear to be based on a theory of knowledge that differs from how authentic science views knowledge (Chinn & Malhotra, 2002).
- Improvements to inquiry dimensions of the curriculum require aligning activities more closely with practices that reflect the work of scientists in the discipline, integrating learning of content knowledge with learning about inquiry, and adjusting evaluation protocols to more accurately assess inquiry (Trumbull, Bonney, & Grudens-Schuck, 2005).
- Guidance needs to be provided on strategies teachers can use to selectively hold back answers from students in order to maintain a classroom atmosphere that encourages student-directed inquiry (Furtak, 2006).
- Teachers need to shift in roles from explaining what the teacher knows toward diagnosing what students are thinking and responding in ways (including silence) that prompt progress in learning (van Zee, Hammer, Bell, Roy, & Peter, 2005).
- Teachers need to recognize and respond to the abilities and inclinations that children display with respect to analogy use during inquiry (May, Hammer, & Roy, 2006).
- Guided peer critiques of others' explanations are more likely than self-assessments to be fruitful in getting students to evaluate the quality of written explanations (Sandoval & Reiser, 2004).

- Teaching science through inquiry can make students more positive about science (Gibson & Chase, 2002).
- Experienced teachers are more inclined than beginning teachers to associate inquiry with scientific research (Tamir, 1983 in Lewis, 2006).
- Teachers' conceptions of the nature of science may or may not influence how they teach scientific inquiry (Lederman, 1999 in Lewis, 2006).
- Teachers are the key to how inquiry happens in classrooms (Shepardson & Britsch, 2006).

Design Technology Problem Solving

Much research in design technology has centered on trying to describe what is involved in solving design technology problems and shaping these processes into models of the design process. Mawson (2003) believes that many of these models have been based on fundamental misunderstandings of how professional designers work and have been driven by management and assessment needs. He believes that models should be downplayed and more attention given to providing children with necessary design skills and practices. Hill and Anning (2001) question the utility of a generic approach to teaching design technology without close examination of skills required for different design fields (e.g., architecture, engineering, industrial design).

Be that as it may, the following ideas about the design process have been offered by various researchers:

- Design process is iterative rather than linear and is comprised of a need, problem analysis, statement of the problem, conceptual design, selected schemes, embodiment of schemes, detailing of solution and working drawings. Conceptual design is the heart of the process (French, 1999 in Lewis, 2006).
- Design technology tasks can be broken down into naming the task, visualizing the path ahead, reflecting on device construction and reflecting on paths taken. The ability to troubleshoot is important (Gustafson, MacDonald, & Gentilini, 2003).
- Six components of practice that are key features of technology are planning for practice, technological practice of others, brief development, solution as conceptual design, solution as mockup, solution as prototype (Compton & Harwood, 2005).
- Engineering design process has three phases: need identification, conceptual design and realization (Kroll, Condoor, & Jansson, 2001 in Lewis, 2006).
- Systematic design involves four main stages: product planning and task clarification, conceptual design, embodiment design and detail design (Pahl & Beitz, 1995 in Lewis, 2006).
- Design involves three common strategies: taking a systematic approach to the problem, framing the problem in some distinctive way and designing from first principles. Designers do not follow standard stepwise procedures (Cross and Cross, 1998 in Lewis, 2006).

Lewis (2006) sums up these different design conceptions in the following quote:

“Engineers proceed along roughly similar paths when they do their work. Once they frame the problem, they engage in divergent thinking in search of possible solutions. This quest is bounded by constraints including cost, safety considerations, social factors, and the present state of the art. Previous experience is drawn upon through the employment of heuristics (see Glossary of Terms) in a way that frees cognitive resources that can be devoted to finding the eventual solution. The final choice of solution requires evaluation-based decision-making. The journey from initial framing of the problem towards arrival of a final design solution is nonlinear” (p. 265).

From this work on design technology models have come studies about how these ideas translate to the classroom. Ideas that have implications for teaching design technology include:

Teacher Knowledge

- Development of improved teacher knowledge and awareness of technological practice enables teachers to plan authentic units of work, plan quality formative assessment and give children feedback on authentic practices (Fox-Turnbull, 2006).

Concepts, Skills and Attitudes

- Conceptual knowledge is needed to design and make technological objects and devices (Cajas, 2002 quoting AAAS, 1993).
- Technological capabilities are needed to design and make technological objects and devices (Cajas, 2002 quoting ITEA, 2000).
- Prior to formal instruction, children have a great number and range of useful ideas related to design technology activities. The task of classroom activities is to transform initial awareness into conceptual and procedural knowledge (Gustafson & Rowell, 1998).
- A situated view of learning has much to offer; children’s knowledge is learned in context. Problem solving and design are prominent types of knowledge relevant to technology classrooms (McCormick, 2004).
- Teachers often treat design problem solving as a series of ritualized steps. Solutions are often given by the teacher rather than found by students (McCormick, 2004).
- Designing is a complex intellectual activity that requires higher order thinking. Higher order thinking is best facilitated by nonabstract representations of knowledge, such as visual images and concrete representations (Middleton, 2005).

Children’s Planning

- Children need assistance to see the purpose of oral planning and 2-D design work, to concentrate on design work from a number of perspectives (e.g., front view, side view), to include detail in their designs, and to see the benefits of reworking their designs (Fleer, 2000).
- Children do not tend to use sketching as a way to generate, develop and communicate design ideas but rather want to move immediately to three-dimensional modelling (Welch, Barlex, & Lim, 2000).
- Children need to be allowed to discuss their planning and justify their decision making (Fox-Turnbull, 2006).

- Opportunistic planning, where children change initial ideas as they work through building, is characteristic of design practice (Fleer, 2000; Gustafson, MacDonald, & Gentilini, 2003).

Classroom Interaction

- Technology education needs to be active, contextualized, authentic and collaborative. Pupils must have a sense of ownership and teachers must create supportive learning environments. Opportunities must be given for learners to reflect. Problems should be ill-defined or loosely defined and must be real problems. Work should be collaborative and social. In a community approach, issues relating to the made environment are discussed and from this initial discussion projects and activities are devised (Dakers, 2005).
- Children need a chance to research the topic to acquire sufficient background knowledge. They need instruction in methods of construction and opportunities to use a variety of construction techniques. Specific teaching may be required during designing and making. A few days for incubation of design ideas is helpful. Design activities should include opportunities for children to expand their knowledge (Webster, Campbell, & Jane, 2006).
- Children spend most of their time on emergent problems. They try to solve problems while dealing with classroom culture. Children are most effective when they both share tasks and thinking (McCormick, 2004).
- Useful design technology interactions happen when teachers find out which ideas children already have about a problem, issue or situation; know what children think should happen; take children's ideas seriously; give them the opportunities to try out their ideas; challenge children in discussion to find evidence for their own ideas, especially by ensuring that children talk through their ideas; organize discussions so that different ideas about the same things can be brought together; enable children to become aware of different ideas; offer a designer's view of a problem or brief, allowing children to explore its value for themselves; provide challenges for children to use or modify their ideas, as well as to make sense of new experience (Järvinen & Twyford, 2000).
- Visualizing through guided classroom talk is very important. Conversations should highlight the intellectual demands of design technology problem solving rather than a focus on the best end-product (Gustafson, MacDonald, & Gentilini, 2003).
- Collaborative technological problem solving requires attention to the development of language skills (Rowell, 2002).

Assessment of Learning

- Need to balance product purpose, e.g., build a bridge that supports a load, with teaching purpose, e.g., developing scientific literacy (Gustafson, MacDonald, & Gentilini, 2003).
- Progression matrices (i.e., rubrics) related to components of technological practice can provide a picture of student achievement, as well as a basis for collaboration with colleagues, guidance for unit planning, and direction for enhancement of classroom interaction (Compton & Harwood, 2005).

Gender Issues

- The interests of both girls and boys can be aroused by technology education, significantly reducing gender differences (Mammes, 2004).
- Female students encounter difficulties when engaged in design and technology problem solving because they work in different ways from male students, leading to misjudgments that frame students' learning, capabilities and performance. If female students experience difficulties with studying technology because they tackle problems in different ways than men, educators must be concerned about the potential learning outcomes for this significant group of students. Female students tend to focus on aesthetic variables, talk about the process and are more attuned to the needs of the user whereas the males seemed capable of commencing a task and working on the fine detail of the technological activity without overt reference to a more global view of the task (Ginns & Stein, 2003).

Professional Development

- If teachers are to plan design-technology lessons that allow children to experience the full scope of practical reasoning, as well as develop their technological awareness, capability and literacy, supportive networks must be available. These networks will help teachers understand how their pedagogical decision making directs the scope and nature of children's technology talk and understanding (Gustafson & MacDonald, 2004).

Teacher Knowledge

Research on teacher knowledge tends to be focused on identifying knowledge needed to teach science and design technology in an effective manner, observing that many teachers do not possess this knowledge, and offering ideas about the professional development opportunities needed to improve matters.

With respect to the knowledge needed to teach science and design technology effectively, researchers offer the following insights:

- Teaching is a complex and subtle activity that requires many forms of knowledge (Barnett & Hodson, 2001).
- Exemplary science teachers utilize four kinds of knowledge: academic and research knowledge, pedagogical content knowledge (see Glossary of Terms), professional knowledge and classroom knowledge (Barnett & Hodson, 2001).
- Elementary teachers lack confidence with science content and have low science teaching efficacy (Hanson & Akerson, 2006).
- Two factors appear to contribute to the lack of confidence in science teaching: unfamiliar content and unfamiliar pedagogical strategies, especially laboratory work and experiments. It is apparent that the more enthusiastic and confident the teacher is about science, the more time is spent on teaching science, the more hands-on experiences are used, and the more likely the course is to encourage student-led activities (Hodson, 2002).

- Preservice teachers identified subject content knowledge as what they most needed. Fewer mentioned pedagogical content knowledge and curricular knowledge (Rowell & Gustafson, 1996).
- Preservice teachers should have the opportunity to explain scientific concepts during their undergraduate program in order to improve their explanatory abilities. Preservice teachers seldom use model-based reasoning to explain phenomena described to them or to predict and explain their predictions about what happens during a given intervention (Leite & Afonso, 2004).
- Preservice teachers' confidence in their ability to teach elementary science can be enhanced by a self-regulated learning environment but this may not improve their overall content knowledge in science. This confidence, an essential component for preservice teachers to adopt in the classroom, may be attributable to them having the opportunity to undertake the whole learning process, including researching a topic and implementing an activity-based, investigative task (Jarvis & McKeon, 2005; Taylor & Corrigan, 2005).
- Any suggestion that elementary teachers who teach younger children need lower levels of content knowledge was rejected by participants in the study. The general conclusion of course participants was the "more science the better" (Schibeci & Hickey, 2000).
- Content knowledge alone will not necessarily lead to more effective teaching. Effective teaching requires a level of comfort with content knowledge and the knowledge to make the science ideas teachable (pedagogical content knowledge) (Schibeci & Hickey, 2000).
- Teachers must have knowledge of inquiry, general pedagogical knowledge, know students' existing ideas about science topics, know how to facilitate collaborative learning, present activities that are meaningful and authentic, know science content, know how science ideas are constructed, have pedagogical content knowledge, understand the intellectual demand of understanding concepts, know about teaching strategies, have knowledge of curriculum materials, and have knowledge of learners (Guilbert, 2002b).
- Teaching science at the elementary level requires a robust set of general and interactive knowledge bases (Mulholland & Wallace, 2005).
- Four factors were identified as most influential in teaching: knowledge of nature of science, knowledge of subject matter, pedagogical knowledge, and intentions toward teaching nature of science. Participants with strong intentions, well-developed nature of science views, and extensive knowledge of science content were most successful in their instruction (Lederman, Schwartz, Abd-El-Khalick, & Bell, 2001).
- Teacher development must precede that of students. Significant changes in metacognitive skills of students can be achieved only by teachers who, themselves, possess appropriate understanding, attitudes and abilities (Hodson, 2001).

Some researchers have focused on design technology alone when investigating what teachers should know in order to teach well. They report that preservice teachers and practicing teachers all require support to develop the knowledge necessary for teaching this key and often new learning area, as many currently have a limited or narrow perception of design and technology teaching (Deaudelin, Lefebvre, Brodeur, Dussault, Richer, & Mercier, 2005; McRobbie, Ginns, & Stein, 2000).

Jones and Moreland (2004) have tried to identify the key features of teacher knowledge that are important for teaching design technology, how these features can be enhanced and the classroom benefits of such enhancement:

- Seven features of pedagogical content knowledge (PCK) important for effective teaching and learning in design technology are nature of technology and its characteristics; conceptual, procedural and technical aspects of technology; knowledge of the relevant technology curriculum; knowledge of student learning; specific teaching and assessment practices; understanding the role and place of context; classroom environment and management.
- Critical aspects of professional development identified as enhancing PCK include negotiated intervention, planning frameworks, reflection on case studies, workshops, classroom support, appropriate resources, teacher meetings and analysis of portfolios of student work.
- Enhanced PCK resulted in increased teacher knowledge about technology including the nature of technology areas of technology and specific technological knowledge; changed pedagogical approaches; improved teacher-student interaction; refinement of appropriate learning outcomes; more effective critical decision making; improved teacher confidence; and enhanced student learning.

Overall, the research on knowledge needed to teach science and design technology paints a complex picture of what teachers should know in order to teach in an effective manner. Mulholland and Wallace (2005) note that many teachers simply resort to using curriculum materials to improve their science knowledge and that this may well limit growth in this important knowledge area. Recognizing these knowledge demands and how the school context can even limit the development of these knowledges, researchers have offered ideas about the kind of professional development that should be in place to support teachers:

- When teachers' beliefs about teaching and learning are acknowledged and addressed, professional development is more successful in bringing about reform (Levitt, 2001).
- Changing teachers' pedagogical knowledge occurs through reconstruction and teachers themselves must undergo a process of conceptual change (Stofflett, 1994 in Avraamidou & Zembal-Saul, 2005).
- There should be a shift away from short-term, one-shot teacher workshops and movement toward practice-based inquiry where teachers work to collaboratively plan, implement and discuss science lessons (Shapiro, 2006).
- Long-term staff development programs are needed to actually change experienced teachers' practical knowledge (Van Driel, Beijaard, & Verloop, 2001).
- Professional development opportunities must address elementary teachers' needs to learn science content and new strategies for helping learners, and must address new perspectives about the realities of the culture of science learning. Professional development opportunities must also take into account the need for time and the development of structures that allow for new social and personal constructions about what it means to be a teacher (Shapiro & Last, 2002).

Ideas about professional development linked to more specific teaching practices include helping teachers:

- to enrich and reflect on their understanding of the nature of science and acquire and extend pedagogically appropriate nature of science approaches and activities. In other words, teachers need support to develop their nature of science pedagogical content knowledge (Akerson & Abd-El-Khalick, 2003).
- to focus on conceptualizing and developing strategies for enhancing children's scientific reasoning (Tytler & Peterson, 2004a & 2004b).
- to be responsible for teaching design technology activities to develop subject content knowledge, to understand the processes of technological design, to know about the role of language in understanding, and to know how to assess children during design technology units (Rowell & Gustafson, 1998; Wilson & Harris, 2003).

It is important to note that changing pedagogical practices is not easy. Teachers are reluctant to alter their practices; implicit beliefs held by teachers about teaching and learning are hard to change. Policy level initiatives often do not translate into lasting changes in practice. New teachers are often drawn into the status quo; preservice teachers need chances to explore their implicit theories. Teachers may perceive that the practices they are being asked to adopt contradict administration and community demands. Exams that focus on memorized facts are a barrier to change; there is a need to implement forms of assessment that evaluate understanding. There is a need for very strong teacher support mechanisms. Teachers need to be involved in all stages of the development of new policies and practices. Teacher learning and change requires active engagement (Dow, 2006).

Teacher Practices: Instruction and Assessment

Much research has focused on how teachers can effectively teach science to children. Researchers have observed that the following teacher actions hold promise for promoting children's scientific understanding:

- Deep learning results when children try to understand and make sense of material, relate ideas and information to previous knowledge and experience, critically evaluate material, use organizing principles to integrate ideas, relate evidence to conclusions and examine the logic of arguments (Barker, 2006).
- Teachers should pose open-ended questions as often as possible and allow children their own talk time. Teachers should know the science content in order to scaffold children's learning (McIntyre & Juliebo, 1995).
- Teachers should help students to draw links to the family and the community (Buxton, 2006).
- Good science teachers use their knowledge to address big ideas and major concepts; plan what they are doing and help their students do so; consistently treat their students with respect and apply ideas of fairness and equity in their classes; conduct investigations and help students to generate and interpret data; make students work in heterogeneous groups; relate new ideas to previously presented ones, especially to the driving question and to their previous investigations; request that students present their work to the whole class and revise these final presentations; use technology, throughout units, for various

purposes such as learning about structure of matter, doing investigations, collecting data and building models; allocate enough time for their students' learning; provide various opportunities for learning meaningful ideas, in meaningful ways; and address individual differences and needs of their students (Tal, Krajcik, & Blumenfeld, 2006).

- Teaching strategies that focus on knowledge enrichment, belief revision and discussions that expose students' nonscientific beliefs are rarely enough to adequately challenge their nonscientific framework theories. Consequently, teaching should focus on diagnosing students with nonscientific and scientific framework theories. All students should be given opportunities to elaborate their framework theories in class, not simply state their beliefs about specific instances (Venville, 2004).
- Carefully planned activities, student engagement and group work are not enough to ensure children's understanding. Critical to understanding is active teacher scaffolding that employs the intellectual resources students bring to class (Southerland, Kittleson, Settlage, & Lanier, 2005).
- Teachers need to help students build robust understandings of the nature of scientific evidence and data, including an understanding of what constitutes data, and strategies for critically evaluating the content and sources of scientific information commonly made available to the public (Sadler, 2004).
- Teachers are more than facilitators, organizers, managers and discussion leaders; they also have to be skilled practitioners of science, with a keen appreciation of science as a cultural phenomenon (Hodson, 2001).
- Some reforms have put an emphasis on objectives in science teaching, while others have focused on why children should study science and others yet on the different ways of teaching the subject. However, science should be conceived from a constructivist perspective (Mujawamarya, 2000).

Common barriers to effective teaching include (King, Shumow, & Lietz, 2001):

- lack of classroom materials
- lack of help during hands-on investigations
- lack of strategies for dealing with behavior problems
- ineffective professional development.

Other factors that can significantly influence learning include (Nolan, 2003):

- how textbooks are written and used
- the pressure teachers feel that they must portray an image of being right and knowing all the answers
- teachers' messages, articulated and unarticulated, that they perceive male and female learners differently.

Recently, some researchers have examined the role of talk and argument in helping children develop an understanding of how scientific evidence and explanations can be evaluated. Any education *about* science, rather than education *in* science, must give the role of argument a high priority if it is to give a fair account of the social practice of science, and develop a knowledge and understanding of the evaluative criteria used to establish scientific theories (Driver, Newton, & Osborne, 2000).

Also, from a societal or STS perspective, individuals have to make many personal and ethical decisions about socio-scientific issues and these decisions are arrived at through weighing different claims and coming to some resolution (Levinson & Turner, 2001; Ratcliffe & Grace, 2003 – all in Osborne, Erduran, & Simon, 2004). In media reports of such socio-scientific issues, people must assess whether the evidence is valid and reliable, distinguish correlations from causes, observations from inferences, and assess the degree of risk (Millar & Osborne, 1998; Monk & Osborne, 1997 – all in Osborne, Erduran, & Simon, 2004). Therefore, researchers maintain that there is an urgent need for students to understand argument in general, and argument in scientific contexts in particular (Osborne, Erduran, & Simon, 2004).

Supporting the development of scientific argument in classrooms involves:

- engaging students in argumentative reasoning to improve science teaching and learning (Osborne, Erduran, & Simon, 2004)
- providing students with relevant evidence, at least a feel for the criteria for evaluating scientific evidence, and the opportunity to marshal support for one theory or another (Osborne, Erduran, & Simon, 2004)
- dividing students into groups, asking them to argue the case for one view or the other, and asking them to think how they would argue against any items of evidence that are not supportive of the idea they are defending (Osborne, Erduran, & Simon, 2004)
- avoiding the perception that speedy recitation of correct answers is what is valued – instead, teachers should be perceived as valuing student understanding and independent thinking (Osborne, Erduran, & Simon, 2004)
- providing opportunities for students to practice justifying claims, attend to counter-positions, understand uncertainty and dissect arguments (Kanari & Millar, 2004; Sadler, 2004)
- providing a comfortable discourse environment where children are encouraged to ask questions to understand one another's thinking (Puntambekar & Kolodner, 2005; Van Zee, Iwasyk, Kurose, Simpson, & Wild, 2001).

With the current emphasis on hands-on, minds-on activity in science, some studies have focused on how laboratory activities are used in science education. A recent review of that literature since 1982 concluded that (Hofstein & Lunetta, 2004):

- Many activities outlined for students in laboratory guides continue to offer cookbook lists of tasks for students to follow ritualistically. They do not engage students in thinking about the larger purpose of their investigations and of the sequence of tasks they need to pursue to achieve those ends.
- Assessment of students' practical knowledge and abilities and of the purpose of laboratory inquiry tends to be seriously neglected, even by high stakes tests that purport to assess science standards. Thus many students do not perceive laboratory experiences to be particularly important in their learning.
- Teachers and administrators are often not well informed about what is suggested as best professional practice and they do not understand the rationale behind such suggestions. Thus there is a high potential for mismatch between a teacher's rhetoric and practice that is likely to influence students' perceptions and behaviours in laboratory work.

- Incorporating inquiry-type activities in school science is inhibited by limitations in resources and by lack of enough time for teachers to become informed and develop and implement appropriate science curricula. Other inhibiting factors include large classes, inflexible scheduling of laboratory facilities and the perceived foci of external examination.

Assessment of learning is another important area of teacher practice. Current assessment tends more often to be summative rather than formative. Some researchers suggest that more emphasis needs to be placed on formative assessment (Bell & Cowie, 2001; King, Shumow, & Lietz, 2001). Based on the notion that documented characteristics of formative assessment can guide teachers in improving their practice in that area, some researchers suggest that formative assessment (Bell & Cowie, 2001):

- is responsive
- includes sources of evidence
- is a tacit process
- uses professional knowledge and experiences
- is an integral part of teaching and learning
- is done by both teachers and students
- has purposes
- is contextualized
- involves dilemmas
- requires student disclosure.

Teaching Science in Diverse Contexts, Including Aboriginal Contexts

Some recent science education research has focused on urban science education and the linguistically and culturally diverse classrooms frequently found in these schools. Researchers tend to agree that excellence and learning in urban schools is determined by various social, cultural and linguistic factors (Fraser-Abder, Atwater, & Lee, 2006). Teachers are the key to success in that their willingness to relate to students' linguistic and cultural experiences can lead to these students feeling included or excluded from the classroom culture (Lee, Deaktor, Hart, Cuevas, & Enders, 2005). Ideas from research about urban science education include:

- Teachers need to develop subject matter knowledge (see Glossary of Terms) that is not separated from relevant pedagogical content knowledge in order to change their teaching practices for diverse students (Tal, Krajcik, & Blumenfeld, 2006).
- Teachers need examples from students' home languages and cultures in science instructional units (Lee, Deaktor, Hart, Cuevas, & Enders, 2005).
- Teachers need to incorporate linguistic and cultural funds of knowledge that students of diverse backgrounds bring to the classroom (Moll, 1992 in Cuevas, Lee, Hart, & Deaktor, 2005).
- Teachers may encounter areas of discontinuity between "Western traditional science" and their students' cultural and linguistic perceptions of science. These areas necessitate transitions or border crossings between the students' home culture and the culture of science (Cuevas, Lee, Hart, & Deaktor, 2005).

- Elementary students from nonmainstream backgrounds or those with limited science experience require the teacher's explicit instruction and scaffolding to engage in scientific inquiry (Cuevas, Lee, Hart, & Deaktor, 2005).
- School settings convey elaborate systems of signs (furniture arrangement, test setting, policy messages, time allotted for science) to learners indicating what it means to be a competent learner in science classrooms. We reward students according to the degree to which they have modelled these signs for us (Shapiro & Kirby, 1998)

Research on science education in rural contexts has been confounded by the difficulty of arriving at a common definition for rural science education. In many studies claiming to have a rural emphasis, it is unclear whether the study would meet government definitions of "rural." To compound the problem, government definitions of rural vary internationally.

Otto (1995) studied rural science education in the United States and examined a wide range of issues such as the status of rural education, STS, distance learning and the integration of diverse children into rural classrooms. The most significant question in this study was "Does the rural school offer the student a deficit education with regard to science learning?" The authors of this edited study seemed to agree that it did not.

Baird, Prather, Finson and Oliver (1994) conducted a needs assessment of 1,258 teachers in eight states. The top four needs identified by teachers (rural and nonrural) were the same and ranked in the same order:

- Motivating students to want to learn science.
- Identifying sources of free and inexpensive materials.
- Using computers to deliver science instruction.
- Using hands-on science teaching methods.

This study echoes others that suggest a lack of difference between rural areas and their nonrural peers. A question lingers, however, about the potential of information technology to bring universal access to knowledge to all students regardless of the school context. Finson and Dickson (1995) found that using distance learning technologies available at the time helped students surmount barriers presented by an isolated geographic location.

The research and discussion about Aboriginal students and science is relatively new and still undergoing change. There is no clear-cut consensus on this issue at present. Below are some perspectives.

- Some Aboriginal students hold at least two sources of knowledge to explain some science concepts, their own experience and science. Students place importance on earned or experiential knowledge. Teachers need to foster intrinsic motivation by tapping into students' informal experiences. Teachers need to enhance student decision-making about their own education through encouraging them to set their own academic goals (Sutherland, 2005).

- Western and Aboriginal ways of describing and explaining nature are two diverse knowledge systems. For many Aboriginal students, a Western scientific perspective on nature does not harmonize with their own worldview. Aboriginal students bring the worldviews they have learned at home into contact with a Western science worldview presented at school. Many students experience this as a cross-cultural event. To balance the two cultures, school science should be cross-cultural in nature. Central to a cross-cultural approach to science teaching is the tenet that Aboriginal children are advantaged by their own cultural identity and language (Aikenhead, 2002).
- “Western” or modern science is just one of many sciences that need to be addressed in the science classroom. Instructional strategies are needed that can help *all* science learners negotiate border crossings between “Western” modern science and Indigenous science (Snively & Corsiglia, 2001).
- Good science explanations will always be universal even if Indigenous knowledge is incorporated as scientific knowledge. “Western science” would co-opt and dominate Indigenous knowledge if it were incorporated as science. Indigenous knowledge is better off as a different kind of knowledge that can be valued for its own merits, play a vital role in science education, and maintain a position of independence from which it can critique the practices of science and the Standard Account of Western science (Cobern & Loving, 2001).
- What holds together diverse sciences and distinguishes them from non-science is family resemblances, a multitude of relationships partially overlapping and criss-crossing. There are sufficient similarities between mainstream science and Indigenous knowledge (IK) and traditional ecological knowledge (TEK) in terms of methodology and knowledge produced such that IK and TEK can be included in science education curriculum (Irzik, 2001).
- Teaching multicultural science is meritorious but what should be taught? Examples must be both anthropologically (historically) and scientifically accurate. Pedagogically sound, accurate, well-documented material must be developed for an elementary level audience (Montellano, 2001).
- Learners need to accommodate new learning with previously held beliefs. Science education of Indigenous students needs to achieve a workable balance between two worldviews. Science teaching to Indigenous students should take full advantage of the understandings they already have without harming their traditional beliefs (Linkson, 1999).
- Western science needs to be thought of as one worldview among many and not the main paradigm with Aboriginal science seen as the other. More needs to be understood about Aboriginal science. More research is needed (Fleer, 1999).
- The most effective way to improve learning in Yupiaq (Indigenous people of Alaska) classrooms is to infuse Indigenous knowledge and worldview into the curriculum. A Yupiaq worldview involves a more holistic view of science that emphasizes the interconnectedness and interdependence of all dimensions of nature and human activity. For example, children in a Grade 3–7 class designed an experiment to find out what substance would work best to remove hair from caribou hides (Kawagley, Norris-Tull, & Norris-Tull, 1998).

- “The truth of the sage or shaman is a fundamentally different beast than the truth of the scientist, and one should not pit them against one another, or get them confused.” Science educators, scientists and native cultures need to work together so that Aboriginal students can better understand the geology of their native lands in the context of their traditional, cultural knowledge (Riggs, 1998).

Integrating Computer Technology

A wide variety of digital resources are currently available for science education: word processing; desktop publishing; computer-assisted instruction, e.g., spreadsheet, database and graphing applications; presentation software, e.g., PowerPoint; graphic organizer software, e.g., mind maps; simulations and animations; information bases; microcomputer-based laboratories; the Internet, e.g., Webquests, school and class Web sites, scientific research; e-mail; video applications; interactive whiteboards; etc. New applications are constantly being introduced; e.g., iPods and PDAs are now being used in some science classrooms.

During the 1970s and 1980s, educators were often highly enthusiastic about the possibilities for learning with computers. A more reflective attitude has now set in that is focused around seriously investigating the meaningful use of technology to learn science and trying to draw valid conclusions about the value of technology for learning.

In mainstream science education journals, more specifically, *Research in Science Teaching* and *Science Education*, there are few studies of the integration of computer technology into science education and most focus on secondary and post-secondary contexts. For the purposes of this literature review, two additional more specialized publications were also investigated. Review of all articles in the *Journal of Science Education and Technology* from 2005–2007 found no appropriate elementary science studies so a switch was made to the *Journal of Computers in Mathematics and Science Teaching*. Although it was again found that the main focus was on secondary and post-secondary education, some studies of the integration of computer technology into elementary science were extracted from the latter journal.

- Pre-instructional simulations can serve as a foundation for further learning, assist in the development of students’ conceptions, reveal alternative conceptions in students’ thinking processes and encourage development of questions related to content (Hargrave & Kenton, 2000).
- In research performed on network science programs, individuals describe several common features – communication, collaboration, authenticity, access to real-time information and first-hand resources. Carefully designed and well-orchestrated network science projects have the potential to empower students to hold positive motivational beliefs and discover what it means to learn and do science (Mistler-Jackson & Songer, 2000).
- A computer-supported learning environment can result in growth and reinforcement in various social and thinking skills. Several factors that contribute to these outcomes are the software’s instructional design, enthusiasm, on-task behaviour, cooperation and collaboration among students, improved cognitive learning outcomes, attitudes toward science, the teacher’s pedagogical approach and attitudes toward incorporating technology into the curriculum, and an integrated curriculum (Eshet, Klemes, & Henderson, 2000).

- Factors that result in improvements in affective, social and cognitive outcomes for students and teacher during computer-related activities include allocating sufficient time to each student to learn with the software, using partners when learning at the computer, using a cognitive apprenticeship approach that encourages student-initiated problem solving and decision making, ensuring students are aware that the software is integral to the curriculum unit being taught (Eshet, Klemes, & Henderson, 2000).
- Children in low-income areas more often use computers for repetitive practices rather than inquiry pedagogy. Two significant constraints are low levels of computer competency and unreliable Internet connections. Use of computers as part of an inquiry-rich pedagogy to track live storms increased children's enthusiasm, improved science content knowledge, fostered inquiry thinking and improved technological competency (Songer, Hee-Sun, & Kam, 2002).
- Children can develop strong knowledge of PowerPoint and Excel as tools to report findings (Harrell, Walker, Hildreth, & Tyler-Wood, 2004).
- In a study of ecosystems, digital photography was associated with time students spent thinking about their ecosystem and relevant concepts. Students' desire to participate and feelings of ownership were enhanced. Photographs emphasized to students factors not easily measured as well as the holistic nature of ecosystems (Rivet & Schneider, 2004).
- Teachers need to be aware of gender differences and take them into account during instruction (Eshet, Klemes, & Henderson, 2000; Li, 2002; Voyles & Williams, 2004).
- Barriers to ICT integration into science education include shortage of technology, logistical problems, changing role of the teacher, time and accountability. Carefully developed small-scale projects may give teachers successful first-use experiences (Knezek et al., 2000).
- Successful implementation of computers in the classroom depends largely on the teacher pedagogy employed. Adequate time must be devoted to helping teachers become comfortable with both the technology employed and the new teaching principles that are necessary for implementation (Mouza & Bell, 2001).

Other authors of studies about ICT present detailed descriptions of specific technologies and strategies and hypothesize that their implementation will improve science learning; however, evaluation of their proposals through research has yet to be done (Slater, Beaudrie, Cadiz, Governor, & Roettger, 2001; Yair, Mintz, & Litvak, 2001; Rezaei & Katz, 2003; Tsuchida, Suzuki, & Takahashi, 2003).

Teaching Science in French Language Classrooms

Science is taught in French in the Francophone and the French Immersion schools of Alberta. Research indicates that language presents a difficulty when learning science in French (Laplante, 1997; Laplante, 2004; Pruneau & Langis, 2002). Laplante focuses on science learning with French Immersion students whereas others (Pruneau & Langis, 2002; Cormier, Pruneau, & Rivard, 2004; Cormier, Pruneau, Rivard, & Blain, 2004) focus on Francophone students in a minority setting. All agree, however, that it is important to incorporate language learning strategies with science teaching strategies.

- Diverse linguistic groups: Although academic English proficiency continued to be a struggle for some students, it is difficult to determine the degree to which linguistic limitations effected expression of inquiry concepts (Lee, Buxton, Lewis, & LeRoy, 2006).
- In French Immersion programs, it is important to integrate the teaching of language and content. The use of tasks that use content-related material encourages students to focus on language form (Swain, 2001).
- Students must learn to “talk science.” This can be done by appropriating certain elements characteristic of scientific discourse into scientific tasks. By adopting such a teaching approach, it is possible to switch from a reactive mode of teaching in which the language dimension is essentially implicit to a proactive mode in which language functions are taught explicitly. Mathematics and science are languages that can be taught and learned by the use of language semiotics (see Glossary of Terms). These results have numerous implications for science teaching in French Immersion classrooms as well as for content-area teaching in a second language. This implies that science teachers must be aware of the language capabilities of their students, and know how to teach a language as well as how to teach science (Laplante, 2000; Lemoyne, 2004).
- It is important to consider the culture of the Francophone school and the students as well as the professional identity of teachers when planning a program of studies for Francophone schools in a minority setting as Francophone schools represent the survival of the Francophone communities (Laplante, 2001).
- Language and culture tend to be perceived by teachers as subject specific (French and social studies) whereas in reality teachers in French schools in a minority setting should be aware of their role as agents of language and culture regardless of the subject matter they teach (Gérin-Lajoie, 2006).
- Whether the language of instruction is French or English, some of the factors that influence learning are the same: the social and socio-economic characteristics of students, the attitudes of students and their parents toward science, and the teachers’ pedagogical practices (Herry, 2000).

(NOTE: A more complete review of research on this outcome topic can be found in Appendix B.)

Research Related to the *Alberta Elementary Science Program (1996)*

Research on the *Alberta Elementary Science Program (1996)* has primarily been conducted by researchers and graduate students at the University of Alberta, University of Calgary and University of Lethbridge. The 1996 version of the program contained topics categorized as Problem Solving Through Technology or Science Inquiry and generic skills organized into general patterns of activity (e.g., Focus, Explore and Investigate, and Reflect and Interpret). The program did not feature any overall conceptual framework to illustrate how concepts were connected to each other and revisited within a number of contexts within the program. Instead, concepts were alluded to in each topic overview and within some specific learner expectations. Teachers were provided with lists of approved teaching resources, but funding to support the professional development needed to implement the program was dependent on school districts with little or no funds earmarked for this support. Some school districts (e.g., Edmonton Public Schools, Parkland School Division) created teaching resources to accompany program topics while a variety of other organizations worked to provide additional kit and print supports (e.g., Science Alberta, Centre for Mathematics, Science, and Technology Education – CMASTE).

What appeared to catch the interest of Alberta researchers was the overall intent and emphasis of the program, the decision to insert design technology into the science program for the first time, and the alignment of the Problem Solving Through Technology and Science Inquiry topics and models. Ideas from researchers are as follows:

- Researchers maintained that the program did not have a Science/Technology/Society (STS) emphasis (Gustafson & Rowell, 1995; Rowell, Gustafson, & Guilbert, 1999; MacDonald, 2002; Rowell & Ebbers, 2004). For program writers to make this claim, much more had to be done to help children understand the interconnections among science, technology and society. Program writers were advised to give careful consideration to what was involved in helping children become more scientifically and technologically literate.
- Researchers wrote that the way in which design technology was located within the science program would likely reinforce existing misconceptions about technology being only an application of science (Rowell, Gustafson, & Guilbert, 1999).
- Researchers argued that the decision by program writers to parallel the Science Inquiry and Problem Solving Through Technology skills models and use similar terminology within each model, would likely lead to teachers and children being unable to distinguish between the two and the processes being inadequately characterized. Another outcome might be that teachers would teach toward technological capability rather than technological literacy (Rowell, 1995).
- Researchers observed that the Problem Solving Through Technology skills model bore little resemblance to how people in technology professions (e.g., engineers) described their jobs. Professionals emphasized the importance of context in decision making, how their work is geared to meeting some need, and how problem solving is characterized by a complex interplay between conceptual knowledge and technical skills (Rowell, Gustafson, & Guilbert, 1997).
- Researchers predicted that by pairing Science Inquiry and Problem Solving Through Technology topics (e.g., Grade 5 – Electricity and Magnetism paired with Mechanisms Using Electricity), teachers and students would arrive at the inaccurate perception that technology was an application of science. As long as teachers did not critique this view, the distinctive features of technology will remain untaught (Rowell, 1995; Rowell, Gustafson, & Guilbert, 1999).
- Researchers found that preservice teachers tended to believe that technology is an application of science. If this review remains unchallenged, then as teachers they would find this view confirmed in the Alberta program and would be unlikely to seek a more accurate view of the relationship between science and technology (e.g., the more accurate view found in an STS approach) (Gustafson & Rowell, 1995).
- Researchers observed that the program had given priority to skill development rather than recognizing that skills were the tools used by children to develop a conceptual understanding of program topics (Rowell, 1995; Rowell, Gustafson, & Guilbert, 1997).
- With respect to the design technology topics, researchers argued that if skills continued to be seen as the goal rather than the means of learning, and if the focus further fell on making rather than thinking about the making, then the potential for developing children's critical thinking would be restricted (Rowell, Gustafson, & Guilbert, 1997).

Rowell and Ebbers (2004) conducted a survey of Alberta elementary teachers to explore general trends and issues in elementary science teaching. In this survey, at least 50% of teachers agreed on the following objectives as being important goals for teaching science (ideas are presented in no particular order):

- Understanding concepts, facts and laws.
- Developing skills and processes of investigation.
- Developing scientific attitudes.
- Understanding how scientific knowledge is developed.
- Understanding the nature and process of technological or engineering activity.
- Understanding the history and philosophy of science.
- Understanding science in society.
- Understanding practical applications.
- Understanding how science is relevant to our lives.
- Relating science to the child's world.
- Relating science to careers.
- Developing an awareness of Canadian science.
- Developing social skills.
- Developing reading skills.

Even though 11 years have passed since the mandatory implementation of the program, professional development and teaching resources continue to be two areas in need of improvement:

- Many Alberta teachers have engaged in professional development activities that have done little to help them develop the content knowledge, pedagogical content knowledge and principled knowledge (e.g., knowledge that helps teachers make informed decisions about what to do, when to do it and why it should be done) that they need to teach science well (Guilbert, 2002a).
- 75% of Alberta teachers reported that current curriculum resources are obstacles to effective teaching (Rowell & Ebbers, 2004).

Designing Science Programs

Research on science program design has involved an exploration of curriculum emphases (see Roberts' conception of curriculum emphases in the Glossary of Terms) or the goals of science teaching, the integration of technology and society into science programs, suggestions about topics and the arrangement of those topics, and a strong call for ongoing professional development.

A diversity of aims of science education makes science attractive to a range of learners. Distinctions can be made between learning science, learning about science and learning through science (Wellington, 2001). Some researchers have recommended that children be exposed to as many curriculum emphases or goals of teaching as possible (Bailey, 1998). Some researchers still make reference to Roberts' (1982) conception of curriculum emphases and others to his later

related work on companion meanings (Roberts, 1995). DeBoer (2000) summarizes some of the goals of science teaching that have appeared in the research literature and in international standards programs:

- Teaching and Learning about Science as a Cultural Force in the World.
- Preparation for the World of Work.
- Teaching and Learning about Science that has a Direct Application to Everyday Life.
- Teaching Students to be Informed Citizens.
- Learning about Science as a Particular Way of Examining the Natural World.
- Understanding Reports and Discussions of Science that Appear in the Popular Media.
- Learning about Science for its Aesthetic Appeal.
- Preparing Citizens Who Are Sympathetic to Science.
- Understanding the Nature and Importance of Technology and the Relationship between Technology and Science.

Lewis (2006) and others provide a more in-depth discussion of the similarities and differences between science and technology that should be made evident in school programs and how children benefit when programs include these areas of study:

- Design technology and science are both reasoning processes that bridge the gap between problem and solution (Lewis, 2006).
- In both science and design technology, the eventual solution may require backtracking, dead ends and a restatement of the problem (Lewis, 2006).
- Science and design technology are often inseparable in society (Lewis, 2006).
- Science and design technology differ in their purposes, role of trade-offs, role of failure, role of context and practicality (Lewis, 2006).
- When science and design technology are included in school programs, children can enact the commonplace collaboration between scientists and engineers, can see connections in the curriculum, can increase their learning and, in the end, can participate in more authentic, relevant learning (Lewis, 2006).
- The value of both design technology and science can be enhanced if both subjects are taught together as part of an integrated program in primary schools. When science and technology are appropriately combined, they appear to be complementary (Ginns, Norton, & McRobbie, 2005).

Some researchers have examined children's understanding of program topics and have commented on the appropriateness of topics, their sequencing in science programs and how they are connected:

- To promote scientific literacy, science should be connected to students' personal experiences and to general societal problems (Salend, 1998 in McCarthy, 2005).
- Students should be thinking about science in terms of connected and interrelated themes that are linked across disciplines and studying these concepts in depth (AAAS, 1989 in McCarthy, 2005).

- Ideas about the nature of science should be integrated into activities and program expectations (Osborne et al., 2003).
- Differentiated curricula can make a difference for students from different socioeconomic and ethnic backgrounds (Hayes & Deyhle, 2001).
- Children encounter some science program topics in elementary that are not revisited in secondary programs. These findings are a strong argument for giving greater emphasis to science in the elementary program (Shapiro, 2004).
- Chemistry is a relatively neglected area in elementary science programs even though it holds much promise for getting children actively involved in scientific inquiry (MacDonald, 2003).
- Energy degradation should be an important component for understanding energy conservation. At all grades, instruction about energy should focus on the concept itself and on how energy is applied in various contexts (Liu & McKeough, 2005).

Other researchers have focused on design technology topics and sequencing in school programs and have suggested that:

- It is essential to intensify design technology education in elementary school because it is the earliest opportunity for curriculum intervention (Mammes, 2004).
- Design technology topics should be authentic to technological practice or real world technology (Turnbull, 2002).
- Design technology programs should include a balance between content (conceptual knowledge) and skills (procedural knowledge) (Stein, McRobbie, & Ginns, 2001).
- Design technology programs should have a clear focus on providing students with an understanding of technology as a situated human endeavor (Compton & Harwood, 2003).
- Design technology programs should provide opportunities for students to build devices, critique the practice of others, examine the cultural and historical development of technology, and develop technological knowledge and capabilities (Compton & Harwood, 2003).
- Design technology programs should include opportunities for children to develop knowledge, skills (cognitive and practical), capabilities and competencies (problem identification, designing and making, and evaluating), and attitudes (values and awareness) (Reddy, Ankiewicz, de Swardt, & Gross, 2003).

Some researchers have drawn attention to the observation that there is a lack of curriculum effect on student performance and this outcome reflects the design of programs and the way these programs are implemented by teachers (Pine et al., 2006). Simply, programs must be authentic and teachers require support to implement programs. Ideas about needed teacher support include the following:

- Systematic, ongoing professional development is necessary to assist beginning and experienced teachers to implement new programs (Kelly & Staver, 2005).
- It is important to implement professional development at the beginning of the implementation of the curriculum and to continue it so that it is ongoing (Jones, Harlow, & Cowie, 2004).

- Targeting ongoing professional development activities are needed for teachers who lack confidence in their ability to teach scientific inquiry and to understand science content (Kelly & Staver, 2005).
- Teaching resources alone are insufficient; professional development is essential to help teachers plan for and learn from new programs (Schneider, Krajcik, & Blumenfeld, 2005).
- Once teachers have begun implementing a program, they need time to meet and analyze and discuss what they are doing (Loucks-Horsley, 1998 in Kelly & Staver, 2005).
- Staff development with constructivist underpinnings plus regular and frequent opportunities for interactions with colleagues and outside support personnel contribute to teacher learning of new programs (Davies, 2003).
- The process of large-scale adoption involves additional, individual teacher-directed design, fitting and adaptation for local circumstances (Barab & Luehmann, 2003).
- The surface level appearance of a curriculum that is dubbed developmentally appropriate or constructivist may mask the more important and perhaps contradictory values and attitudes, beliefs, and expectations that are fostered in the relationships between students and teachers (Hayes & Deyhle, 2001).
- Teaching design technology well means that teachers need opportunities to develop knowledge about technology, knowledge in technology, and general technological pedagogical knowledge. This includes knowledge of content, general pedagogy, educational contexts and educational ends (Moreland and Jones in Reddy, Ankwicz, de Swardt, & Gross, 2003).
- Various extrinsic factors associated with the school environment, in particular those relating to the role of the principal, as an institutional leader, are major influences on effective science program delivery. Intrinsic factors, such as the complex knowledge base, beliefs and attitudes of teachers, also compound the complexity of the delivery process (Lewthwaite, 2005).
- A motivating curriculum and qualified teachers play a major role in keeping students interested in science (Reiss, 2004).

A Vision for the Future

The following ideas enjoy considerable support among science education researchers and should be given consideration by program writers charged with designing a lived curriculum for K–6 students.

Science programs should include authentic learning experiences that help children develop scientific and technological literacy within a Science/Technology/Society instructional approach.

Science programs should be connected to the culture of children and involve applying science and technology to public, social and community purposes.

Science programs should include an interconnected framework of concepts, skills and attitudes that children need to understand in order to engage in scientific inquiry, design technology problem solving and a lifetime of learning.

Science programs should include target ideas about the nature of science, the nature of technology and the relationship between science and technology. These ideas should be embedded within the framework of scientific inquiry and design technology problem solving activities.

Science programs should allow children the time to revisit concepts within a variety of contexts in order to construct meaningful understanding and study concepts in depth.

Science programs should provide opportunities for children to engage in argumentative reasoning that allows them to practice justifying claims, argue different views, understand uncertainty and begin to develop an understanding of how to evaluate scientific evidence.

The scientific and Indigenous worldviews are two different ways of explaining nature and both should be valued for their own merits. School science should help all learners negotiate between scientific and Aboriginal ways of knowing.

A variety of digital resources should be designed, developed and carefully tested to determine their value in helping elementary children meaningfully learn science.

Teaching science in French language classrooms should involve acknowledging the important role that language plays in students' scientific comprehension. Language learning strategies should be incorporated into science teaching practices.

Teachers must be provided with systematic, ongoing, collaborative professional development and appropriate teaching resources that helps them to develop the pedagogical knowledge needed to teach science and design technology effectively. Teachers are the key to program success and children's learning.

Glossary of Terms

Alternative Conceptions: These are the alternative ideas that children may have about various science phenomena (e.g., the sun goes around the Earth). These ideas are different from those held by scientists. Other terms used by researchers to describe alternative conceptions are “alternative frameworks” and “misconceptions.”

Attitudes: Attitudes describe the characteristics children should try to develop through in-school and out-of-school experiences. Related to the ability to use attitudes is the willingness to use them. Typical attitudes associated with **scientific inquiry** include showing curiosity about the natural world, using critical thinking, showing perseverance, displaying open-mindedness, showing respect for evidence, being willing to work with others, developing moral sensitivity, being honest and accurate, and appreciating how diverse people have contributed to science. Typical attitudes associated with **technological problem-solving** include displaying inventiveness, showing curiosity for the manufactured world, showing perseverance, being willing to work with others, developing moral sensitivity, developing empathy for the challenge of invention. Typical attitudes associated with **STS decision making** include showing respect and tolerance, being responsible toward the environment, being willing to work with others, respecting the rights and opinions of others.

Authentic Science: Characteristics of authentic science mentioned in research literature include science that follows investigative pathways over time, includes natural problem-solving contexts with high degrees of complexity, requires the application of many cognitive processes, includes an accurate view of the nature of science, models what scientists do, addresses the culture of children, and involves applying scientific inquiry to public, social and community purposes. A more exhaustive description of authentic science can be found in Buxton (2006).

Cognitive Constructivism: Cognitive constructivist theory is focused on how individuals learn. Cognitive constructivism was widely discussed during the early 1980s when science education researchers explored the implications of constructivism for individual children learning science in classrooms.

Concept: A concept is a statement of important knowledge underpinning children’s scientific inquiry or technological problem solving or STS decision making (e.g., living things require water for the use and maintenance of their parts). Any one concept could underpin any number of activities (e.g., activities about mealworms, pond life), providing teachers with an educationally significant way to connect lessons and topics.

Constructivism: Constructivism is a theory of learning currently dominant in science and technology education. A key underlying assumption in this theory is that learners interpret what they are being taught in light of their existing ideas (see also “cognitive constructivism” and “social constructivism”).

Design Technology: see **Technology**

Heuristics: Heuristics are general guidelines or “rules of thumb.” In science education, heuristics are usually discussed with respect to problem solving or investigative techniques that can be used to improve performance or assist a student to arrive at a defensible explanation. These heuristics provide direction for how to problem solve and can include using a fair test, trial and error, or following a certain pattern of argumentation.

Pedagogical Content Knowledge (PCK): Knowledge about how to transform subject matter content into ideas, words and activities that children can understand.

Roberts’ Conception of Curriculum Emphases: A curriculum emphasis (Roberts, 1982) communicates a message as to why it is important to learn science. It is usually implicit, requires time and repetition if is to “take,” goes in and out of fashion, and is politically and economically driven. Roberts recognizes seven different curriculum emphases: personal explanations (how science explains the world for individuals), correct explanations (the products and findings/ideas/laws/theories of science), scientific skill development (the physical and conceptual processes of science), everyday applications (usefulness of science in helping us cope with everyday life), science technology and society (limits of science and technology in coping with the practical affairs of society) and solid foundations (today’s science learning as a foundation for tomorrow’s science learning).

Science: Science involves gathering evidence and constructing explanations of the natural world. Science is concerned with answering the question “Why?” and scientific inquiry is the investigative approach connected with science.

Semiotics: Semiotics is the study of signs and sign systems and how people interpret these signs and systems. In science education, semioticians could study the physical structure of the classroom, the structure of the lesson, how time is used and the interactions between the teacher and students to discuss the messages contained in these phenomena. For example, the way in which a science teacher organizes a class discussion contains subtle messages about what the teacher believes about how children construct meaning in science classes. Another example could involve the arrangement of seating in the classroom (e.g., in rows or in groups) and how this arrangement can reflect the teacher’s belief about how children learn and the nature of appropriate classroom interactions.

Skills: Skills are the cognitive, procedural and manipulative tools children use during scientific inquiry, technological problem solving and STS decision making. Common **scientific inquiry skills** include asking questions, researching information, planning simple investigations (observing, classifying, inferring, formulating hypotheses, predicting, designing fair tests), employing equipment and tools to gather data (measuring, observing), recording data and using the data to construct reasonable explanations (formulating models, defining operationally, communicating). Common **technological problem-solving skills** include identifying a problem, designing a solution or product (drawing ongoing designs, considering constraints, troubleshooting), implementing a proposed solution (choosing materials, using appropriate techniques), evaluating the completed design or device and communicating with others. Common **STS decision-making skills** include understanding the issue, organizing information, identifying alternatives, analyzing and synthesizing information, deciding on a course of action, taking action, evaluating actions and decision making.

Social Constructivism: Social constructivist theory is focused on the social rather than individual nature of learning. Social constructivism is now used by many science education researchers to interpret interactions within science classrooms.

STS (Science/Technology/Society): An instructional approach STS that considers the many complex interactions among science, technology and society (and environment). For example, an STS view recognizes that:

- new scientific discoveries can inform current and new technology (e.g., the laser and research on light)
- new technology can assist scientific inquiry and the generation of new scientific discoveries (e.g., the electron microscope)
- society influences the kinds of scientific questions that are asked (e.g., questions about stem cell research) and the kinds of technologies that are built (e.g., technology that allows us to harvest stem cells)
- technology that is created (e.g., the automobile) and scientific ideas that are constructed (e.g., the science behind organ transplants) influence the direction of society.

Subject Matter Knowledge: Knowledge about content – how it is organized and the general and specific concepts that comprise that content.

Technology: Technology involves practical activity focused on the manufactured world. Technology arises from human wants and needs and is concerned with answering the question “How?” Design is a key feature of technological problem solving. A term commonly used to describe technology topics in the *Alberta Elementary Science Program* is “design technology.” This term helps to distinguish these topics from “information technology.”

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Appendix A:
Journals Consulted and Number of Articles Reviewed
and Extracted

Name of Journal	Number of Articles Reviewed	Number of Articles Extracted
English Language Science Education		
<i>Science Education (2000–2006)</i>	365	45
<i>Journal of Research in Science Teaching (2000–2006)</i>	353	56
English Language Design Technology Education		
<i>International Journal of Technology and Design Education (2000–2006)</i>	137	27
Aboriginal Science Education		
<p><i>Research in Science Teaching, Science Education, and Canadian Journal of Mathematics, Science and Technology Education. Also, various issues of Research in Science Education, Australian Science Teachers' Journal, International Journal of Science Education, American Indian Cultural and Research Journal, and Journal of Geoscience Education</i></p>	<p>A number of these articles have been collected over an extended period of time so there is no accurate count of the number of articles reviewed.</p> <p>For this literature review, 11 articles were extracted.</p>	

French Language Science, Design Technology Education		
<i>Revue canadienne de l'enseignement des sciences, des mathématiques et de la technologie (Canadian Journal of Mathematics, Science, & Technology Education) (2000–2006)</i>	165	19
French Language General Education		
<i>Revue canadienne de l'éducation (Canadian Journal of Education (2000–2006))</i>	146	1
<i>Revue des sciences de l'éducation (2000–2006)</i>	276	4
<i>Revue canadienne des langues vivantes (Canadian Modern Language Review (2000–2006))</i>	156	2
<i>Éducation et francophonie (2000–2006)</i>	232	4
Integrating Computer Technology		
<i>Journal of Science Education and Technology (2005–2007), Journal of Computers in Mathematics and Science Teaching (2000–2005)</i>	193	11
Alberta Program of Studies		
<i>Alberta Science Education Journal (1995–2006)</i>	98	22
Other Relevant Journals and Documents Containing Articles about the Alberta Context		
<i>Journal of Technology Education; Research in Science and Technological Education; assorted CMASTE publications; journals and edited books containing articles by Alberta researchers</i>	n.a.	22
TOTAL	Reviewed: 2121 Extracted: 224	

Appendix B:

Teaching Science in French Language Classrooms

Prepared by: Yvette d'Entremont

NOTE: This literature review is a clear indication that there is much research on the subject of teaching science at the elementary level. There is less research on teaching science (in French) to Francophone and French Immersion students. It must be made clear that the two are not the same. There are five Francophone school boards in Alberta that meet the needs of Francophone students across the province. The language of instruction is French, except for the English class. There are also 25 public school jurisdictions, 14 separate school jurisdictions and 3 private schools offering French Immersion. These two situations are quite different and each has a unique clientele. The majority of students in French Immersion do not have French as their first language. For the Francophone students, learning in French in a minority setting, such as Alberta, is quite different from learning in French in a majority setting, such as Québec. One must consider the distinctive role of each in order to fully understand what teaching means in those settings. This review does not attempt to describe and compare Francophone and French Immersion education in Alberta. I have attempted to put together a few references relevant to teaching science in French in minority settings.

A number of studies have concluded that learning science is like learning a language and that strategies used to learn a language should be used in the science class (Laplante 1997, 2000, 2001b, 2004; Cormier, Pruneau, & Rivard, 2004; Cormier, Pruneau, Rivard, & Blain, 2004; Rivard, 1994, 1998, 2002, 2004; Rivard & Straw, 2000; Laufer, 2003; Lemke, 1990, 1998).

ABSTRACT:

Laplante (2004) explores issues related to the integration of content and language in learning, especially in French Immersion classrooms. Laplante compares learning science in French for French Immersion students to a double-edged sword, the two sides of the sword being the content knowledge and the language knowledge. Content knowledge refers to the scientific content. Language knowledge refers to the necessary language strategies that are needed to read and understand a written text, the syntactic structures necessary to be able to define scientific concepts and to compare scientific facts and knowledge. His experiences as a teacher and a researcher lead him to conclude that if French Immersion students are to progress in their knowledge of scientific content, it is essential that as much emphasis should be placed on the language as on the scientific content.

RÉSUMÉ:

Laplante (2004) indique:

Cette double tâche, à laquelle les élèves font continuellement face en immersion, est d'autant plus difficile à accomplir que la dimension langagière des situations d'apprentissage proposées reste trop souvent implicite ou se limite, dans le meilleur des cas, à l'apport d'un certain vocabulaire. Il semble que beaucoup d'enseignants en immersion aient plutôt tendance à enseigner de façon « réactive » (Laplante, 2000). C'est à dire qu'ils ne font que réagir à certains

des besoins langagiers immédiats des élèves. Ils leur fournissent le vocabulaire nécessaire et corrigent parfois certaines de leurs erreurs de langue. C'est un peu comme si on s'attendait à ce que les élèves parviennent à maîtriser les autres éléments de la dimension langagière (entre autres, les structures syntaxiques et les caractéristiques discursives) sans qu'il soit indispensable de les enseigner d'une façon ou d'une autre. Sans vouloir minimiser l'importance du vocabulaire, il faut réaliser qu'il ne constitue qu'un élément de la « dimension langagière ». Mon expérience en tant qu'enseignant et chercheur en immersion m'amène à conclure que si nous voulons que les élèves en immersion progressent dans leur apprentissage des matières et de la langue cible dans laquelle elles sont enseignées, il est essentiel de donner une place dans l'enseignement tant à la dimension propre, à la matière enseignée qu'à la dimension langagière. © <http://uregina.ca/~laplantb/CAT.BRC/texte-conference.htm> (le 21 février 2007)

Pruneau & Langis (2002) summarize the results of a mini-study with Francophone students in New Brunswick. The results indicate that language is a barrier to scientific comprehension. This is a result of the interaction between the nature of the scientific content and the language competencies of Francophone students in a minority setting.

The following is taken from Pruneau & Langis (2002):
<http://www.acelf.ca/liens/crde/articles/20-pruneau.html>

ABSTRACT:

It seems that a number of scientific concepts do not make *sense* to students in minority cultures. The scientific concept in question may have never been observed, may have not been discussed, or it may have been discussed in another language. The lack of familiarity with a concept therefore limits the construction of knowledge. The scientific events and phenomenon will therefore remain unfamiliar to students. Because of shyness or malaise, these students participate less in scientific discussions. The attention of the student is shared between two processes: the learning of the scientific language and the learning of the scientific content. They experience difficulties when trying to decipher what content is important or what tasks are to be accomplished. These decisions influence their results on tests and assignments. The socio-constructivist process (e.g., describing observations, describing experiences, discussions with classmates, writing a report) is also comprised. Writing a text becomes more complicated when one is dealing with limited language competencies.

RÉSUMÉ:

Il semblerait d'abord que plusieurs concepts scientifiques n'ont pas vraiment de *sens* pour les élèves des minorités culturelles. Le phénomène représenté par le concept n'a jamais été observé ou, s'il l'a été, il n'a souvent pas été nommé ou il a été nommé dans une autre langue. Durant une leçon, le manque de familiarité avec un concept limite la construction d'une compréhension partagée entre les élèves et l'enseignant (Rosenthal, 1996). Les phénomènes et les événements décrits demeurent non familiers pour les auditeurs. Ceux-ci, par malaise ou par gêne, participent moins à la discussion scientifique suscitée par l'enseignant et recommandée par le programme d'étude. Étant donné le manque de compréhension, l'attention des élèves est partagée entre deux processus : apprendre la langue et comprendre les sciences (Lemke, 1990). Ils éprouvent parfois de la difficulté à discerner les éléments importants de la matière ou à

comprendre les tâches à accomplir, ce qui influence leur réussite lors d'exercices ou de tests (Lee & Fradd, 1996). Les démarches de discussion et d'écriture exigées par la démarche socio-constructiviste (décrire ses observations, ses expériences, discuter avec les camarades, rédiger un rapport de recherche...) pose également des problèmes importants (Laplante, 2000)). Quand on compose avec des compétences langagières limitées, il est plus compliqué d'organiser un texte et de lier des idées pour démontrer une causalité (Duran, Dugan, & Weffer, 1998).
©Pruneau & Langis (2002): <http://www.acelf.ca/liens/crde/articles/20-pruneau.html>

The results of national and international tests indicate that students from Francophone minority settings attain lower results in science than students in an anglophone setting (Cormier, Pruneau, Rivard, & Blain, 2004). In order to improve student results in science in French minority settings, they studied the specificities of teaching in a minority setting and developed a pedagogical model specific to teaching science to students in minority settings. This model integrated language elements such as writing, discussion and reading, all specific to learning science (Cormier, Pruneau, & Rivard, 2004).

Abstract from:

Cormier, M., Pruneau, D., & Rivard, L. (2004). S'appropriation d'un vocabulaire scientifique en milieu minoritaire. *Cahiers francophones de l'ouest*, 16(1-2), 175–197.

ABSTRACT:

The poor results in science of Francophone students in minority settings at the national and international level have prompted the creation of a pedagogical model to teach science specifically to this group of students. The model integrates aspects of language learning to science learning: writing, reading, discussion. The model is inspired by the socio-constructivist and leans on the experiential. One objective of the study was to see if the model improved the acquisition of scientific vocabulary of the students. Before the study, students used a more common scientific vocabulary whereas they used a more scientific vocabulary after the study.

RÉSUMÉ:

Les faibles résultats en sciences, pour les élèves du milieu francophone minoritaire, lors d'épreuves au plan national et international, interpellaient la recherche de solutions. Nous avons créé un modèle pédagogique pour l'enseignement des sciences spécifique à ce milieu. Ce modèle intègre des éléments langagiers : l'écriture, la discussion et la lecture, à l'apprentissage scientifique. Cet apprentissage préconise une démarche d'évolution conceptuelle d'inspiration socio-constructiviste tout en s'appuyant fortement sur l'expérientiel. Un aspect de notre recherche visait à savoir si ce modèle favorisait une acquisition d'un vocabulaire scientifique chez les élèves, en rendant l'usage du vocabulaire authentique et réal à travers les activités langagières communicatives exploitées. Une classe de cinquième année a participé à la mise à l'essai de notre modèle et a étudié les marais salés de leur localité. Nous avons constaté que les élèves utilisaient des mots surtout communs (plantes, oiseaux, insectes) avant l'intervention tandis qu'ils étaient en mesure de mettre à profit des mots scientifiques (spartine alterniflore, détritrus, chevalier à pattes jaunes) à la fin de l'intervention. Le modèle développé pourrait ainsi bien servir aux élèves du milieu linguistique minoritaire.

© Cormier, M., Pruneau, D., & Rivard, L. (2004). S'approprier d'un vocabulaire scientifique en milieu minoritaire. *Cahiers francophones de l'ouest*, 16 (1-2), 175–197.

Abstract from:

Cormier, M., Pruneau, D., Rivard, L. & Blain, S. (2004), Un modèle pédagogique pour améliorer l'apprentissage des sciences en milieu linguistique minoritaire. *Francophonies d'Amérique*, 18, 21–36

http://muse.jhu.edu/journals/francophonies_damerique/v018/18.1cormier.html

ABSTRACT:

A pedagogical model was developed to teach science to students in a Francophone minority setting. This article examines the specificities of teaching in a minority setting. The researchers propose a process that will guide the evolution of science concepts. The contributions that language brings to science are presented.

RÉSUMÉ:

Dans le but d'améliorer l'apprentissage des sciences en milieu minoritaire, nous avons commencé à élaborer un modèle pédagogique pour l'enseignement des sciences adapté à ce type de milieu. Dans le présent article, nous examinons d'abord certaines spécificités de la pédagogie en milieu minoritaire. Nous proposons ensuite une démarche visant le changement et l'évolution conceptuels en sciences. Nous présentons enfin les divers apports des éléments langagiers à l'apprentissage des sciences. Ces propos théoriques nous amènent à élaborer un modèle pour améliorer l'apprentissage des sciences en milieu minoritaire, modèle qui sera expérimenté dans une recherche ultérieure.

© Cormier, M., Pruneau, D., Rivard, L. et Blain, S. (2004), Un modèle pédagogique pour améliorer l'apprentissage des sciences en milieu linguistique minoritaire. *Francophonies d'Amérique*, 18, 21–36

http://muse.jhu.edu/journals/francophonies_damerique/v018/18.1cormier.html

Rivard has published a number of articles on the subject of language-based activities in science. Rivard and Straw (2000) indicate that “analytical writing is an important tool for transforming rudimentary ideas into knowledge that is more coherent and structured. Furthermore, talk combined with writing appears to enhance the retention of science learning over time. Moreover, gender and ability may be important mediating variables that determine the effectiveness of talk and writing for enhancing learning” (p. 566).

Thouin (1996, 1997, 1998, 2001, 2004b, 2006) has published a number of books on teaching science at the elementary level. The books are written in French but do not deal specifically with teaching science to French Immersion or Francophone students in a minority setting. The collection of science education books by Thouin is an excellent resource in French. They are very valuable to teaching elementary science as they address topics related to this subject. For example:

- knowledge, skills and attitudes
- measure and evaluation
- constructivism

- children’s conceptions of science
- technology and information (TIC)
- problem solving
- the language of science and technology
- integration of subject content

The collection also contains scientific content for elementary teachers.

In 1996, l’Académie des sciences, under the initiative of 1992 Nobel physicist Georges Charpak, launched a program to promote scientific investigation in French schools. The program was called *La main à la pâte* and continues to exist.

L’Académie des sciences (1996) outlines certain principles that can be used by teachers and parents to teach science to students. For example:

- constructing knowledge
- making time for understanding
- language and science
- scientific research in the classroom
- scientific knowledge of children
- the role of the teacher

La main à la pâte Web site (<http://www.lamap.fr/>) is to help teachers, program developers, scientists and educational institutions prepare and deliver quality science teaching in the French elementary schools. The Web site contains classroom activities, scientific and pedagogical documents, opportunities for professional development, and collaborative opportunities.

ABSTRACT:

La main à la pâte recommends the construction of knowledge through exploration, experimentation and discussion. Students learn through action and participation. They learn by progressing slowly and by making mistakes. Situations that develop scientific reasoning can be approached through student questions. The teacher can then guide students and discuss the different points of view while paying particular attention to the language.

RÉSUMÉ:

La démarche préconisée par *La main à la pâte* privilégie la construction des connaissances par l’exploration, l’expérimentation et la discussion. Les élèves réalisent des expériences, pensées par eux, et discutent pour en comprendre l’apport. Ils apprennent par l’action, en s’impliquant. Ils apprennent progressivement, en se trompant. L’enseignant propose, éventuellement à partir d’une question d’élève, des situations permettant l’investigation raisonnée. Il guide les élèves sans expérimenter à leur place, il fait expliciter et discuter les points de vue en accordant une grande attention à la maîtrise du langage, il fait énoncer des conclusions valides par rapport aux résultats obtenus, il repère ces conclusions par rapport au savoir scientifique. Ainsi, l’enseignant gère des apprentissages progressifs.

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