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ABSTRACT

Originally prepared for the Science Council of Canada, this document presents a rationale and general framework for a science and society curriculum for Canadian students. Pointing out ways in which citizens are scientifically illiterate, it argues that science education must address social issues and prepare individuals to make social and political decisions. Section one identifies three broad topics which should guide the development of a science and society curriculum: the characteristics of science, the limitations of science, and the place of science in Canadian society. Recognizing the student as a consumer of science education with individual needs, section two elaborates on four fundamental issues for consideration in developing a curriculum: different kinds of knowledge developed from science education, different roles that graduates will play in society, different ways graduates will use knowledge developed from science class, and decision-making processes used in resolving science-related social issues. The final section discusses the characteristics and limitations of science which must guide the development of a curriculum. (DC)

Science in Social Issues

Implications for Teaching

A Discussion Paper
by Glen S. Aikenhead

Science Council of Canada

Discussion Paper D80/2

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December 1980

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FOREWORD

This paper has been prepared for a study of Canadian science education being undertaken by the Science Council of Canada, under the direction of its Science and Education Committee. The study, which began in the spring of 1980, has three overall aims:

- to establish a documented basis for describing the present purposes and general characteristics of science teaching in Canadian schools;
- to conduct an historical analysis of science education in Canada;
- to stimulate active deliberation concerning future options for science education in Canada.

As this third aim suggests, the Science Council has, at present, no collective view on desirable directions for science education in Canada. It is seeking, however, to develop such a view and to this end is actively soliciting a diversity of opinions concerning possible directions. It is intended that these viewpoints, articulated in the form of discussion papers and disseminated as widely as possible, will prompt science educators and others to review current policies and practices. By sharing in these deliberations and at the same time conducting a systematic inquiry into current and past policies and practices, the Science Council hopes to acquire a good understanding of the state and needs of science education in this country, and thereby make constructive recommendations.

The first discussion paper in this series, *A Canadian Context for Science Education*, was published in 1979. Its author, James E. Page, argued strongly for greater attention to the achievements and the impact of science and technology in Canada.

The present paper takes part of this argument a step further, and raises important questions about the type of science education members of society will require in the latter part of this century. The author, Glen S. Aikenhead, himself experienced in both science teaching and curriculum research and development, outlines some of the complex ways in which science relates to social and political decision making. This analysis leads to the identification of a set of goals for science education which, he argues, are needed if Canadians are to be able to comprehend and contribute to their technologically-oriented society. The remainder of the paper provides a detailed account of how such goals can be implemented through the use of appropriate teaching strategies.

It must be stressed that the views expressed in this discussion paper are those of the author, and not necessarily those of the Science Council or its Science and Education Committee. However, in publishing the paper, Council believes that a well argued position has been set out, and that discussion amongst a wider audience can benefit both the study and Canadian science education, in general.

James M. Gilmour,
Director of Research,
Science Council of Canada

PROLOGUE

Under Section 236 of the Criminal Code of Canada, it is against the law for a person to drive with over 80 mg of alcohol per 100 mL of blood in the bloodstream. The law requires that a test be available for assessing a person's blood alcohol level, and Borkenstein's breathalyzer provides the technical means for such a test.

This technological device draws upon established scientific knowledge and methods; for example, gas laws, oxidation-reduction principles, equilibrium, taking accurate instrument readings, use of control samples, and estimation of measurement errors. Like most technological advances, Borkenstein's breathalyzer has had social implications. It has enabled police to test drivers suspected of driving while impaired, and has discouraged some potentially dangerous drivers from operating their cars while under the influence of alcohol.

But at the same time, it has caused unforeseen problems in Canadian courts when results of breathalyzer tests are used as evidence. To obtain a conviction of impaired driving, the evidence against a person must be "beyond reasonable doubt". With a Borkenstein breathalyzer, this evidence consists of a reading from a scientific/technological instrument. The problem for the courts is that to establish proof beyond reasonable doubt, judicial reasoning or scientific/technological reasoning may be used. (The two are not necessarily the same, as will be shown.) Should the courts use scientific/technological reasoning for cases in which Borkenstein breathalyzer readings are used as evidence? Some Canadian judges say "yes", while some say "no"!

Two recent cases, *Regina* v. *Moreau*, and *Regina* v. *Maclellan*, have questioned the validity of scientific thinking in Canadian courts.

With a blood alcohol level of 90 mg per 100 mL, Moreau was charged with, but not convicted of, impaired driving. The Quebec courts accepted his defence that measurements from the Borkenstein breathalyzer, like all scientific instruments, contain an inherent margin of error. Experts considered this margin of error to be ±10 mg. The Quebec courts understood the law to mean "above 80±10 mg". And, of course, a reading of 90 mg is within this margin of error. However in 1978, the Supreme Court of Canada overruled the Quebec courts, and in a 5 to 4 split decision convicted Moreau of impaired driving. The Supreme Court majority contended that a reading from an instrument that has been approved by the Solicitor General does not have a measurement error associated with it. One year later, the Solicitor General's Office sent a memorandum to all officers operating the Borkenstein breathalyzer. It asked them not to lay charges unless the suspect "blows 90 mg or over."

In the Maclellan case, a British Columbia court found Maclellan not guilty because the breathalyzer technician failed to follow proper scientific procedures on three points: 1) the technician did not take the room temperature. (The equilibrium in the standard potassium dichromate solution is affected by room temperature, and the operating manual states that the temperatures of the room and solution must be within 1°C of each other); 2) the technician used inappropriate sampling techniques to ensure the suitability of the dichromate solutions; 3) the technician did not use a control for each breath sample analyzed. In his written judgement, Mr. Justice Washington stated:

> "...Surely, therefore, before in fact anyone is convicted by a machine it must be clearly demonstrated on the evidence and beyond reasonable doubt that the machine's answers are as a result of strict accuracy and strict observance and compliance by the technician in operating to the operation manual.
>
> "Nowhere in this manual does it state the Borkenstein Model 900A is a self-testing machine or error-proof. *To hold that it is*, therefore, in my judgment, *would be for the Court to place itself, in chemical and scientific knowledge and technical operation, above the knowledge of the experts who have written the manual.*
>
> "Any machine can malfunction or (in this context) give incorrect readings if it is not correctly operated and this is clearly set forth in the manual. Surely, therefore, not one of the instructions can be ignored or by-passed or performed in any way but precisely as set forth in the manual. Only then can the final readings be accepted by the Court as proof of anything."* (Italics mine.)

The Supreme Court of Canada *overruled* Mr. Justice Washington, and convicted Maclellan of impaired driving.

Canadian courts do not agree on the relevancy of scientific thinking. In order for the courts to achieve consensus, judges would require a common literacy about science and a common wisdom for deciding when scientific reasoning is appropriate.

But where in our society can judges and other citizens develop a literacy about science and the wisdom for utilizing scientific thought? High school science courses that teach about the relationships between science and society could provide one means. This paper outlines what the objectives of such courses might be, why these objectives are vital to Canadian society, and what attributes of science need to be taken into consideration in developing materials for a science and society curriculum.

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*Penticton Registry, Doc. No. 129/78, December 1978, pp. 19,20.

RETHINKING THE GOALS OF SCIENCE EDUCATION

In February 1975 during a debate on an abortion bill, a federal cabinet minister said that he would wait until science defined when an embryo becomes human, before he would take a stand on the abortion issue. The cabinet minister, recognizing the abortion issue as a science-related problem, believed that the scientific community could therefore define when an embryo is human. After all, that is what science does, doesn't it: it makes clear definitions!

In Canada today, major decisions on science-related issues are being made by those who misunderstand what science does. This misunderstanding occurs with government agencies, corporate boards, industrial experts, and citizens voting on plebiscites. Canadians are constantly making decisions about future energy resources (e.g., nuclear or conventional), food production (e.g., bioengineered or natural), and pollution (e.g., acid rain and insecticide poisoning). If decisions are being made by people with as little knowledge about science as the federal cabinet minister, the cost to Canadians will be severe. James Page came to the same fundamental conclusion in his paper, *A Canadian Context for Science Education.*

> "If Canada is to deal effectively with its future, then a citizenry able to comprehend science issues is a necessity. This goal will be possible only if our present and future scientists are critically aware of the impact their research and teaching can have on Canadian society, and only *if the*

> *general population understands the important relationship between science and society.*"[1] (Italics mine.)

The relationship between science and Canadian society is complex, intricate, and multifarious. The scientific enterprise affects Canadian society in a number of ways. Canadian society likewise influences science. The two interact. The more the general public and professional scientists understand this interaction, the more likely that effective resolution to science-related problems will be achieved.

For many citizens, including many who will go on to further education, the primary and possibly only opportunity for acquiring an understanding of the interaction between science and society will be in science courses taken as part of a general education. School science teaching has, therefore, a special responsibility to ensure that its goals and practices provide an opportunity for students to learn about this vitally important area. Yet, traditionally, science education has been concerned with other things. Now is the time for these traditional goals and practices to be reformulated with the express intention of incorporating and emphasizing this science/society interaction. This idea is not new; the same point has been made in the United States,[2,3,4,5] in Britain,[6] and also here in Canada.[7,8] In the words of Paul Hurd, we must "align the teaching of science with social realities."[9]

While it is not the purpose of this paper to argue in detail about what a comprehensive set of goals for science education should be, a subset of those goals is described here as embodying a "science-and-society" orientation.*

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* For another account of such an orientation, see Orpwood and Roberts.[10] A more detailed account of objectives concerning the process, nature, and social aspects of science is set out by Aikenhead[11] and Welch *et al.*[12]

Let us return briefly to the cabinet minister who believed that science could define the point at which an embryo becomes human. Such a definition is clearly beyond the domain of science *per se*. However, scientific knowledge (embryo physiology or biochemistry) may be drawn upon in a rational way when political, ethical or judicial decision makers formulate a definition. Although defining humanness is not a scientific task, scientific knowledge may be useful to a limited extent. Thus an important lesson is learned from the abortion debate scenario: rational discussion of science-based issues will invariably be mediocre without a realistic appreciation of what *can* and *cannot* be done with scientific methods and knowledge. In order to make rational decisions on science-related issues, Canadians require answers to three vital questions:

1. What does science actually do, and what is it really all about?

2. What are the limitations of science: what can it do and what can it say?

3. How can science, with all its limitations, be used to help Canadians resolve "real life" social problems, and cope with, and manage, a complex scientific, technological society?

Science education in Canada can certainly help students answer these questions by assisting them in learning:

1. *The characteristics of science*; including its aims and values, its human character, and its strategies for decision making and extending knowledge;

2. *The limitations* of scientific knowledge, scientific values, scientific strategies, and scientific techniques; including the recognition that science is but one knowledge system among many in our society, and an examination of the boundaries between science and politics, science and economics, science and religion, science and technology, and science and ethics;

3. *The characteristics of science and its place in Canadian society*; including Canadian case studies of science-

related problems; and including personal interpretation of one's community by making decisions as a consumer, as a voter, and in career planning.

These objectives merit the highest priority in any curriculum with a science and society focus.

How do people such as the aforementioned cabinet minister come to believe that science alone can settle complex value judgement problems? What would such people need to know to prevent them from coming to such conclusions? One thing seems certain. Scientific knowledge by itself, for example meiosis/mitosis, embryo physiology, and the role of RNA in cell differentiation, will not alter erroneous expectations of science. One may have memorized the major phyla, and have learned to balance redox reactions. One may have excelled at solving physics problems. And one may have received A's in high school science. But when interpreting the "real" world at a crucial moment of decision, one may be ignorant. Generally speaking, such people do not understand the characteristics and limitations of science.

The remaining two sections of this paper expand on the objectives identified here. As pointed out earlier, a reorientation of the current science curriculum is being proposed: from a curriculum that is structured after the discipline itself, to another - the science and society curriculum - based on the social context of the student and the role science plays within that context. In order to explore the implications of teaching a science and society curriculum, one must recognize that students are *consumers* of science education. Section II of this paper addresses the consumer/student viewpoint. As a consequence of this perspective, some important characteristics and limitations of science are examined in section III. This analysis is illustrated by reference to a set of curriculum materials, *Science: A Way of Knowing*,[13] developed and tested in Saskatchewan for use in teaching science at the junior high school level.

II THE CONSUMER OF SCIENCE EDUCATION

Introduction

The type of knowledge acquired in most science classes is inadequate for the future needs of the student. The study of science has traditionally been socially and culturally sterile, and instruction has not prepared many students for their future social responsibilities. Perhaps if science instruction focused more on the relationships between science and Canadian society, people such as the aforementioned cabinet minister would be better prepared to discuss moral and social issues, such as abortion.

Adopting a science and society curriculum for Canadian schools has many implications. While exploring some of these implications, one must constantly keep in mind the interests of the clientele. The consumers of science education develop different kinds of knowledge from their science classes. They see that knowledge as relevant only if it relates to their needs, interests, or social responsibilities. Different social responsibilities lead to different uses being made of that knowledge. These realities suggest at least four fundamental issues, each representing a vital component of the students' education in science:

A. The different kinds of knowledge developed from science education;

B. The different roles that Canadian high school graduates will play in society;

C. The different ways Canadian high school graduates will use the knowledge developed from science classes;

D. The decision-making processes used in resolving science-related social issues.

These four topics help to define the consumer's point of view. By conducting a study of science education in Canada, the Science Council of Canada has indicated its desire to participate with provincial science educators in deliberations concerning the future of science education in this country. In this context, an appreciation and understanding of the needs of the consumer are important to the quality of those deliberations. For this reason, the issues listed above are developed at greater length.

A. Different Kinds of Scientific Knowledge Developed

A fair amount of research and discussion in science education has been predicated on the belief that there are a variety of different legitimate goals in a child's science education. One classification scheme that emerged in the 1960s looked at science goals in terms of "product" and "process". Another popular scheme, rooted in educational psychology, described three domains: "cognitive", "affective" and "psychomotor". Klopfer applied this psychological system to science instruction.[1,2] His classification scheme is the one most often used in science education literature today. Although Klopfer's expanded system contains many details, one can recognize five different categories of knowledge that students develop from their science experiences:*

1. Subject matter facts, concepts, principles, and skills (intellectual and manual), and their application to new situations in science and technology;

* This five-category scheme is a heuristic device. It gives some reasonable structure to the paper, and thus it guides the reader through an otherwise complex quagmire.

2. The ability to engage in the processes of scientific inquiry;

3. General ideas about the characteristics and limitations of science;

4. Important relationships between science and society;

5. Attitudes and interests related to science.

Because the purpose of this paper is to examine the consequences of adopting a science and society content in science classes, a thorough treatment of each category is not included here.* Instead the discussion will focus on the relationship between knowledge acquired from science education and understanding the interactions between science and Canadian society.

1. The first category is the set of traditional facts, principles and skills of the discipline. For example, students may learn to define "mass" and "atom", to describe the structure of the atom, to recognize the difference between fusion and fission, to compare meiosis with mitosis, to calculate density, to analyze an event in terms of the conservation of energy, and to use the atomic molecular model in explaining familiar physical phenomena. With this knowledge, students deal with science using a frame of reference, or perspective, restricted to the domain of the discipline. In a sense, it is seeing and experiencing science through the eyes of the professional practitioner. This aspect of science education has long been recognized as pre-professional training.[4,5,6,7] High school teachers and students perceive it as the content of university entrance or placement exams.

A purely discipline-centred curriculum does not produce an opportunity for studying the relationships between science and Canadian society. These relationships involve the integration of knowledge from

* For a thorough treatment, based on an integration of psychological empiricism, science education, and a philosophy and epistemology of science, see Aikenhead, 1978.[3]

various disciplines. Rather than being integrated, discipline-bound courses are usually isolated in an academic vacuum. They appear to have little relevance to everyday life. Where relevance does exist, it is primarily for the university-bound student, who may require pre-professional training in science. While Jerome Bruner's *The Process of Education*[8] enthusiastically encouraged the discipline-centred curricula of the 1960s, his paper "The Process of Education Reconsidered"[9] supports the need to broaden curricula in order to deal with other vital knowledge such as the relationship between science and society.

Recent research has shown that many students can be adept at mimicking the language and problem-solving skills of scientists without actually learning the scientist's frame of reference.[10] Just because students appear to learn the subject matter of science does *not* mean they have understood it as a scientist understands it. Many students resist learning the structure of the discipline.

2. Engaging in scientific inquiry has been espoused as an important objective of science instruction. This activity requires student participation in problem solving, decision making, critical thinking, and/or knowledge generation. John Dewey's idea of learning to inquire into natural phenomena was revitalized in the post-Sputnik professional literature of science educators.[11] On the one hand, this kind of knowledge could be acquired as pre-professional training, learning to carry out the processes of science through the eyes of a scientist. On a broader basis, scientific inquiry could be a personal experience from which students reflect on the *nature of* scientific inquiry (its purposes, its assumptions, its characteristics and limitations).

From either perspective however, engaging in this type of inquiry is unlikely to occur in most American schools today.[12] Canadians have a critical lesson to learn from their American neighbours on this point. During the post-Sputnik era in the US, the National Science Foundation and professional science education associations encouraged teachers to alter their science curricula to include scientific inquiry. Welch's research group described a cycle of reasons for the American lack of success: the absence of inquiry in university science classes, the dearth of inquiry in a teachers' professional courses, the anticipated problems in implementing curricula changes (equipment, space, and time), the paucity of textbooks that include inquiry as an integral part of the content, and the subtle but powerful antagonism of the community's values toward inquiry.[13]

The implications for Canadian science educators are clear. Altering the traditional view of good science teaching will require concerted action on a number of fronts. To overcome the inertia of the status quo, this action must be guided by wisdom. The wisdom of Canadian science educators could be augmented by the experiences of their American colleagues. In this regard, the inquiry story is worth studying.

3. A third category of knowledge for science classes concerns some general ideas about the char~ teristics and limitations of the scientific enterprise. For example, students may learn that scientific theories are developed to explain natural phenomena and to guide further experimentation, and that scientific theories such as evolution or nucleon attraction are not developed to arbitrate on religious or political issues. Students may also discover that because scientific knowledge is developed by humans, it is subject to all the characteristics and limitations of the imagination, logic and foibles of human nature. Alternatively and unfortunately, students might acquire the misconception that scientific knowledge is objectively correct and unalterable, "a rhetoric of conclusions."[14]

When acquiring this third area of knowledge, a student uses a frame of reference that exists beyond the domain of science. It is a matter of stepping outside the confines of the discipline, and as an outsider, looking back upon the discipline, examining it, analyzing it, and reflecting on it. In this broader frame of reference, students deal with such questions as: What are the major objectives of scientists in pursuing their research? What thought processes are useful to scientists? What are some of the fundamental unproven assumptions they make in order to do this work? How do they substantiate the knowledge claims they make? What human characteristics help to advance or retard the development of scientific knowledge? How do scientists change their ideas or theories to keep up to date? How do scientists resolve disagreements? Why do they believe what they believe? What are some inherent limitations to their methods of thinking and believing?

Even though a teacher might not consciously plan for teaching in this third area of knowledge, students nevertheless develop some understanding or misunderstanding of the nature of the scientific enterprise.[15] For example, a physics lesson might have the objective of teaching that Force = mass x acceleration (F = ma). The teacher might plan an experiment in which the relationship F = ma is generalized from observations by the class. Alternatively, the teacher might state the relationship as a scientific fact and give mathematical examples. In each type of lesson, a student is likely to learn something more than F = ma. Exposed to the first method he or she might learn: science is not as precise as the mathematics it uses. Exposed to the second he or she might learn: science is a body of precise, unalterable knowledge.

It has been argued earlier in this paper that misconceptions and distorted knowledge about the nature of science have foreboding consequences to individuals wishing to cope with a scientific and technological society. Research in science education suggests that many high school graduates in the United States and Canada have inadequate and grossly distorted knowledge about the nature of science.[16,17,18,19] Present high school science courses generally do not ameliorate a student's misconceptions and false images of science.[20,21] An evaluation of the Saskatchewan chemistry program indicated that students develop as many misconceptions as realistic understanding about science and scientists.[22] Moreover, research clearly indicates that students tend to learn more about the characteristics and limitations of science, the more it is explicitly taught.[23]

In reformulating Canadian science education with a science and society emphasis the following points must be taken into consideration:

1) that students will come to their classes with many misconceptions about the scientific enterprise;

2) that changing these misconceptions into simplified understanding, and then on to more sophisticated insights requires explicit instruction and evaluation;

3) that it is difficult to alter adolescents' misconceptions about science and scientists (probably because we are dealing with their beliefs as opposed to their impersonal repository of traditional subject matter); and

4) that it takes time to change misconceptions, time that would normally be spent in the pursuit of pre-professional training.

Specific ideas about the characteristics and limitations of science are described in some detail in the concluding section of this paper. Students require a realistic understanding about the scientific enterprise in order to study the important relationships between science and the rest of society.[24]

4. The main reason for explicitly teaching the characteristics and limitations of science is its application in the study of the interaction between science and Canadian society.

A science and society perspective would use a frame of reference broader in scope than the one used in the previous knowledge category. Such a perspective views science as a social enterprise that influences human affairs. In the lives of cabinet ministers, corporate board members, the voting public, and inquisitive adolescents, science exists in the context of Canadian society. Science interacts with for example technology, economics, politics, and religion. These areas are themselves affected by science through the technological implementation of scientific knowledge, or more subtly, by the intellectual influence of scientific ideas.25-31 Conversely, science is affected either directly by the degree of their material and moral support, or more subtly by society's metaphors and problems.32 Just as an individual is shaped by his or her cultural environment (sociobiology notwithstanding), science is molded by its societal environment. Hence, there is a separate category of knowledge concerning the interaction of science and society.

In coping with day-to-day life, most adolescents deal with science in this social context. They are "outsiders" trying to make sense out of a society that has in large measure been shaped by science and technology, and continues to be reshaped each year. Typical questions that arise in this fourth area of knowledge are: What are the relationships between science and technology? What is the value of a scientist's opinion when he or she is speaking on a social issue? How does a person work out a relationship between religious claims and scientific claims? Where do scientists acquire the imagery and metaphors they use in their creative thinking? To what extent does financial support influence the direction of science? How do science and technology generate ethical questions? What power do social institutions have in supporting or suppressing scientific research that is detrimental to the public? How can the public influence research carried out in the private business sector? Who mediates conflicts between the interests of public health and the interests of corporate profits? In what ways, and to what degree, is scientific knowledge useful in resolving science-based social issues? Research concerning this fourth area of knowledge reveals a paradox in the minds of many American students:

"We are confronted with a paradox. Young people perceive science and technology as a cause of problems, but they are confident science can solve the problems. They think science has changed life for the better and worse, and beyond a sense of wonder, they are hopeful or indifferent."33

Learning about the relationships between science and society was a major topic of Page's analysis of Canadian science education.34 Concern over an apparent mediocre understanding of these relationships prompted the Science Council study of science education in Canada.35 Thus, the fourth category of knowledge represents the crux of a new direction envisioned for science education in Canada.

Just as this category of knowledge is intricately related to the third (characteristics and limitations of science), it is also closely associated with a fifth, concerning feelings.

5. Attitudes and interests have traditionally been set aside as a separate kind of learning. (However, it can be argued that in the minds of science students cognition is inseparable from affect.36) Therefore a fifth category of knowledge is proposed. Attitudes are developed in the home, in the community, and at school. They may be, for example, positive, negative, accepting, rejecting, valuing, showing awarenesss, or organizing a life outlook.37,38

Two extremes in attitude can be identified as having a very detrimental effect on the study of science and society. On the one hand, there are Canadians who are repulsed by anything scientific and thus, they refuse to acknowledge the productive contribution science and technology can make to the management of Canadian society. On the other hand, there are Canadians who suffer from the delusion called "scientism", the dogmatic belief that all social problems could be solved by science if the resources were available.39,40,41,42 These two attitudes have been described by Schroeer as an allegiance to viewing the world from a holistic, or conversely, a mechanistic perspective.43 A purely holistic person will surely disagree with a purely mechanistic person over a decision concerning a science-related social issue. One's orientation (attitude) carries with it a wealth of values and assumptions, which may be said to form a person's ideology. People with differing ideologies will *perceive* a problem differently, and therefore will conceive of science's role differently.

Science teachers appreciate knowing what attitudes their students possess. However, it is difficult to achieve consensus on a conceptual definition of attitude. "Attitude" can have many meanings.[44,45] It is even more difficult to *assess* someone's attitude.[46] The subject of attitudes, however, falls outside the scope of this paper. For more information the reader is referred to the studies cited.

Summary

Consumers of science education learn different kinds of lessons from their science classes. Training, education, and miseducation develop in the areas of:

1) scientific knowledge;
2) scientific inquiry;
3) the characteristics and limitations of science;
4) the interrelationships of science and society; and
5) feelings or attitudes.

The proportion of training, education, and miseducation that high school graduates acquire depends in part on the student's experiences in science classes. While the subject matter studied is influenced by the home and community, the role of the teacher is a particularly important factor.[47,48] Curriculum materials by themselves can only influence positively or negatively a teacher's idea of what course content is appropriate, or what constitutes good science teaching.[49] It is simply naive to believe that content analysis of curriculum guides and materials will describe what is actually learned by the students.

Researchers wanting to assess the impact of science instruction on students need to use evaluation techniques that move beyond the educational research habits of testing students with standardized instruments, of analyzing curriculum materials, and of amassing questionnaire responses. Other methods of inquiry more appropriate to the task exist; using qualitative data, and conducting ethnographic and philosophical analysis of classroom proceedings.[50,51,52]

Educators who wish to achieve a new direction for science education by enhancing the value placed on science and society content (the fourth category of knowledge), will need an appreciation of the interdependency of the community, the university, the teacher, and the curriculum materials. This homeostatic-like cluster will resist and reject small-scale tinkering. The entire system requires explicit attention.[53]

Furthermore, science education reformers must be aware of the interdependencies among the different kinds of knowledge. Learning to deal effectively with category four, science and society, assumes certain degrees of development in categories three and five. In turn, category three does not exist in isolation from categories one and two.

However, deciding what categories of knowledge should be taught is a hypothetical decision and therefore irrelevant, unless we consider the way in which Canadians will put their knowledge acquired to use. Of course, one's use of knowledge is contingent upon one's role in society.

B. Different Roles in Society

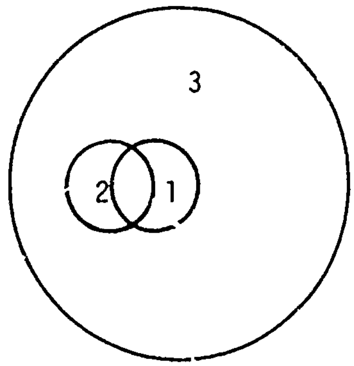
Not only do students develop different kinds of knowledge and misconceptions as a result of their science instruction, but as adults they put that knowledge, or those misconceptions, to use in a number of different ways, depending upon the situations in which they find themselves. Canadians undertake a wide range of social roles. For the sake of discussion, it is convenient to divide these diverse roles into three groups:

1. *Professional scientists and technologists*: most often found in university departments of engineering, medicine and science; and in government and industrial R&D projects.

2. *Key decision makers*: specialists who, perhaps unexpectedly, make decisions on corporate boards, in government agencies, in political office, or on judicial panels.

3. *Citizens*: the general citizenry who try to make sense out of the messages from the advertising media; who try to cope with the scientific and technological advances in their supermarkets, their employment, their leisure, their health, and generally in the quality of their environment; and who are called upon to voice opinions on plebiscites or at public hearings.

Figure II.1 - Societal Roles



1. Professional scientists and technologists
2. Key decision makers
3. Citizens

Figure II.1 illustrates the relationships among the three arbitrary categories.

By considering seriously the probable roles that high school graduates will assume during their lifetime, science educators will acquire a more realistic attitude toward science curricula. Personal, social and national relevance of scientific knowledge is reflected in the different social roles played by consumers of science education. From the consumers' point of view, good science teaching means relevance in the preparation for their responsibilities: in their professional careers; as judicial, business, industrial, and governmental decision makers; and as citizens.

Professional Careers

An adequate pool of scientific and technological human resources is a high priority for any industrial nation. However this need may have overly influenced present Canadian science curricula. Consequently almost all students who enrol in science courses find themselves in pre-professional training. Scientific pre-professional training is an unrealistic and irrelevant goal for 90-95 per cent of high school students because only 5 to 10 per cent actually train for scientific or technological employment.

Nevertheless, this 5 to 10 per cent of high school students will be called upon to form a cadre of excellent Canadian scientists and technologists. Therefore, any good science program in Canadian schools must provide for pre-professional training.

In many Canadian schools, occupational training is a traditional goal in a number of subject fields. For example, students can develop technical trade skills in auto mechanics or develop secretarial knowledge in business education. Some of these programs are financed largely by federal agencies. A similar career program might be desirable in the area of science. It is certainly necessary that special science classes be offered for students who express a career preference for scientific or technological employment. These pre-professional science classes could be financed by appropriate federal and provincial agencies.

Judicial, Business, Industrial, and Governmental Decision Makers

In June 1980, the United States Supreme Court ruled that new forms of life created through genetic engineering can be patented. Canadian judges are expected to apply Section 237 of the Criminal Code, relating to the breathalyzer test. In numerous Canadian cities, civil servants and municipal officials are setting standards for the disposal of radioactive waste. The future of hydrogen fuel is an issue discussed by some corporate boards. Large sums of money and international political power are at stake in the quest for alternate energy resources. And further, the Bayda Commission has made general recommendations concerning the development of a uranium industry in Saskatchewan.

As can be seen, crucial decisions are being made daily by people who are expected to consider scientific and technological knowledge along with the economic, political, and ethical implications. The role of key decision maker pervades Canadian society. This role, however, is not as clearly defined as the role of the professional scientist. Potential decision makers are less easily identified than are future scientists. However, key decision makers carry out a prominent function in determining the quality of Canadian society.

When deliberating on science-related social issues, decision makers must deal with the vital question:

> In which ways, or to what degree, are scientific knowledge and scientific methods useful in resolving science-based problems?

The answer is complex in that it varies with different problems. Given the limited scope of this paper, a thorough answer is not possible. Nonetheless the question must be foremost in the minds of those developing curricula with a science and society emphasis, as the following example illustrates.

A science and society emphasis would examine the methods scientists use in making a scientific decision. Reaching consensus on an observation, or picking a workable hypothesis, are typical examples of scientific decision making. Making decisions involves values; for example, the value of suspending judgement until sufficient evidence is available (a subjective decision itself). However, in the "real world" of Canadian society, decisions must be made with much less information than a scientist would accept when making a scientific decision. Two historical examples illustrate this point. The decision to develop the steam engine did not wait for scientists to formulate hypotheses to describe and explain thermodynamic phenomena. The electrical industry blossomed before scientific circles reached consensus on electrical theory. At the very least, these examples illustrate how scientific decision making can be separate from social decision making. The point leads to a pragmatic generalization. "Thinking scientifically" is not necessarily the way to approach important social issues. Therefore, to train high school students to "think scientifically" does not necessarily prepare them to make good decisions in the arena of science-related social issues. Orpwood and Roberts make this same point in their discussion of a philosophical dimension to science and society curricula.[54]

The science education required by the judicial, industrial and governmental decision maker is an education in using scientific knowledge (present and future) to resolve science-related social problems. Decision-making techniques and wisdom do not develop unless they constitute the explicit content of science classes and examinations. Canadian science curricula currently lack these explicit objectives. Consequently, citizens who become key decision makers tend to perceive their science education as largely irrelevant to the important tasks they perform in Canadian society.

Let us consider in more detail a decision maker's science education in light of an important judicial decision: whether or not to grant patents on organisms produced by cell fusion techniques. What biochemical knowledge and inquiry techniques does a judge need in order to decide if patent laws pertain to man-made biological organisms? What understanding of the characteristics and limitations of scientific knowledge should a judge have in order to compare and contrast scientific concepts with legal concepts? What insights into the interactions amongst science, technology and society would be most helpful to the judge? What judicial attitudes toward science and technology will result in a fair hearing? These questions illustrate science content that addresses the needs of key decision makers in Canadian society. (This viewpoint is obviously different from a preprofessional training perspective: what biological knowledge do students need to prepare for Biology 102?).

Good science teaching for future key decision makers involves carefully selected transitional subject matter plus concomitant experience in decision making related to that subject matter. In other words, if "knowledge is power" then responsible science education should not "abandon" students after they develop some "knowledge"; science education should go the second mile and have students inquire into the wise use of that "power".

In developing new curricula for this purpose, educators need to investigate and work toward an optimum balance amongst traditional subject matter, inquiry, the nature of science, and activities that simulate decision making on science-related issues.

Consider the concept of density for example. Different substances have different densities; less dense substances tend to rise while denser substances tend to settle. This statement is not necessarily a professional scientific statement, but it can be used to follow an argument (about air pollution, for instance) without understanding density as a scientist understands density; i.e., "the ratio of a body's mass to its volume." Proportional reasoning with "abstractions" such as mass and volume is not common among lay people. (The memorized algorithms that students use to solve D = M/V problems are manifestations of this.) Therefore, the usual quantitative approach to teaching density in Canadian schools turns out to be inappropriate for many students. However, there are other approaches to teaching about density. Students could inquire into problems in their environment, in industry, or in law, in which the density of materials is obviously important. If no such applications can be found, then the curriculum developer may decide not to include density in the syllabus. (If however, there are compelling reasons for believing that the density of materials may be important in 2001, the curriculum developer may wish to include the concept.) The practical reasoning over the inclusion or exclusion of specific subject matter does *not* revolve around the prerequisite knowledge necessary to build a professional scientist's view of the world. Instead the practical reasoning focuses principally on which decisions in government, business, industry, and law are explicitly related to the scientific subject matter.

The Citizenry

The car radio carries a Chalk River scientist's voice to the ears of Alice and John Canuck. They hear that nuclear reactors emit less pollution than burning coal. This and other technical data support the scientist's opinion that it would be better to invest in nuclear power rather than coal for the production of electricity. Then the radio announcer interviews an Alberta MP who analyzes the entire nuclear process cycle and the entire coal process cycle of electricity production. The politician points out how the scientist has presented a limited viewpoint. The politician's conclusion contradicts the scientist's conclusion. The industrial and political decision makers apparently disagree. How do Alice and John make sense out of what they have just heard?

In general, Alice and John must cope with, or attempt to manage, their scientific and technological community. Whether they are deciding on the purchase of supermarket produce containing "artificial" additives, voting on a fluoridation plebiscite, or interpreting bulletins in the news media, they are trying to grapple with their complex and changing society.

Considering the full range of knowledge developed from science classes,

1) scientific knowledge,

2) scientific inquiry,

3) the characteristics and limitations of science,

4) the interrelationships of science and society, and

5) feelings or attitudes,

is there any one area that could help Alice and John more than the others? Probably not. Attitudes will have a great deal to do with how they interpret daily events, including whether or not they even listen to the Chalk River scientist or the Alberta MP. Of all the other types of knowledge, knowing about the interrelationships of science and society seems most germane to their personal needs. Also helpful is appreciating that science is limited to answering scientific questions (category three). This makes using science alone inappropriate for answering economic, ethical, or political questions, such as whether it would be better to invest in nuclear power or in coal-fired generating stations to produce electricity. Although science and technology by themselves cannot resolve the question, their subject matter and technical data are essential to an effective solution. Thus, categories one and two are involved to some extent in problem resolution.

Knowledge gained from categories one and two can help Alice and John in other ways. It can assist them, for example, in understanding and monitoring body functions, such as hormone balance and taking temperatures accurately, or in paying attention to labels such as reading the volume marked on shampoo bottles in order to decide which bottle contains more shampoo.

Alice and John need to draw on all areas of knowledge. An education balanced by instruction in each category is sometimes called an education toward "scientific literacy". A curriculum designed for the citizen would be similar to the one described for the key decision maker. Many of the concerns of citizens require making decisions, even a decision on whether to read a newspaper article concerning scientific studies, or whether to pay attention to scientific information at all.

Some examples from a science and society curriculum illustrate the citizen/consumer viewpoint. The electromagnetic spectrum represents scientific concepts related to wave phenomena and energy. Corresponding to these concepts are technological implementations, each related to a social issue: for instance, radio waves and the case of a Saskatchewan Crown corporation jamming TV signals received by a private cable company; radar and the legality of speed-detectors and "fuzz busters"; microwaves and the responsibility to warn people with pace makers of possible dangers; infrared rays and the photographic detection of cancer, forest fires, and winter heat loss from houses; colour and the effects of applying laser technology to supermarket checkout automation; ultraviolet rays and the effect of sun tanning or the selection of protective lotions; X-rays and their biological effects (should lead aprons be worn in the dentist's chair?); gamma rays and problems of storing radioactive substances.

A number of teachers and curriculum developers have designed exciting and intellectually challenging consumer-oriented science materials and activities; for instance, *Properties of Matter*, *Technology & Society Report Series*, *Interdisciplinary Approaches to Chemistry*, some elective modules to ALCHEM, *Environmental Chemistry*, *Consumer Chemistry Learning Activity Packages*, and *Chemistry of Common Substances*.[55]

A consumer approach is not simply a return to "toaster science" - how do toasters work? - of past years. Instead, toasters could be used as concrete examples in the analysis of energy transfer to benefit man and in the analysis of the side effects of technology. The consumer context for instruction in this case would naturally demand a working knowledge of voltage, current, resistance, power and energy. The consumer context would structure this information in a way that students would most likely apply or transfer their new knowledge to other, not yet invented gadgets. The curriculum would *not* structure the information to fit the professional scientist's conceptual framework.

If Alice and John Canuck had studied high school science focused on the consumer, then their ways of thinking might be different. For example, when talking with friends about public transportation and the need to eliminate automobile pollution, Alice and John might recall that when the automobile was first used it saved cities from a serious pollution problem caused by the large number of horses. (How different things would be today if the 19th century inventors had restricted themselves to pollution control devices for horses!) A good science and society curriculum would also have taught Alice and John different ways of looking at technological advance. Scientific and social perspectives would have been integrated using a societal context for structuring the curriculum,56 thereby teaching Alice and John the important relationships between science and Canadian society. Studying the discipline of science without personal relevance is nonfunctional; studying daily events without scientific knowledge is superficial.57

Summary

In exploring the implications of adopting a science and society curriculum for Canadian high schools, one important aspect of that exploration is a realistic analysis of how this knowledge will be used by those who develop it. Canadian high school students will assume different responsibilities in society, and therefore their science education will be put to use according to these different roles: the intellectual scientist/technologist, the insightful key decision maker, and the informed citizen. Each of these social roles contributes to the quality of Canadian society. Because the informed citizen role represents the most pervasive responsibility in Canada, and because the professional scientist's and the key decision maker's responsibilities are special cases of this pervasive responsibility, Canadians would be justified in demanding a science and society focus to their science education.

C. Different Ways of Using Scientific Knowledge

The preceding discussion of social roles revealed how knowledge is used differently for different social responsibilities. This societal perspective will be further supported by a short analysis of different ways of using scientific knowledge.

Greek myths had the pragmatic value of helping an ancient citizenry feel more comfortable in an environment fraught with trials and tribulations. Greeks *memorized* their rich mythology. They *associated* it with specific triumphs and catastrophes. They *applied* predescribed divine attributes to explain daily events. They made personal sense out of their real world by *interpreting* or judging it in terms of their understanding or misunderstanding of their mythical world. Thus, the ancient Greeks used their knowledge of mythology in a number of different ways. (This use was influenced of course by whether they were slaves, plebians, aristocrats, or priests.)

Certainly 20th century science, with its abstractions, mathematical language, and probabilistic "truth" claims, is a far cry from Greek mythology. Interestingly enough, science's abstract and mathematical lexicon has made it a "priesthood" unavailable to many lay people.58,59,60 However, Greek mythology and modern science are similar in the sense that they both constitute knowledge systems. And just as the ancient Greeks used their knowledge system in diverse ways, so do 20th century Canadians.

Broudy (1969) has conceptualized four uses for scientific knowledge:

1. Replicative: rote memory

2. Associative: "the rearousal of learning by a wide range of clues that are related to the learning by the laws of association.

3. Applicative: "the solving of a problem by bringing it under a more general theoretical framework, for example, applying the p.inciples of organic chemistry to the problem of air and water pollution or the principles of mechanics to designing new systems of transportation."61

4. Interpretive: making sense out of information or events, judging relevance, and "crap detecting".62

Broudy described the first three categories as largely limited to the responsibilities of the professional specialist. Not only must scientists and technologists become familiar with scientific theories (in the replicative and associative senses), but they must know the territory where, and problems to which, these theories are applied: that is, they must know how to translate scientific and technological theory into concrete examples of problem solving. To accomplish this, industry and government hire experts.

Broudy's fourth category, the interpretive use of knowledge, highlights the theme of this paper. Broudy argues strongly that a nation's citizenry will almost exclusively use its scientific knowledge in an interpretive manner. Whenever cabinet ministers, judges, corporate board members, or Alice and John Canuck think about science-related social problems, their knowledge of science, if it is used at all, will be used in an interpretive way. Their knowledge, whether accurate or mythical, will be used to make sense out of a wide variety of complex situations. Their knowledge may help them form opinions on matters in which science and technology are relevant. It may help them assimilate new information from newspapers, magazines, and television. It may also help them recognize a viable role in society for professional experts such as scientists and technologists.

Broudy carries his analysis of knowledge further when he distinguishes between *focal knowing* and *tacit knowing*. For example, a student may likely forget subject matter details (genus and species, or Kepler's three laws), but he or she will still possess a generalized type of knowledge (scientists search for regularity). Broudy calls details "focal knowledge", while generalized notions are named "tacit knowledge" - an idea proposed in Polanyi's *Personal Knowledge*.[63] Focal knowledge is factual, and is usually overtly memorized in a relatively short time. Tacit knowledge, on the other hand, is implicit personal knowledge. (In terms of retention, focal knowledge tends to be easily forgotten, while tacit knowledge lingers on and on.) Tacit knowledge is the knowledge resulting from someone having made sense out of an event in his or her own terms; for instance, the impressions or misimpressions that students acquire about the characteristics and limitations of science or about the relationships between science and Canadian society.

It may be an oversimplification, but there seems to be an interesting relationship between the five categories of scientific knowledge described previously (page 16), and Broudy's analysis of knowledge. Figure II.2 illustrates the relationship as it pertains to the way science is traditionally taught. In current science instruction, categories three and four are usually implicit if dealt with at all. Thus, Canadians' tacit knowing is understandably riddled with misconceptions about science and about the relationship between science and Canadian society.[64] Sophisticated understanding in those areas of knowledge cannot be assured unless the implicit curriculum becomes explicit.[65]

The science and society orientation suggested in this paper requires that science instruction be balanced not only by incorporating the full range of areas of knowledge, but by ensuring that science instruction explicitly address the *interpretive* function of that knowledge, in a way that renders at least category four as *focal* knowing. This new direction for Canadian science education is depicted in Figure II.3, a revision of Figure II.2. The difference between the figures lies in the increased sphere of the replicative, associative and applicative uses of knowledge, and in the increased sphere of focal knowing. This means that students would be involved in remembering and applying information and ideas from categories three and four (and perhaps category five). Students would discuss newspaper clippings, magazine articles, books, or TV programs concerning science and technology. They would study science fiction, biographies, and cases from the history of science and technology. As a result, they would learn about relationships among science, technology and Canadian society. For purposes of evaluating learning, students would be given an article or TV excerpt to which they would apply their knowledge by discussing, analyzing, or evaluating the article or excerpt with respect to the information and relationships studied in class.

Figure II.2 - Current Science Instruction

Kinds of Knowledge Developed from Science Classes	Uses of Scientific Knowledge Developed from Science Classes	Mental State of Knowing
1. Facts, principles, skills 2. Inquiry	replicative associative applicative	focal
3. Characteristics and limitations 4. Interaction with society 5. Attitudes, feelings	interpretive	tacit

In other words, science instruction would broaden its scope to make explicit (focal) the characteristics and limitations of science, the interaction between science and society, and perhaps also, one's feelings about science and technology. The overall consequence for a *teacher* would be to shift from the present emphasis on the applicative use of scientific knowledge to an emphasis on the interpretive use of scientific knowledge. The potential consequence for *students*, would be a shift from an impersonal, easily forgotten, rhetoric of conclusions, to a personally relevant inquiry into their "real" world. The potential effect on *Canadian society* would be a shift from a populace who failed to become professional scientists, to a citizenry informed enough to contribute to effective decision making and informed enough to make some sense out of their scientific- and technologically-oriented society.

Figure II.3 - Science and Society Instruction

Kinds of Knowledge Developed from Science Classes	Uses of Scientific Knowledge Developed from Science Classes	Mental State of Knowing
1. Facts, principles, skills	replicative	
2. Inquiry	associative	focal
3. Characteristics and limitations	applicative	tacit
4. Interaction with society	interpretive	
5. Attitudes, feelings		

Broudy summarizes his viewpoint by hypothesizing that general education presupposes an interpretive use of knowledge. A working familiarity with this interpretive use of knowledge will expedite any discussion concerning a science and society context for Canadian science teaching.

D. Decision Making for Science-related Social Issues

On 4 September 2003 AD, Mark Canuck goes to the store to get bread for his grandparents, Alice and John Canuck. Mark discovers that he has a choice between bread baked with natural wheat and bread baked with "bioengineered" wheat. Which does he choose?

Typical of life's decisions, Mark's predicament is intellectually messy. Many societal considerations come into play in Mark's decision. *Science* could shed some light by explaining DNA alterations via cell fusion and describing the process of "nitrogen-fixation". *Technology* could instruct Mark on how wheat leaf cells are altered so they carry out the nitrogen-fixation normally found in the plant roots. Technology would also address the potential health hazards of "bioengineered" wheat. A *political* point of view might bring to Mark's attention the social disruptions in producing nations and in consuming nations caused by eliminating an entire line of fertilizers. Some investigating would reveal a history of astute political decisions concerning which research and development projects had been financed by the government over the years. A *business* or *economics* perspective would find Mark deciding which bread is the better buy. Technological data related to nutrition are germane. Marketing and advertising might affect his decision. (Will he detect the persuasion?) In addition, Mark might consider which industry he wants to support, an emerging one requiring new capital and offering new investment opportunities, or the old one desperately trying to make the best of its capital investment. Mark may not have heard about the landmark *legal* decisions that gave patent rights to industries producing things like "bioengineered" wheat. There are also a host of *ethical* questions for Mark. Should he support a scientific advancement that tampers with evolution? Does society sufficiently comprehend the long term and subtle effects of manipulating gene pools? Where does humanity stop in its quest to gain power and dominion over nature?

This description of buying a loaf of bread was painful in its excess, but instructive in its relevance to our discussion. How does any Canadian reach a decision on a social issue in which science plays a key role? For a detailed answer, the reader is referred to books on decision-making strategies, for example Kurfman's *Developing Decision-Making Skills*;[66] and to curriculum materials specifically designed for making reasonable decisions, for example de Bono's *CoRT Thinking Lessons*[67] or the College Entrance Examination Board's *Deciding*.[68]

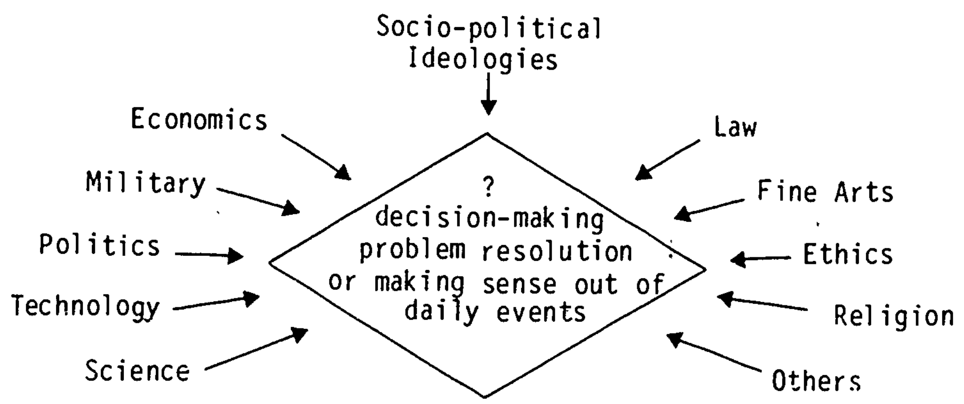
Mark Canuck's experience uncovers an important concept of decision making: a variety of social institutions and concerns impinge upon the decision maker. Figure II.4 summarizes many of these areas.* While the sources of influence listed in Figure II.4 appear to be discrete entities, the fact is they overlap; some more than others. The aim of proposing and labelling them is to clarify a multifarious, intellectually messy, "real life" situation. Figure II.4 serves to remind us of the diverse knowledge systems that are potential contributors to a person making sense out of a newspaper article, a TV news item, or an expert's opinion.

The various sources listed in Figure II.4 require brief descriptions to prevent misunderstanding. The intention is to describe them succinctly instead of defining them in a rigorous way. Science is the enterprise principally moved by curiosity to inquire empirically into natural phenomena for the purpose of describing and explaining. Technology (applied science, engineering etc.) is primarily concerned with improving everyday life by developing useful materials, equipment, and processes. Politics is the art or science of government; local, provincial, federal, and international. The military represents the armed forces. Economics encompasses business, industry, and government. A socio-political ideology refers to those values associated with a group's political persuasion (socialism and capitalism are obvious examples). Law comprises Canada's legal system, including law enforcement agencies. The fine arts refer to literature, music, drama,

* A comprehensive list of social institutions and concerns is, again, beyond the confines of this discussion.

and the visual arts etc. A whole range of normative judgements can be thought of as ethical considerations. (What ought to happen? How should one behave?) Religion is closely associated with ethics, but is more organized as a social institution. The last category, "others", is included as a reminder that the list is not complete.

Figure II.4 - Various Sources Impinging Upon Decision Making



One might think that a science and society curriculum should deal simultaneously with *all* facets of society outlined in Figure II.4. This seems naive, however, because not all areas are relevant to every issue. Thus, one approach to a science and society topic is to decide which social areas are relevant. This tactic will usually eliminate many areas from consideration. Unfortunately, eliminating pertinent areas contributes to mediocre decisions. This happens when people, alienated by science, reject its potential contribution to resolving social issues.

The next step in decision making would be to identify from which social domain the final decision should be made. In the cases of breathalyzer data and patent rights on recombinant DNA organisms, law had prime responsibility. Dropping the atomic bomb on Hiroshima was a political decision. Developing colour television was a technological decision. Each aspect of society (law, politics, and technology in these examples) has its own knowledge base and its own tradition in decision making. Thus, the rules for making decisions differ significantly amongst lawyers, politicians, technologists and scientists.* This fundamental realization leads to two noteworthy points.

The first is illustrated in the booklet *Science and Political Decisions*.[69] In legislating lead pollution standards, British politicians worked within the rules of political decision making in Parliament. But they drew upon science, technology and economics explicitly, and perhaps socio-political ideologies implicitly. The politicians had to integrate scientific, technological and economic knowledge into the arena of politics. When integrating two or more knowledge systems, one system's rules must supersede the other system's rules.[70] In this example, knowledge from the subordinate systems (science, technology, and economics) is subjected to judgements of relevance, validity and reliability in terms of the *super*ordinate knowledge system (politics). Therefore, in resolving a large number of science-based social problems, scientific knowledge is necessarily subordinated by social considerations dictating the final decision. This does not mean scientific knowledge is ignored or lacks influence. It does mean, however, that scientific knowledge is put into a different context, and consequently is treated differently.

The second point follows logically from the first. A scientist cannot transplant a scientific argument into the realm of religion and be credible. Similarly, ideological arguments are not acceptable in scientific decision making. The Lysenko affair is a prime example.[71] Religious viewpoints such as the concept of creation cannot be grafted onto scientific knowledge and make sense in science. In sum, the knowledge systems of Canadian society (partially listed in Figure II.4):

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* Granted, there are some important similarities to their rules. However, the significant differences are discussed here to highlight potential problems in making decisions on science-related issues.

- require different rules for making decisions;
- have different assumptions underlying each system;
- have different purposes in society; and
- view the world differently.

Therefore the credence of a scientist must change whenever he or she shifts from a scientific frame of reference to, say, an ethical or political frame of reference. This explains some of the frustrations felt by scientists who do not understand this relationship between science and the rest of society. Scientific and technological information may be sought by social agencies, however its relevance will have to conform, not to scientific norms, but to the norms of, for example, legal, ethical, or political thought. Thus, scientific knowledge may, to the annoyance of scientists, lose some of its character (such as its tentativeness based on suspended judgement) when it is used in another framework. This makes scientific knowledge susceptible to misuse or misinterpretation in other areas of society. This potential for abuse will be examined shortly.

Some significant implications for science teaching emerge from the foregoing discussion. Because a rational approach to resolving science-based social problems begins by identifying various aspects of society germane to the problem, science students will have to learn a simple way of identifying these social groups before embarking upon a study of the relationships between science and society. For example, Saskatchewan tenth graders studying *Science: A Way of Knowing*[72] are taught to identify the principal aims of politics, art, logic, economics, technology, religious faith, and science. Being able to identify simplified aims of various social groups allows students to analyze some "real life" situations with less confusion. It also presents them with the perspective of examining science as *one* of several legitimate social considerations.

Understandably, science teachers become overwhelmed by the rich diversity of knowledge systems involved in a science and society focus. It is easy to retreat within the well defined cloisters of the discipline's rigours. But this need not happen as long as the relevant social areas are identified without examining them in too much depth. An in-depth analysis should be reserved for the scientific enterprise itself.

Take, for instance, the energy crisis. In a science and society curriculum, several social areas would be identified: a political component (national independence of consuming nations and international power of producing nations), an economic component (capital already invested in existing nuclear and hydro technology and the lack of capital for developing new forms of technology, e.g., solar and tidal power), an ethical component (reasonable life styles in terms of energy consumption), a socio-political ideological component (resource development paid for by the state, the consumer, or the corporations), a technological component (nuclear power stations and solar cell batteries), and a scientific component (nuclear decay, radiation, waste storage, acid rain, conservation and transformation of energy, the second law of thermodynamics, and principles of electricity). After identifying each component as contributing to the social issue, students would then turn their attention to the contributions of science. This inquiry into the function of science ensures that science would *not be isolated* from real life. In the students' eyes, science would be seen as interacting with society. The main point is that when discussing the relationships between science and society, teachers and students only need to *identify* social institutions (Figure II.4), they do not necessarily have to have extensive knowledge of, or be well versed in, the processes of those institutions. Of course in decision making, the more one understands each area, the better the ultimate decision will likely be. However in a science and society curriculum, the ultimate decision, while intriguing, is not the end product, but rather the vehicle for discussion.

In many cases when key decision makers and the general public deliberate upon social concerns, scientific knowledge is more often *misused* than ignored. The federal cabinet minister's decision on an abortion bill illustrates this. Other familiar examples include: using a political argument to evaluate scientific data in a court of law; using the biological concept of natural selection as a justification for a particular socio-political ideology, "survival of the fittest"; using Einstein's relativity theory as a justification for accepting all viewpoints of ethics; and using the prestige of physical science inquiry techniques to justify dubious social, psychological and medical experiments. If such abuses of science are to be avoided in the future, then rational thinking about science-related societal concerns must rely heavily upon insightful "crap detectors".73 Guided experiences in this intellectual activity would need to be characteristic of the study of science and Canadian society.

Science often *poses* the very questions that precipitate a social issue in the first place. Recombinant DNA research did that for ethics, politics, economics, and law.74 The line of research forced decisions to be made in the public arena.

This scientific contribution to society leads us to the other side of the science and society question, and not discussed so far. How does society, with its many facets, contribute to decisions on what scientific research should be undertaken? What have scientists done in the past when the prime responsibility for a decision rested with them?

The problems of obtaining funding for scientific research reflect the control society exercises over decisions on what research should be done. For example, the Canadian policy of funding only "applied research" may lead to a serious depletion in the number of Canadian scientists involved in "basic research".75 Society does influence the decisions made by scientists. One way students can learn about these influences is by playing the simulation game, "Noble Prize", in Unit 11 of *Science: A Way of Knowing*.76

Another example illustrates what happens when scientists take prime responsibility for a decision. Deciding whether or not to conduct recombinant DNA experiments was a *social* issue for which scientists assumed prime responsibility. Participants in that decision had a responsibility to make a "good" decision. This shows that scientists *do* have social responsibilities. An implication exists for science education. Whenever students inquire into decision making for science-related social issues, they need to examine the social responsibility of scientists. Mendelsohn has reviewed some key historical cases, and has suggested some specific values that could guide professional scientists in making responsible decisions.[77] The social responsibilities of scientists are discussed in most publications on science and society.[78] A current example is the debate over how to conduct certain kinds of cancer research. Scientists and technologists are apparently being influenced by political and economic facets of society.[79]

A social-issues approach to a science lesson brings with it specific expectations. Teachers must realize that the class will:

1) not resolve the issue, but will tentatively identify the role science might play; thus, there are no "right answers" in such lessons (contrary to traditional expectations for science classes);

2) learn scientific subject matter that is pertinent to the role science might play (There is no intention here to suggest which should come first in a lesson, the social issue or the science subject matter. Either sequence could occur, depending upon the particular context.);

3) learn characteristics and limitations of science by studying the interaction of science with other aspects of society; in other words, learning what can and cannot be done with science;

4) develop a personal view (tacit knowing) of science, based on the realities of Canadian society and not on myths;

5) practice making independent, critical and reasonable judgements, which may conflict with those of the teacher;

6) clarify the values that become important when the class attempts to make a decision on a science-based issue.

We began this section with a fictitious purchase of bread. But we never did find out which loaf of bread Mark chose, the natural or the "bioengineered". The reader deserves to know. Mark is four years old in 2003 AD. He can only reach the baker's bottom shelf. He bought the natural loaf because it happened to be stacked on the bottom shelf (Figure II.4, category "others").

Summary

Many facets of society contribute to decisions on social issues. Science is one. Conversely, different groups within society will influence the decisions that scientists make about their research.

When making a decision on a social issue, one should list the sectors of society that will influence the decision, and one should note the sector that has prime responsibility for that decision. Students can recognize the various social groups by studying their principal aims.

In a science class, equal treatment need not be given to all sectors of society that impinge upon a social issue. Science could receive an in-depth analysis including: pertinent traditional subject matter, pertinent characteristics and limitations of the enterprise, and the social responsibility of scientists.

Scientific knowledge can change in character when it is taken out of its original context and put into the context of some other sector of society. Out of context, scientific knowledge and methods are vulnerable to misuse. "Crap detecting" becomes the decision maker's survival tactic. Along the same lines, the credibility a scientist earns in science will necessarily change in other areas of society, such as ethics or politics.

In one social role or another, all consumers of science education will use their knowledge of science to interpret their world and make decisions. Their world, Canadian society, is changing rapidly due to its interaction with science. A realistic awareness of this interaction will help consumers interpret their world and make decisions wisely.

III CHARACTERISTICS AND LIMITATIONS OF SCIENCE

Introduction

The aim of this section is to delineate some important characteristics and limitations of the scientific enterprise. Clarification of these areas is important if curriculum materials are to be developed that will facilitate the kind of science teaching described earlier.

Of the many issues related to teaching a science and society curriculum, one crucial topic stands out: the attributes and limits of scientific knowledge and scientific thinking. Canadian courts grapple with these limits everyday. Cases of impaired driving are but one illustration. Business, industry, and government run high risks of making mediocre decisions whenever a limitation of science is overlooked. The federal cabinet minister's approach to an abortion bill is a case in point. An uninformed citizenry cannot appreciate where the awesome power of science and technology legitimately stops. An unquestioned acceptance of a Chalk River scientist's economic-based decision to finance nuclear instead of coal energy, illustrates this point.

These examples support the importance of paying attention to the characteristics and limitations of science. However, a more graphic illustration was provided by my experience with a group of grade ten students in Saskatoon who were attempting to deal with the interaction of science and society. Their academic naiveté preempted a distinction between scientific claims and religious and other claims. Their youthful gullibility encouraged a wide-scale adoption of the "its-not-what-you-say-but-who-you-are" posture. Before these students could realistically deal with any relationship between science and society, they had to learn about: a) the characteristics of science, and b) the limits to which science can be pushed when it interacts with other sectors of society.

In response to the Saskatoon experience, Reg Fleming and I developed a full year science course for grade ten which, among other objectives, focused students' attention on the attributes and limitations of science. The course, *Science: A Way of Knowing*[1] is described and evaluated elsewhere.*[2] The course is mentioned because its content includes many of the limitations of science. It is referred to in order to discuss the characteristics and limitations of science in the context of actually teaching them to average grade ten students.

"Science and society" books invariably deal with the characteristics and limitations of science before considering the interaction between science and society.[3-7] While characteristics and limitations of science are clarified below, there is no pretense of exploring them, rigorously and thoroughly.

The Nature of Science

Philosophers of science are in continual debate about the nature of science. This paper does not provide an analysis of that debate. However, the reader should be aware that, in setting out one account of the characteristics and limitations of science, this paper is taking a "position" in that debate. I make no apology for the fact that *Science: A Way of Knowing* harbours a bias toward Schwab[8] and Kuhn.[9]

* A copy of the table of contents of *Science: A Way of Knowing* is found in the Appendix.

The Principal Aim of Science

The goals of individual scientists vary from prestige, to helping humanity, to the pursuit of "truth". However, the collective consciousness of the scientific community recognizes the satisfaction of curiosity as its principal goal. Science is limited by this aim. Science cannot be stretched beyond its function of satisfying curiosity about natural phenomena. Beyond that function, and beyond natural phenomena, one would look to another sector of society, such as technology, religion, or perhaps the pseudo-sciences.

Science and Technology

This "principal aim of science" will help us to make a distinction between science and technology. If a description or an explanation about some natural phenomenon is required, a scientist would be consulted. If a way to solve a problem is needed, for example to test pharmaceutical drugs, your money would be better invested by paying someone who would draw heavily upon scientific knowledge, but who would also apply a body of practical knowledge unique to the problem at hand.

Technology is the application of science. Technology is used principally in improving human welfare through the development of materials, equipment and processes that serve specific purposes. "Science describes the world as it is, technology remakes that world to serve human desires."10 Cancer research and putting people on the moon are largely technological programs. Obviously some activities belong to a "grey" area between science and technology. One person can be both a scientist and a technologist.

Science and technology interact. Technology supplies science with new phenomena (such as the steam engine) and with new or improved instruments. Thus science is limited by the available technology. On the other hand, science supplies technology with descriptions and explanations about the natural world.

The distinction between the two kinds of activities is a prerequisite to clear thinking by key decision makers or by the general public. It sharpens the blade of "crap detectors" in matters pertaining to science-based problems.[11]

> "Many of the major economic, political, social, scientific, and personal decisions for the rest of this century depend upon a clear understanding of technology, its potential and direction."[12]

Most Canadians experience science indirectly, via the technological implementation of science. For them, technology acts as a bridge between science and society.* No wonder students find science classes foreign to everyday life. Science is an abstraction of their daily lives while technology is the concrete experience in their daily lives. Orpwood and Roberts describe how technology fits into a science course with a science and society emphasis.[13]

In *Science: A Way of Knowing*, initially students learn the distinction between science and technology by classifying a list of questions according to which area they belong. From then on, science and technology are explictly treated as two different areas.

The Myth of the Scientific Method

A general description of what scientists do can be helpful to students. Unfortunately however, students can easily develop the impression (tacit knowledge) that the "five steps of the scientific method" prescribe a successful, puzzle-solving and knowledge-generation process used by all scientists. The concept of "the scientific method" encourages scientism, or at best a naive view of science. Careful analysis

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*Strictly speaking, we should use the extended phrase "the interaction of science, technology, and society" to express the special relationship technology has with science. However, as long as it is clear in our minds that technology is a legitimate sector of society, the phrase "science and society" works well. When we speak of an activity that encompasses both science and technology, we should use both terms to avoid confusion.

of the history of science and modern practices shows that scientists do not use the so-called "scientific method." Its existence is largely mythical.

When dealing with science-based social problems, it is most important to view science in a realistic, rather than in a naive, way. Otherwise the scientific enterprise is expected to supply advice or results, it cannot possibly furnish.

In *Science: A Way of Knowing*, "the scientific method" is presented as a myth. Students discuss this myth on several occasions.

Facts

When we claim that something is a "scientific fact" we expect less argument than when we claim something is an "ethical fact". Somehow we associate more validity with a scientific fact and as a consequence, often have the "wool pulled over our eyes."

The British curriculum program *Science in Society*,14 devotes an entire unit to facts, as their way of dealing with the characteristics and limitations of science. Goldstein and Goldstein in *How We Know* describe the process by which scientists accept facts.15 A consensus must be achieved before something is considered a scientific fact. Understandably then, disagreements over facts can arise. It turns out that scientific facts are generally "theory laden".

> "The facts we select are in large part determined by some theory or preconception as to what facts are important and what facts are not."16

Scientists can sharply disagree over which facts are significant. Goldstein and Golstein think of facts as:

> "... having a man-made component rather than being purely objective facts of an already existing nature, although they can be as tangible and inescapable as such other man-made objects as 10-ton trucks."17

The myth that science is a collection of experimentally verifiable facts arranged in an orderly manner and that all scientists agree on these facts, prohibits a realistic view of science. Such a description is more fitting of a telephone book than it is of science.

The limitation of scientific facts is a simple but important one: facts are useful only to the extent to which people agree to use them. The Supreme Court of Canada did not agree to use the "fact" that measurements taken by instruments contain inherent margins of error. Attitudes play a major part in deciding on the significance of a scientific fact. A person biased toward a mechanistic view of the world will surely have difficulty agreeing on significance with a holistically-oriented person.

It is circular reasoning to claim something is a fact because many scientists accept it as such. Those scientists were trained to view the world in the same way in the first place. Consensus does not mean irrefutable truth. But consensus is useful.

When science interacts with other facets of society, science finds itself in unfamiliar territory. A scientific fact takes on different significance when it moves from science to another sector of society, from one context to another. As discussed previously, the significance of scientific thinking is subordinated by the sector of society with which science is interacting. This state of affairs is originally confusing for grade ten students because they have been taught that a fact is a fact, no matter what.

Scientific Logic

Scientists use logical rules when making scientific statements. Therefore, to understand scientific thinking we need to know something about these rules. Unit 3 in *Science: A Way of Knowing* teaches truth-functional analysis, classical fallacies of argument (to sharpen the blades of "crap detectors"), and a comparison of deductive and inductive reasoning.

The rules for inductive reasoning are different from the rules for deductive reasoning. Creating an hypothesis, or generalizing a set of observations into a law are examples of inductive reasoning. Using the hypothesis or law to predict what we should observe in an experiment is deductive reasoning.

Scientific predictions are based on the rules of deduction, whereas scientific arguments of induction are based on judgements most accurately described, I think, as faith. The notion that scientific logic is either right or wrong is a myth. Scientific *deduction* is valid or invalid. But believing a scientific *inductive* argument depends on a number of somewhat subjective decisions. And here lies a major limitation to scientific thinking. An example from technology should clarify the point.

The vials used in the Borkenstein breathalyzer test come from a factory. A police analyst checks a batch to ensure quality control. The analyst takes a sample of vials, and carries out a chemical test on each one. But how many vials in the batch need to be tested before we are to believe that the entire batch is suitable? If 5 per cent are acceptable, do we conclude (by induction) that they are all acceptable? There are no right or wrong answers, just conventions and faith. What if one vial in a sample of ten is not suitable? For the Borkenstein test, the whole batch would be returned. However in some areas of science (interpreting peaks, for instance), one poor observation in ten could be quite permissible. Who is to decide? In science, usually a consensus exists among the practitioners.

Thus, scientific *inductive* logic depends on a consensus of scientists. Scientific knowledge is logically limited to that consensus.

One of the cases of induction studied in *Science: A Way of Knowing* is Piaget's theory of cognitive development (Unit 7). Students decide how many observations are needed before they personally can have faith in a generalization. A comparison between sample size in psychology and in chemistry shows why chemists have more faith in molecules than psychologists have in formal operational reasoning. A consensus is easier with larger sample sizes.

The process of scientific deduction may be illustrated by means of the Borkenstein breathalyzer. Assuming that all the required experimental conditions are met, the analyst *deduces* from a reading of 60 that 100 mL of a blood sample contains between 50 and 70 mg of alcohol. All the scientific laws and theories upon which the technological device was constructed combine to predict that conclusion.

The fact that we have faith in these laws and theories means that we will use them, it does not mean they are absolutely correct. This is the spirit in which Canadians must use scientific thinking in a social issue, if they are realistic.

Science as Imagination

Scientific knowledge has been compared to maps.[18] Maps are very useful for specific purposes. Take the map of Saskatchewan for instance. If one wanted to drive to Warman, Saskatchewan, a road map might give the following information: its location, what highways lead to it, the category of highway, the presence of campsites, the approximate population, and the presence or absence of an international airport. Some maps could furnish information on the soil conditions, types of vegetation found near the town, and elevation above sea level.

However, with all the data available from maps, one would have no idea: what Warman looks like, what the real estate conditions are, what a proposed uranium refinery did to split the town into factions.

If one is interested in the real Warman, there is no substitute for being there. But if one is satisfied with a schematic representation, maps are useful. Maps are representations of reality, with much of reality left out.

And so it is with scientific knowledge. Models and classification schemes, equations and hypotheses, concepts and facts, all are useful representations of reality. They are the results of man's imagination interacting with reality. They are not reality itself. Sir Arthur Eddington is known for his expression:

> "We have found a strange foot-print on the shores of the unknown. We have devised profound theories, one after another, to account for its origin. At last we have succeeded in reconstructing the creature that made the footprint. And Lo! It is our own."

This view of science challenges the dogmatic belief that science is objective reality and ultimate truth.

In Unit 2 of *Science: A Way of Knowing*, students distinguish between "what is really out there" and "what you think is there." The original lesson deals with visual illusions, but later students apply this distinction to scientific knowledge itself, by comparing the discovery of gold with the discovery of a scientific theory.

A specific illustration may clarify the issue. Suppose we are confronted with the "death with dignity" issue. If we cite scientific knowledge to support a point, we are not alluding to nature's reality, but to a man-made viewpoint representing nature's reality. At what point is someone dead? Scientific knowledge cannot arbitrate what is reality. It cannot define death. But it can be used as a source of information when determining the criteria of death. If we cite an ethical position to support a point concerning death with dignity, we easily recognize it as a product of human thought. Why is it so difficult to see science in the same light? Perhaps we have been taught the myth that science is objective reality itself.

This idea may seem philosophical. Nevertheless, it is a stumbling block to clear thinking about science-based social issues. Grade ten students of average ability come to appreciate the idea by constantly assessing the importance of imagination in the work of scientists, and by noting how different kinds of imagination lead to different scientific ideas. An overemphasis on science as a product of human imagination helps students realize that scientific knowledge is metaphorical, like a road map.

Science as a Cultural Phenomenon

The cultural milieu has long been recognized as a social influence on scientific thought. Modern science is a Western phenomenon.[20] Those who have introduced science or technology into a community in a developing nation, or those who have attempted to teach science to children raised in those communities will know the full impact of that statement. For instance, many cultures do not believe as we do in the value of relating events in terms of the relationship between cause and effect. We have been steeped in the scientific tradition of a mechanistic view of the world,[21] while others have learned "witchcraft", an equally effective way for them to relate to their world.[22]

Thus, science must be viewed as a social phenomenon in which people are trained to view the world in certain ways. These world views are bound by traditional habits of perceiving and thinking. Art and visual illusions can illustrate how we have been taught to perceive in certain ways. What is a visual illusion in one culture is not necessarily a visual illusion in another. *Basically, we see what we have been taught to see.* In other words, we see as much with our brain as we do with our eyes.

Students are introduced to this idea in Unit 2 of *Science: A Way of Knowing*. They study visual illusions and eventually discuss the question, "what is the relationship between a scientist's education and the ideas he or she comes up with in his or her work?" In Unit 7, students use this relationship to make sense out of why Canadian medicine is based on scientific research while acupuncture is based on a completely different perception of the human body. (There are no experiments with yin and yang.) The idea that we see what we have been taught to see, supports students when they first try to observe a cell through a microscope. They have difficulty perceiving a cell because they have not been taught to conceive of a cell.

Students in the *Science: A Way of Knowing* course come to expect that scientists with different educational backgrounds will arrive at different, and perhaps conflicting, theories. This human component of scientific knowledge puts science more on an equal footing with economics, religion and politics, for example. This equal footing is important in clarifying relationships between science and Canadian society.

If in a deliberation of a political problem a scientific classification scheme were to be used, the people involved should recognize the arbitrary nature of the scheme.23 The decision to use the scientific scheme cannot be made with the idea that the scheme is true, or that it is more valid than schemes from other areas of society. Instead, the decision must be made on the basis that the scheme may be helpful in the political sphere of problem solving.

When viewed as a cultural phenomenon, science is seen as having human character. There is an obvious limitation. Science is limited by the human characteristics of those creating and extending its knowledge, and therefore science is affected by human foibles such as fads, falsifying, dogmatism, nationalism, and male chauvinism.

Decision Making in Science

We have seen that consensus plays a large role in science. This means that scientists are constantly making decisions. For example, how to set up an experiment, or which hypothesis is best.

One basic ingredient of decision making is the data used. The validity and reliability of the data must be considered before a rational decision can be made. How valid and how reliable must the data be before a scientist acts on them? Tradition and faith usually answer this question for a scientist. No wonder some people outside of science become impatient with the apparent timidity of scientists who will not take a position on a social issue because according to scientific standards the data are insufficient in number, validity, or reliability. The traditions for decision making in science are different from those in other facets of society. This characteristic is another limitation of science.

Science: A Way of Knowing introduces decision making to students in a political context. Students begin to evaluate the reliability and validity of data. This skill is applied to scientific thinking, for example when studying the theory of evolution and the data upon which it is based.

Tentativeness of Scientific Knowledge

Different scientists bring differing imaginations and conceptualizations to bear on scientific experiments and ideas. Technology continually improves scientific instrumentation. This leads to new observations, some of which may conflict with accepted scientific knowledge. Consensus arbitrates what is acceptable. These attributes of science explain why its history is characterized by change. Generally speaking, scientific knowledge is in constant flux. This characteristic contradicts the myth that science is a rhetoric of conclusions.

The tentativeness of science is a major limitation.[24] When other branches of society look to science for ideas in resolving a societal problem, they must expect those ideas to change from time to time. Scientific information alters in substance or significance, depending on the current consensus among scientists. It is frustrating to government agencies, for instance, when scientific and technological findings contradict earlier findings, which had been used as criteria in a regulation. If the agency expected science to offer unalterable information, the agency's unrealistic perspective would likely have rendered their original decision mediocre.

Tentativeness pervades *Science: A Way of Knowing*. Numerous examples of changed scientific ideas prepare students to view current textbook knowledge as tentative, even though it is not presented as tentative in the text.

Assumptions Underlying Science

Every knowledge system rests on unprovable assumptions. Science is no exception. Although the phrase "basic assumption" evades precise definition, several examples from *Science: A Way of Knowing* illustrate its meaning.

Scientists assume that nature acts in a consistent manner with respect to time (over billions of years), with respect to scale (molecular to interstellar), and with respect to place (any place in the universe).25 Scientists also assume that all effects have explainable causes, that experimental results are meaningless unless they can be verified independently, and that nature is susceptible to human ordering and understanding.26 Physical scientists, in particular, assume that nature can be explained in mathematical terms. Einstein made an assumption when he said he thought nature did not play dice.

The relevance of these assumptions to science and Canadian society curricula is two-fold. First of all, the assumptions of science can be identified and compared with the assumptions of other knowledge systems, such as religion. This is done in Unit 9D of *Science: A Way of Knowing*, when comparing the theory of evolution with a concept of creation. By noting fundamental differences in the principal aims and basic assumptions of the two areas, the limits of both science and religion are clearly defined for students. This clarification almost eliminates the conflict that surrounds the evolution versus creation issue in biology classes.

The second point is more logical in nature. Decisions and arguments in science cannot help but be based on the assumptions underlying the scientific knowledge system. Similarly with other knowledge systems of society. When science interacts with another facet of society such as politics, it would be ludicrous to mix a scientific argument with a political argument, because science and politics are based on different, and perhaps conflicting, sets of assumptions. It would be like "adding apples and oranges".

There *are* valid ways to use scientific thinking in political affairs. However, one must realize at the time which set of assumptions, or which knowledge system, will be the most important, the superordinate one.* They cannot share equal importance.

The assumptions underlying science create a realistic limitation. Science cannot logically be used beyond these assumptions. To do so is to abuse scientific knowledge and to confuse those concerned. Consumer beware!

Santayana's popular quip on the empiricist reveals a critical assumption: "The empiricist thinks he believes only what he sees, but he is much better at believing than seeing."

Science and Values

Like any human endeavour, science is imbued with values.[27] These need not be repeated here. The Educational Policies Commission of the National Education Association in the United States listed the following values as the characteristics of rational thought most easily identified with science:[28]

- longing to know and understand,
- questioning of all things,
- search for data and their meaning,
- demand for verification,
- respect for logic,

* The reader is referred to the discussion on the superordinate and subordinate roles of science, page 43.

- consideration of premises, and
- consideration of consequences.

The "Project Synthesis" Inquiry Group described values as safeguards and customs of inquiry.[29] These included: open-mindedness, skepticism, criticalness, commitment to accuracy, integrity, reliance upon verifiable facts for conclusions, and open communication.

Kilbourn's analysis of science curricula revealed a fundamental set of implicit values that teaches students a mechanistic view of nature, the "nature runs like a well ordered clock" simile.[30] This scientific world view places a high value on cause and effect reasoning (action by contact in linear time), reductionism (reducing complex situations into discrete components, and believing the whole equals the sum of the parts), and linear thinking (as opposed to lateral thinking).

Scientific values have been called "characteristics", "virtues", "criteria", "attitudes", "safeguards and customs", and "world views". Whatever their label, values are recognized by scientists as highly desirable but seldom attained. This lack of ultimate success in attaining desirable goals reflects the human character of the scientific enterprise.

In decision making, values and facts are of equal importance, values may even be more important. Values guide decisions. Because scientists are constantly making decisions, they are constantly being guided by values. Scientists utilize both values and scientific knowledge when making a scientific decision.

What happens when a decision must be made outside of the scientific domain? If a scientist is asked to contribute to the resolution of societal problems by serving on a jury or on a board of inquiry for instance, should that scientist be guided by scientific values, ethical values, or judicial values? The answer to this puzzle lies in the realm of wisdom. A wise person decides which set of values is most appropriate for a given social issue. Scientific values are not necessarily appropriate for every societal problem.

Several areas of society share with science the set of values called "rational inquiry". Although we usually associate the safeguards and customs of inquiry with the sciences, these values apply to some social areas beyond the sphere of science. Thus when we use rational inquiry to make decisions in the public sector, it does not mean we are acting in a scientific manner; it simply means we are acting according to the safeguards and customs of rational inquiry.[31]

If a wise person decides which set of values is most appropriate for a given societal issue (as suggested above), then that person must have been aware of his or her values. The process of becoming aware of values is called "values clarification". Some science educators argue that values clarification should be a major goal of science instruction, especially when studying science-related social issues.[32,33,34] We shall return to this point.

One consequence of the interaction of science with society, especially the technological implementation of science, is the social problems it creates, for example legislative, economic, judicial, and ethical problems to name a few. The way we perceive these problems depends upon our values. Therefore when we study the interaction of science and society, we unavoidably become involved with values; values associated with science *and* values outside the domain of science. Science and technology can force us to reinterpret our old values or to form new ones. Whenever key decision makers and informed citizens become involved with the interaction between science and society, usually they can act more wisely the more they clarify their values.

Values clarification is a natural and rational feature of studying the relationships between science and society. Not only do students clarify their own values, but they learn to recognize the values of others. From the viewpoint of a consumer of science education, clarifying values is particularly relevant in coping with a scientific and technological society. In terms of different kinds of knowledge and different uses of knowledge, values clarification belongs in categories three, four and five, and relates to transforming tacit knowledge into focal knowledge. (See Figure II.3, page 38.)

"Teaching science with a values focus provides students with a means for *interpreting* what they have learned within their own experiences."35 (Italics mine.) Hurd sees the goal of values clarification as developing a value sensitivity for studying the interaction of science, technology, and society. Some of his specific objectives are germane to the limitations of science: a) to understand that valuing is also a way of knowing, b) to appreciate that there are aesthetic answers to human problems as well as scientific answers, and c) to go beyond the description of facts and consider how they may best serve people, an explicit study of the interaction of science and society.

In a 1976 lecture series, "Values and Science: A Critical Reassessment", Harvard professor Everett Mendelsohn showed how modern scientific values were developed and shaped by a 17th-century, western European society.36 Using the atomic bombing of Hiroshima and Nagasaki as a case study, Mendelsohn demonstrated the inadequacy of some basic scientific values and attitudes. He suggested four values that could help science interact congenially and thoughtfully with the rest of society:

> 1. Modesty: the arrogance of contemporary science must be replaced by modesty. Conscious choices within science should address the social elements involved.
> 2. Accessibility: science must be accessible to the general public in terms of understanding the enterprise (demystifying its knowledge), participating in important decisions (directions that research should take), and entering its professional ranks (American science has always been [predominantly] white, male, and middle class).

3. Consideration of nonviolent, noncoercive and nonmanipulative research: an oath similar to the Hippocratic oath of physicians would transform the relationship between science and society.
4. Harmony with nature: concern with the long-term effects of tampering with nature.

These are the values which can underlie a science and society curriculum. They are the values whose adoption can lead Canadians toward a peaceful and prosperous future.

IV CONCLUSION

This discussion paper began by briefly examining the Borkenstein breathalyzer. This led to speculation on where people like judges develop a literacy about science and the wisdom for utilizing scientific thought. This in turn focused attention on teaching about the interaction among science, technology, and society. The need for science and society curricula has been expressed nationally in Canada, and internationally in Australia, Britain, and the United States, and by UNESCO.

Science education does not have a monopoly on the topic, however. Science and society sessions are held at Learned Societies meetings across Canada, and were held at the 1980 Canadian Studies conference in Peterborough, Ontario. In the United States, the National Council for the Social Studies published *Science and Society: Knowing, Teaching, Learning*[1] in which some of the major ideas found in this paper are discussed.

A science and society curriculum views science as a cultural phenomenon and within a social context. Even scientific theories, laws, and facts "contain a more or less culturally conditioned component."[2] One theme of this paper is the subjective elements of science: for instance, its notion of reality; its reliance on human imagination; and its use of the decision-making process called consensus, which in turn is based on commonly shared, but nevertheless subjective, criteria, values, assumptions, and faith.

However, before dealing with these characteristics and limitations of science *in terms of legitimate class content*, a context for the discussion was required. The general context adopted was the concern for the consumer of science education. More specifically we explored: different kinds of scientific knowledge "learned" in science classrooms, different social roles that students would assume as adults, and the different ways they would use their scientific knowledge. Special consideration was given to decision making for science-related issues.

At the Halifax International Symposium on World Trends in Science Education, the lead speaker, Fletcher Watson, emphasized that decision making must be the crucial element of future curricula:

> "... not only do we wish the students to 'know that ...,' and know 'how we know that ...,' but also know 'what to do after knowing that ...'."3

Decision making is guided by values. Hurd's point complements Watson's idea:

> "Science provides knowledge; technology provides ways of using this knowledge; and our value concepts guide what we ought to do with both."4

Wisdom is needed in exercising the power of scientific knowledge, not only as a social responsibility of key decision makers, such as politicians and business people, but as informed citizens and professional scientists or technologists. The personal *interpretation* of nature and one's society is the highest priority for the scientifically literate citizen.

SCIENCE: A WAY OF KNOWING
A Tentative Table of Contents

Section I DIFFERENT WAYS YOUR COMMUNITY KNOWS
What are some different and important ways your community gets its knowledge and uses it?

Unit 1	Politics	Experience: Dangerous Parallel (simulation)
Unit 2	Art	Experience: Readings, "Visual perception" (film), projects
Unit 3	Philosophy	Experience: Logic, fallacious reasoning, analysis of ads
Unit 4	Economics	Experience: Reading, project (case study)
Unit 5	Technology	Experience: Reading, Population (simulation)
Unit 6	Religion	Experience: Project (interview)

Section II SCIENCE -- ONE WAY OF KNOWING
What is science really all about?

Unit 7 Observations and Theories: It's All In Your Mind
Experience: a psychological investigation of our minds (labs, reading, video tapes, activities with children)

Unit 8 The Scientist: His Aims, His Tactics and Strategies, His Created Knowledge
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Unit 9A Observations, Laws, Hypotheses, Theories and Models
Unit 9B Doing Some Science
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Unit 10 Putting It All Together: The Scientist and His World
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Section III THE INTERACTION OF SCIENCE AND SOCIETY
Another look at your community: How does it affect science, and how is it affected by science?

Unit 11 Science and Society
Experience: Noble Prize (simulation), film

Appendices Activities Worth Doing (readings, tapes, interviews, case studies)

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