



TEACHING SCIENCE IN THE 21ST CENTURY

An Examination Of Canadian Science Curricula From
Kindergarten To Grade 12

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A tribute to a dedicated teacher: Gordon Hanson (1925-1987)

by C. H. Vanderwolf

The importance of good instruction in science in elementary school may be illustrated by my own career.

I was born of Dutch immigrant parents (Kees and Jantje van der Wolf) who had settled on a farm near the village of Glenevis in the mixed wood boreal forest region of northern Alberta in 1930. Since the area had been only recently settled, it lacked many of the amenities of modern life. It was a time of dirt roads and log or wood frame houses with no electricity, plumbing, or telephones. Local transportation and farm work was largely dependent on the horse. Glenevis East School, which I attended from 1942 to 1951, was a one-room building in which a teacher offered instruction to 20-30 students in Grades 1 to 8. Although I could read fluently by the time of entry to Grade 2 and soon became a skilled contender in spelling and geography matches, which were popular in those days, I disliked school, received mediocre grades, and planned to terminate formal education at the end of Grade 8. That was what nearly all farm boys did at that time.

At this point (1949) fate intervened in the form of a new teacher, Gordon Hanson, a 24-year-old bachelor who had grown up in the region. Gordon truly loved teaching and had a special genius for getting difficult children (I fear I was one) to work hard and co-operate with him. Above all, Gordon had a great interest in science, especially chemistry. I remember vividly the many demonstrations and experiments which he carried out, very likely at his own expense since there was absolutely no equipment for teaching science in Glenevis East School. One day, under his direction, we built an electric motor using a small cardboard box, several 6 or 8 inch nails, a length of wire, 2 bar magnets and a dry cell storage battery to supply power. How incredible it was to see the thing begin to run! On another occasion he placed a loudly ticking alarm clock under a bell jar and began to remove air from the jar with a hand-operated pump. The ticking of the clock grew progressively fainter and finally became inaudible. This, he said, proved that air was necessary for the transmission of sound. "Maybe the clock stopped," I objected. "Let's watch the hands," he replied. The entire school sat spellbound for one or two minutes until it became apparent that the hands of the clock were still moving. Glenevis East School had never before witnessed such things.

Gordon decomposed water into hydrogen and oxygen by electrolysis and demonstrated the characteristic reactions of those gases to a burning splinter of wood (oxygen made the splinter flame up spectacularly while hydrogen exploded with a "pop", then burned with a blue flame).





Perhaps his most dramatic experiment was a demonstration of the production of chlorine. I don't remember the exact method but I think it involved heating a mixture of hydrochloric acid and manganese dioxide. The heavy toxic gas poured out of the reaction vessel in a greenish cloud, forcing us to open the windows and doors and to abandon the school for half an hour or so, until it dissipated.

I was fascinated by all of this and began to think that high school and possibly even university might be a possibility. When Gordon returned to Glenevis East School in September 1950, he was permitted to teach Grade 9 in addition to Grade 1-8. [This was the only time Grade 9 was taught in the entire history of Glenevis East School (1914 to 1953)]. I completed Grade 9, wrote the mandatory provincial exams, and achieved high grades plus a medal awarded by the province to outstanding students. This outcome was astounding, not only to me, but also to everyone who knew me. I attended high school in Onoway, seventeen miles away, the next year (1951). This was possible because a new graveled road had allowed the establishment of regular school bus services that year.

I received high grades in high school, subsequently attended the University of Alberta (BSc, 1958) and McGill University (Ph.D., 1962), and eventually became a professor at the University of Western Ontario, doing research and teaching on the brain and behavior until my retirement in 2001. I have had a long and rewarding career, an outcome that would not have occurred without the instruction and encouragement provided by Gordon Hanson in 1949-1951.

In late May 1986, in company with my wife Judy, two children, Karen and Sarah, and my brother John, I visited Gordon and his wife Maureen at their home in Niton Junction, Alberta. Gordon and I sat talking for hours after dinner. Next morning, we left. I never saw him again. He died March 14, 1987. I hope the accompanying report "Teaching Science in the 21st Century: An Examination of Canadian Science Curricula from Kindergarten to Grade 12" may, in some small way, help to perpetuate the memory of a truly remarkable teacher.

Executive Summary

The science curricula in use in the ten provinces were read and evaluated by four university professors and a retired high school science teacher. Written commentaries and evaluations were made with respect to scientific content, recommended teaching methods, freedom from errors and unsupported dogmatic statements, and adequacy of presentation of the nature of science. An overall grade was assigned in much the same way as would be done in the case of student lab reports, term papers, theses, or in the case of peer review of grant applications or papers submitted for publication in scientific journals. Alberta was judged to have the best curriculum (A) followed closely by British Columbia (A minus); the Atlantic provinces were judged to have the poorest curricula (an overall rating of C); and Manitoba, Ontario, Quebec and Saskatchewan were judged to have curricula of intermediate quality (B).

Most of the of the curricula emphasize “child-centred teaching” a method which originated in the eighteenth century and which has been discredited by scientific studies of the efficacy of various teaching methods carried out in the twentieth century.

The quality of the curricula was related to the results obtained by students from the various provinces in tests of knowledge and understanding of science. Alberta and British Columbia students perform better than those in other provinces but the Atlantic provinces perform poorly.

Acknowledgements

This study was supported by a grant from the Donner Canadian Foundation to the Society for Quality Education. We are also indebted to C. Essex, Professor, Department of Applied Mathematics, University of Western Ontario, who read and commented on several of the Grade 11 and 12 physics programs and on other selected sections of the curricula.





Introduction

This report was written in response to a proposal by Malkin Dare, President of the Society for Quality Education, to evaluate the curricula for teaching science in the primary and secondary schools in each of the ten provinces of Canada. Reading these curricula raised a number of general questions about the nature of science and about education in science.

What is science?

According to C.C. Gillispie¹, “Science connotes both the knowledge contained in such disciplines as astronomy, physics, chemistry, biology, and geology and the activities involved in obtaining it.” It has also come to mean the institutions and people that do science. It is generally agreed that although science first arose from the attempts of ancient Greek philosophers, especially Aristotle, to understand the world in rational naturalistic terms rather than in theological terms, its full development has been largely a product of the past four centuries. However, it is important to be aware that at least one branch of science, astronomy, is much older, having its origins in the accurate observations of celestial events made in ancient Babylon and Egypt.

Why should students study science?

A reason for studying science that is of importance personally to many scientists is that scientific knowledge enhances one’s enjoyment and appreciation of the natural world in much the same way that a knowledge of music, painting, or literature brings delight to those who have studied those subjects. More profoundly, science offers an understanding of ourselves, of the universe, and of our own place in it, which must be ranked as one of humankind’s greatest achievements. Although crafts and technologies of various kinds are much older than theoretical science, it is true that science-based technologies, such as the myriads of applications of a knowledge of the properties of electricity, have had a profoundly beneficial effect on human welfare. Consequently, there are economic benefits, both to individuals who study science, and to countries whose citizens include many individuals with an extensive knowledge of science. Further, many of the problems currently confronting society, such as the looming energy and population crises, global warming, and ethical issues involving biotechnology, require a knowledge of science if they are to be dealt with rationally. Consequently, it is highly desirable that as many voters and politicians as possible have at least some knowledge of science. The achieving of scientific literacy should be considered to be almost as important as achieving basic literacy.

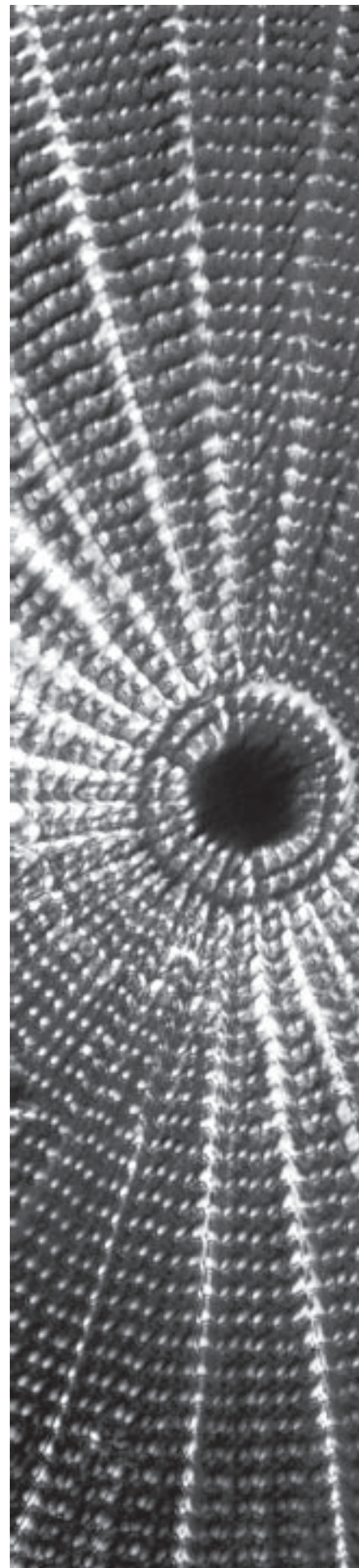
What is the best way to teach science?

Traditional science teaching relied heavily on lectures, reading, and teacher-led demonstrations. An alternative approach, which has been influential in education circles in Canada, originated largely from the philosophical writing of J.J. Rousseau (1712-1778). In his book *Emile* (1762)², concerning the education of an imaginary student, Rousseau proposed that children should not be taught directly but should be allowed to discover things for themselves, especially through play, and that learning how to learn was of much greater importance than teaching factual information. Teaching was to be restricted to posing questions for the student to answer and to creating situations to facilitate discovery by the student. A few selected quotations help to convey the spirit of Rousseau's ideas. "Give your scholar no verbal lessons; he should be taught by experience alone," (p. 56). "Emile will not learn anything by heart, not even fables," (p. 77). "Emile, at twelve years old, will hardly know what a book is," (p. 80). "You teach science; well and good; I am busy fashioning the necessary tools for its acquisition," (p. 90). "I do not profess to teach Emile geometry; he will teach me," (p. 110). "Let him not be taught science, let him discover it," (p. 131). "Ignorance never did anyone any harm," (p. 129).

Method

We acquired printed copies of the school science curricula in use in each of the ten Canadian provinces. This comprised a considerable mass of paper. Manitoba alone submitted an estimated 5,184 pages (estimated by counting the pages in a 7 cm thick sheaf of paper, then calculating the number of pages from a measurement of the total thickness of the mass). The entire body of printed material was read by one of us (C.H. Vanderwolf) over a period of about three months. In addition, parts of the Grade 11 and 12 science curricula were read by at least one other person (M. Cook for Biology; R. Coutts for Chemistry). Further, selected sections of the curricula were read by D. Cropp and by other members of the group. The final report was compiled from written comments supplied by each of the readers.

It is important to note that this report evaluates only the published provincial curricula. No attempts were made to read support documents that may have been prepared by the many local school boards across the country. Further, there is no way of evaluating teacher compliance with the recommendations of the curricula. Therefore, a study of the curricula alone provides only indirect evidence on what actually happens in the classrooms.



Commentary

Content

The science curricula in the different provinces are fairly similar if one simply lists the topics covered. In the first three or four years there is an emphasis on local natural history in many provinces and on natural phenomena occurring in everyday life. Children examine and learn something about local animals, plants, rocks, soil, qualitative properties of solids, liquids, and gases, weather, and the water cycle. A globe, a ball, and a flashlight in a darkened room are often used to demonstrate why we experience day and night, four seasons, and different phases of the moon. In subsequent years, to the end of Grade 9, there is usually a qualitative introduction to magnets, electrostatic phenomena, batteries, electric motors, electric generators, simple electric circuits, simple machines (levers, pulleys, gear trains, inclined planes, screws), density, buoyancy, Archimedes' principle, the particle theory of matter, atoms, molecules, solvents, solutions, acid-base indicators, the solar system, the geological time scale, the rock cycle, earthquakes, volcanoes, tides, continental drift, the nature of heat, temperature, light and sound, lenses, mirrors, prisms, the use of a microscope, Bernoulli's principle and flight by heavier-than-air machines, parts of a plant, photosynthesis, the cell theory, introduction to body systems (skeletal, muscular, circulatory, respiratory, excretory, endocrine, nervous, and reproductive systems), osmosis, diffusion, and an introduction to ecology and biological classification. Different topics may be introduced in different ways and at different times. In British Columbia the theory of atoms and molecules is introduced in Grade 5; in Alberta it is introduced in Grade 7.

Physics, chemistry and biology are always taught as separate subjects in Grades 11 and 12 for students who plan to attend university. However, there may be integrated science courses available for students who do not intend to study science at a post-secondary level. British Columbia, Nova Scotia, Ontario, and Saskatchewan offer distinct high school courses in geology (sometimes called Earth Science). In other provinces, geology is taught only in Grades 1-9 and in general physical science courses.

Physics and chemistry are taught in much more detail in high school than in the earlier grades and quantitative treatment of these subjects is introduced. In physics, there is a discussion of scalar and vector quantities, force and motion, Newton's laws, gravity, electrostatics, Coulomb's law, wave theory and quantitative treatment of refraction (Snell's law), diffraction and an introduction to quantum mechanics. In chemistry, there is more detail on atomic structure, the periodic table, chemical bonding, ions, selected chemical reactions, equations, pH, the gas laws, the mole concept, oxidation-reduction, electrochemistry and organic chemistry. In biology, there is generally an introduction to biochemistry (photosynthesis, Krebs's cycle, oxidation of glucose), much more detail on body systems than in the lower grades and on cell structure, genetics, mitosis, meiosis, the role of chromosomes, and the structure and role of the different nucleic acids. A difficulty in assessing biology programs is that the depth of treatment of, for example, the circulatory system, is not usually explicitly stated. One can only

Although most of the curricula are very properly concerned about safety matters, Quebec has a slightly more relaxed approach. In Physics 416, students are to observe "the behavior of alpha, beta, and gamma rays using appropriate methods." Although no details of "appropriate methods" are provided, this seems to mean that young teenagers are to be asked to work with such materials as cobalt-60, a strongly radioactive gamma ray emitter. Quebec students are also asked to work with mercury (a toxic liquid element), a practice that is avoided in other provinces.

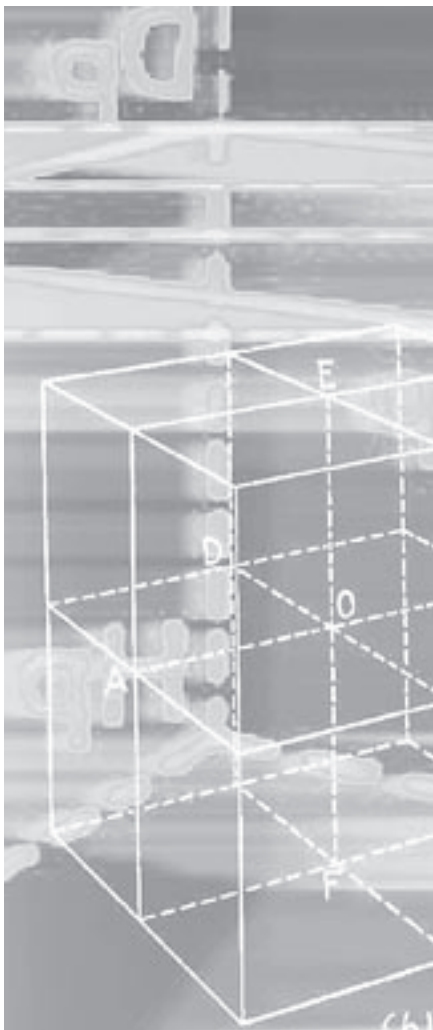
estimate what the level of detail is likely to be from the number of hours devoted to the course.

“Unfortunately, the Saskatchewan high school curriculum seems to have been written by a very different group of people and has none of the merits of the primary school curriculum.”

Although the topics covered in the various provincial curricula are rather similar, the quality of the instruction suggested varies widely. For Grades 1 to 9, the Saskatchewan curriculum could well serve as a model for the rest of the country. The Saskatchewan authors have realized that the way to interest students in science is certainly not to preach about experimental design, logic, measurement, and the control of variables, but rather to show them interesting phenomena. The Saskatchewan authors have also been aware of two practical limitations: (a) there is a limited or non-existent budget for science equipment in elementary schools; and (b) many elementary school teachers have little training in science. Consequently, the curriculum contains many suggested demonstrations/experiments, which can be carried out with bottles, pop-straws, string, modeling clay, and the like, but which, nonetheless, demonstrate some important scientific principle or phenomenon. These projects are each described on a single page, usually with a clearly labeled diagram to show the teacher how to set the thing up, together with a clear simple explanation of how it all works. Some other curricula offer similar advice to teachers (the Blackline Masters documents supplied to Manitoba teachers are especially noteworthy) but the Saskatchewan documents seem clearly superior. Unfortunately, the Saskatchewan high school curriculum seems to have been written by a very different group of people and has none of the merits of the primary school curriculum.

The sheer mass of the curricula varies widely from province to province. At one extreme, the entire Ontario science and technology program from kindergarten to Grade 12, which occupies only 359 pages, contains little more than a list of the topics to be included plus indications of the level of achievement expected. At the other extreme, Manitoba provided an estimated 5,184 pages describing topics to be included, levels of achievement expected, philosophy of education, discussions of the nature of science, and many detailed recommendations about teaching methods. The brief Ontario curriculum has the advantage that it encourages teachers to use their own professional judgment in developing effective approaches to their own particular classes, while the longer Manitoba style curriculum has the advantage of offering detailed guidance to teachers who are unsure of how to proceed. There is a tendency in many of the curricula to offer more guidance in the elementary grades than in high school. This may have been done in recognition of the fact that many elementary school teachers have little training in science while most high school science teachers have had several years of university education in science.





“Prepare a poem or song in which volcanoes and earthquakes are compared and contrasted.”

~ Nova Scotia, Grade 7

“If you could be any polymer, which polymer would you be? Explain.”

~ Nova Scotia, Grade 11

Teaching methods

The curricula in most provinces recommend, to varying degrees, a transition from a “teacher-centred classroom” to a “student-centred learning environment.” This is invariably described as a new approach to teaching science: there appears to be no awareness whatever that this idea is a recycling of the latest educational theories of 1762. Nonetheless, the correspondence to the ideas of Rousseau is astonishing. The Newfoundland curriculum informs us that, “The teacher should not spend a great deal of time telling children about science; instead children should be provided with opportunities to find out on their own.” Similar sentiments are to be found in most of the other provincial curricula, with the notable exceptions of Alberta and Ontario. Thus, in New Brunswick, Grade 9 students are expected to carry out their own experiments with pith balls, balloons, and pieces of fur, an activity that “should eventually lead to the scientific understanding and explanation of static charges.”

Play involving gross motor activity is suggested as a teaching aid in many provinces, even in teenagers. Grade 8 students, playing the role of cells, are to put on plays or skits in Nova Scotia. In British Columbia, Grade 8 students are to position themselves and move about in time to music to represent the movement of “particles.” In Nova Scotia, Grade 11 Chemistry students are to organize into groups and hold hands to represent intramolecular forces. All of this conforms closely to the spirit of Rousseau’s ideas.

Another way in which present day Canadian science curricula are modeled on Rousseau’s ideas is in the tendency to downgrade the use of textbooks. It is widely recommended that students be exposed to a “resource-rich environment” in which they discover information for themselves in a “variety of print and electronic sources” including magazines, newspapers, and the Internet. The overall aim is “not to teach content but to help students become mini-scientists, life-long learners and hypothesizers who understand and practice the process of theory development in science and the nature of science.” (Nova Scotia curriculum).

Arts and crafts are seen as effective teaching aids in many provinces. Students are expected to complete such projects as making a plaster of Paris model of a volcano or murals or three-dimensional models of cells, atoms or molecules. There is often little attention to content, i.e., actual information about natural phenomena, while much space is devoted to advising teachers to have students make up poems, songs, cartoons, skits, or short stories about cells, atoms, wave action, or earthquakes.

In addition to these methods, teachers are encouraged to make use of “pedagogical techniques” such as KWL, a procedure in which students are asked to fill out a chart listing what they Know, what they Want to learn, and what they have Learned. In Nova Scotia, class time is still taken up with this technique in Grade 12.

Group work is widely encouraged in the belief that it is equivalent to collaboration among mature scientists. One variant of this is the Think, Pair, Share technique (TPS) in which students think about a problem and discuss it with a partner. Other

intriguing methods include LINK as a means of exploring some phenomenon. Students, as a group, first List everything they know about the topic; Inquire of each other for clarification; Note what they have learned; and confirm what they Know. In the Jigsaw Technique, used, for example, to explore asexual reproduction in Grade 9 in Manitoba, where the students divide up into small groups and each group looks up information on a specific aspect of the general topic. Each group then teaches the rest of the class what they have learned. This technique is strangely reminiscent of the Lancaster technique devised by Joseph Lancaster (1778-1838)³ as a solution to the scarcity and expense of competent teachers in the late eighteenth and early nineteenth centuries. The method consisted of having an adult teacher instruct a group of the better students, then having each of those students instruct a class of other students. The Jigsaw technique appears to be the modern equivalent of the Lancaster technique but without the benefit of a teacher.

“The emphasis on group work in many of the curricula seems to us excessive.”

Among still other fascinating topics, we have students writing in response to such questions as: “You are a moss. Describe your experiences.” (British Columbia, Grade 11); “If you were transformed into an ionic compound, which would you be? Explain your choice.” (Nova Scotia, Grade 11).

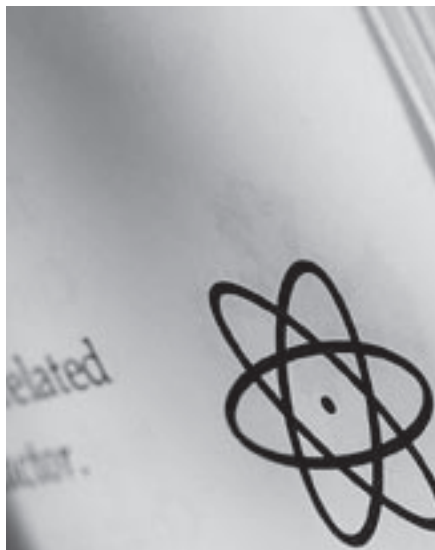
Are such methods likely to be effective?

First, to us it seems of utmost importance that students be provided with well-organized textbooks written by people who are knowledgeable in the subject to be dealt with. Although newspapers, magazines, and the Internet may provide useful information at times, they are also notorious as sources of errors and misinformation on scientific topics. One of the essential aspects of a scientific education is to learn how to assess the probable reliability of a source of information. An approach that treats all sources of information as equivalent deprives students of the opportunity to learn this. Further, science has a logical sequential structure which demands that basic concepts be understood before more advanced topics can be attempted. For example, it is necessary to understand the arrangement of electrons in an atom before one can understand the nature of complex molecules. A good textbook presents different topics in a logical sequence but if students are expected to find things out for themselves, their learning is certain to be slow, haphazard, and incomplete.

“It is quite mad to imagine that a group of students, working alone, could discover in a few hours principles which early scientists puzzled over for years or even centuries.”

Natural science is fundamentally an attempt to achieve a rational understanding of natural phenomena. Students should therefore be encouraged to study nature itself rather than studying only books or computer simulations. However, the enthusiasm for discovery learning displayed in many of the curricula is far too





Errors in spelling were ignored in assessing the curricula but errors of fact and instances of misunderstanding of scientific principles were counted. In interpreting these numbers for the Atlantic provinces, it should be noted that there is a great deal of sharing of the curricula. The curricula for the region as a whole contained 18 detected errors. The total errors detected in each provincial curriculum were:

- Alberta 1
- British Columbia 1
- Newfoundland 2
- Ontario 2
- Quebec 2
- PEI 3
- Saskatchewan 3
- Nova Scotia 6
- New Brunswick 7
- Manitoba 8

extreme. It is quite mad to imagine that a group of students, working alone, could discover in a few hours principles which early scientists puzzled over for years or even centuries. Although student laboratories or teacher-performed demonstrations are essential to science teaching, a competent teacher should always lead and direct the activity. Further, it is relevant to point out that university level laboratory courses for undergraduates usually provide very explicit instructions on what to do together with demonstrations of how to do it. Ordinarily, only senior undergraduates and graduate students have a measure of freedom in planning and carrying out experiments of their own. Even then, there is likely to be a good deal of supervision by a professor. It appears, therefore, that experienced scientists believe that undergraduates require extensive instruction before being allowed to do independent research. Are they mistaken? We suggest that, in most cases, junior undergraduates, as well as elementary and high school students are not yet capable of doing independent research.

The emphasis on group work in many of the curricula seems to us excessive. Students told to work in groups do not constitute a model of collaboration among mature scientists. Two or more scientists may collaborate because each of them possesses knowledge or skills which the other(s) lack(s). Students have not yet acquired special knowledge or skills; they can only share their ignorance. In practice, as every student knows, one or two of the students in every group do all the work while the others watch. In such a situation there is not a fair distribution of opportunities to learn nor of credit for work successfully completed.

Errors

Errors were detected in most of the provincial curricula. Some of these appear to be the result of insufficient care in proofreading. For example, in the Grade 12 Chemistry section for Prince Edward Island, an equation for the oxidation of glucose is labeled photosynthesis while an equation for photosynthesis is labeled cellular respiration. Also C (carbon) is omitted from one side of one of these equations.

Erroneous statements concerning facts may be illustrated by the following examples. (a) The Manitoba Grade 10 curriculum tells us that calcium hydroxide is used as an antacid. (It is much too caustic to be used in this way.) (b) The Quebec Human Biology course for 14-15 year olds tells us that muscles increase in volume when they contract. (It was established in the 17th century that muscles change shape but not volume when they contract.) (c) Both New Brunswick and Nova Scotia state, in the Grade 8 curricula, that animal cells have both a cell membrane and an external cell wall. (Cell walls are characteristic of plant cells but are not found in animal cells.)

Some of the errors indicate a failure to understand basic concepts or, possibly, failure to write clearly. The Nova Scotia Grade 8 curriculum tells us that "Investigations into air pressure at various altitudes will help students gain an appreciation of how the pressure of a gas is dependent upon altitude as opposed to that of liquids." Do the authors really believe that pressure in a liquid does not increase with depth? Similarly, the Grade 9 Newfoundland curriculum tells us that "Natural selection is a theory which proposes to explain how the features or

organisms evolve over time.” (Darwin’s theory of evolution proposed a two-step process: (a) inherited variations; and (b) a selective action of the environment that permits successful reproduction in some individuals but not others. The second step alone [natural selection] is not sufficient to produce evolutionary changes.)

Dogmatic statements unsupported by evidence

Many of the curricula state that science is based on evidence: hypotheses that are not supported by facts must be abandoned. It is, therefore, disappointing that fashionable but unsubstantiated dogmas have a place in several of the provincial curricula. For example, the Manitoba Blackline Masters 7A document tells us that Aboriginal people have “exemplified the qualities of good stewardship in their interactions with the environment” and that their “decisions were made with regard for the environment.” We are also frequently told that science has a long history in all cultures, that different cultures have equally valid perspectives and that science and technology have “evolved from different views held by women and men from a variety of societies and cultural backgrounds.”

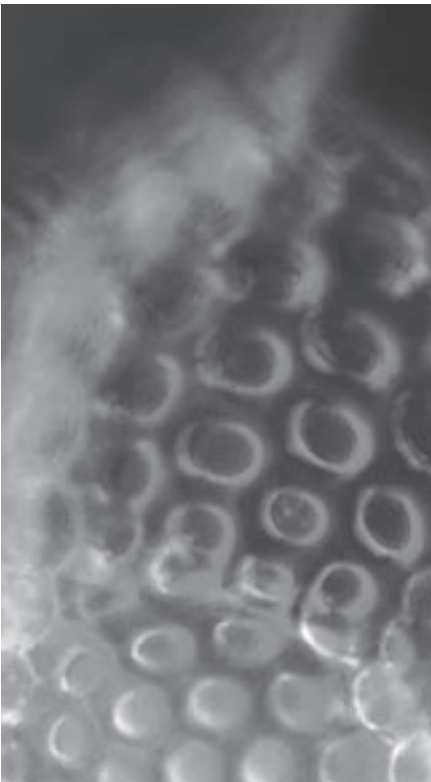
None of these statements is supported by evidence of any kind: most of them are probably false. Ian McTaggart-Cowan, a well-known Canadian zoologist and naturalist, tells us: “There is no evidence that the native people had any concept of numbers applied to their food animals. They took what they could without concern for replacement rate or overkill.”⁴ These conclusions are supported by a recent examination of historical and archaeological evidence.⁵ Further, a recent investigation of the history of great discoveries in science from 800 BC to 1950 shows that virtually all of them were made by Europeans and their descendants in the new world and that only about 5% of them were made by women.⁶ The true situation should not be concealed from students^{7,8}.

“In our opinion, the development of a skeptical questioning attitude is one of the greatest benefits that education in science can confer.”

Other examples of questionable statements presented as truth but without any supporting evidence can be found in some of the curricula. For example, in New Brunswick, Grade 5 students are to investigate sweat lodges, acupuncture, chiropractics, saunas, whirlpool, and herbal remedies and “find out where the technique was developed and how it works to prevent or cure illnesses.” The question of whether all these techniques are actually effective or not is not raised.

In our opinion, the development of a skeptical questioning attitude is one of the greatest benefits that education in science can confer. Whenever a new claim is made, students should be encouraged to ask, “Is this really true?” “Why should anyone believe this?” Although there is no place in science curricula for dogmatic statements with no factual support, a strong argument can be made for the value of teaching students about “junk science” or “pseudo-science” and how to distinguish it from the genuine article.⁹ The importance of confirmation of novel



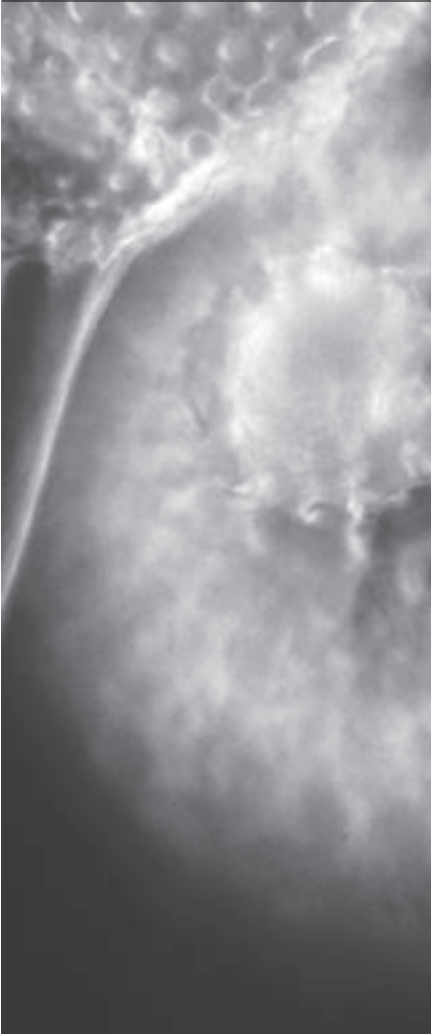


results and the practice of having scientific papers reviewed by other scientists prior to publication (“publication in refereed journals”) should be stressed. Such topics however, are best delayed until high school when some of the basic principles of science have already been learned.

The nature of science

Many of the curricula have lengthy commentaries on the nature of science and of scientific investigation. The Manitoba Grade 10 curriculum tells us that “Among the natural sciences truth is no longer viewed as an objective reality awaiting discovery; rather it is placed in the context of something always to be sought.” We are told that science is only one way of learning about the universe but, unfortunately, the other ways are not described. According to the Quebec curriculum, scientific knowledge is “constructed by human beings and is not necessarily an absolute reflection of reality.”

“The idea that science always begins with a question or hypothesis is quite inaccurate. A great deal of science begins with contemplative observation.”



The majority of the curricula inform us that scientific research begins by posing a question or forming a hypothesis, then proceeds by designing an experiment. Prediction is also said to be important. Students, for example, may be asked to predict what they will see through a microscope before they actually look. In several curricula, “The stages of scientific inquiry” are laid out in a seven-step sequence which if followed properly will, apparently, inevitably lead to a successful result. “The stages of the design process” involve a similar sequence of seven steps which, it is said, will lead to new inventions or the solution of practical problems.

Science is widely viewed in the curricula as an endeavor based on a few simple unifying themes: (a) similarity and diversity; (b) systems and interactions; (c) change; (d) constancy; (e) equilibrium; (f) energy; (g) matter; and (h) models.

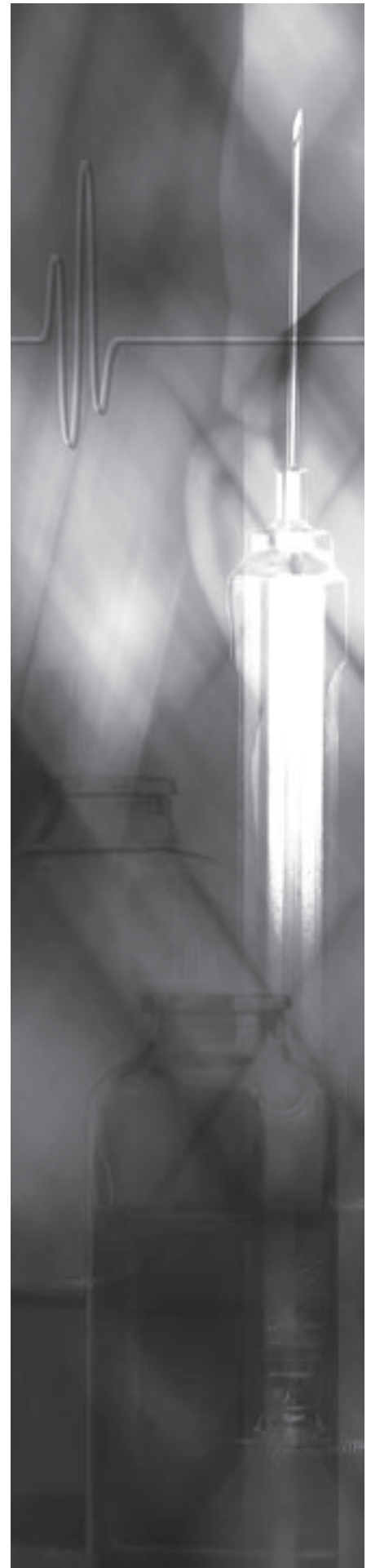
The foregoing views of science are not an accurate description of how working scientists view their field. Scientists generally have no doubt that science is an attempt to describe objective reality and, further, that it is often successful. Anyone who flies in an aeroplane or submits to a major medical procedure is staking his or her life on the assumption that basic scientific principles are an accurate description of reality.¹⁰

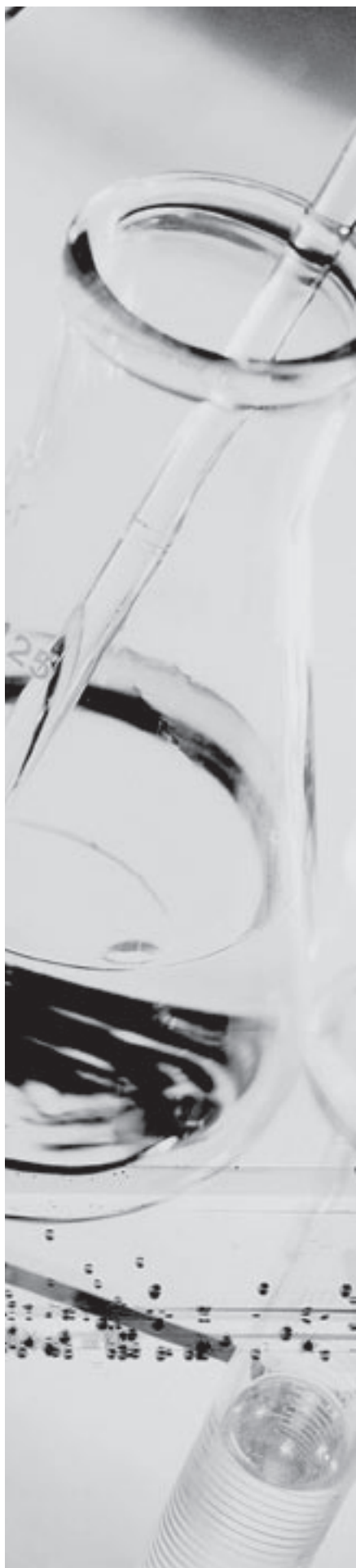
Further, the idea that science always begins with a question or hypothesis is quite inaccurate. A great deal of science begins with contemplative observation. Consider Alexander Fleming who noticed clear round bacteria-free spots in old cultures of staphylococci (leading to the discovery of penicillin) or Louis Pasteur who noticed that crystals of tartaric acid included two types that were mirror images of one another (leading to a recognition of the phenomenon of optical isomerism and an understanding of the molecular structures that produce it).

One of the great classics of science, Charles Darwin's *Origin of Species*, is based almost wholly on thoughtful observation of the natural world.

Most scientists of our acquaintance have a well-merited humility concerning the value and accuracy of their own predictions. Many observations or experiments are made with no better justification than "I wonder if it would be worth looking at..."

The idea that all of science is based on a few "themes" such as diversity, change or equilibrium does not appear to us to be of much value to students struggling with the complexities of the periodic table, electromagnetic phenomena, or cell division. These "themes" are very superficial and general and could be applied to virtually any human activity. Politics and government, for example, are characterized by a *diversity of opinions*, *changes in policy*, an *equilibrium* or balance of power between contending parties, and a system of government that co-ordinates the activities of such organizations as the Cabinet, the Commons, and the Senate.





The Ratings

The curricula from all the provinces were rated A, B, C, D, or F by pooling the evaluations of the raters with respect to: (a) Content; (b) Teaching methods; (c) Errors; (d) Absence of unsupported dogmatic statements; (e) Absence of inaccurate presentations of the nature of science; and (f) overall organization of the curriculum. The last category included a general rating of (a) whether the curriculum was organized in a way that makes it easy for teachers and others to use; and (b) whether separate course streams were offered for students with different abilities and interests.

Alberta ~ A

The Alberta curriculum received very good or excellent ratings with respect to scientific content and freedom from errors and unsupported dogmas. The curriculum made few explicit recommendations on exactly how different topics were to be taught, leaving this to the judgment of individual teachers, and contained a sane discussion of the nature of science. The curriculum also provides separate course streams for (a) university-bound students; (b) students who do not plan to enroll in post-secondary science programs; and (c) students with apparent learning impairments.

British Columbia ~ A minus

The scientific content of the courses was judged to be excellent. The high school biology program is very ambitious and the chemistry program was judged to be the best in Canada. On the other hand, the program contains a heavy arts and crafts approach to science education, includes dogmatic statements with no apparent factual basis, and has a poor discussion of the nature of science. There were few errors. Some provision is made for students who lack a strong academic orientation.

Manitoba ~ B

The scientific program is quite good, with a heavy emphasis on content in Grades 11 and 12, but it is marred by numerous rather serious errors and contains unsubstantiated dogmatic statements. The nature of science is not well described. There is also an emphasis on teaching techniques that probably do more to distract students than to teach them anything about science. Adequate provision is made for students who lack a strong academic orientation.

Ontario ~ B

The brevity of the Ontario curriculum makes it somewhat difficult to compare to curricula from other provinces. There are few errors, no discussion of teaching methods, little or no discussion of the nature of science, and no unsubstantiated dogmatic statements, but there is a (mercifully rather short) section containing rather pointless “education philosophy.” The Grade 9 to12 curriculum covers all the usual topics. The Grade 1 to 8 curriculum is quite unique. All the material is organized in terms of five “strands” (1) Life sciences; (2) Matter and materials; (3) Energy and control; (4) Structures and mechanisms; and (5) Earth and space systems. Each of these “strands” is then organized into eight grade levels, an arrangement that would force a teacher to search through five different sections of the curriculum to find out what was to be taught in any particular grade. The Ontario curriculum offers separate courses for university preparation, college preparation, workplace preparation, and for academically impaired students.

Quebec ~ B

The Quebec curriculum appears to be in the midst of a transition from a strongly teacher-directed program with an excellent scientific content to a program organized entirely in conformity with the educational theories of Rousseau (although the debt to Rousseau is never acknowledged). Many of the suggested laboratory exercises appear to consist of providing students with a collection of equipment and materials and telling them to go discover something. There are few errors in the curriculum but the discussion of the nature of science does not correspond to the views of working scientists. Science is to be studied in Quebec, not because it provides a means of understanding the natural world, but because it has powerful effects on society, politics, and the economy, and because “a society can express its cultural identity only in conjunction with some form of scientific and technological autonomy” (p. 5 of the section on Physics 534). Science and science education, in other words, are to be brought into the service of Quebec nationalism and the desire to build “a society around the doctrine of scientific humanism” (General Biology, vol. 3, p. 47). There is a concern, frequently expressed, that “Quebec universities do not produce the number of scientists required in a modern society.” The sequence of courses and the ages at which they are to be taught was not easily discovered; the authors of the curriculum appear to assume that every reader would already know this. Nonetheless, there is a standard program and an “enriched” program presumably intended for university-bound students.





Saskatchewan ~ B

The Saskatchewan science curriculum for Grade 1 to 9 was judged to be of unusually high quality (see Teaching methods) but the high school curriculum offers only vague guidelines on what is to be taught together with a strong emphasis on the use of the education theories of Rousseau (without acknowledgement of their origin). “By placing less emphasis on traditional lecture presentations, teachers transfer more of the responsibility for learning from themselves to their students... The teacher assumes the role of the learning facilitator.” The scientific content of the high school program was judged to be rather weak; it appears to be assumed that it is possible to teach “critical thinking”, “creative thinking”, and “higher level thinking” without teaching much content. “No one can maintain that there is a particular body of knowledge that all graduates should attain” (p. 2 of an information bulletin for administrators for Grade 10 science.) If this were taken seriously, science teaching would appear to be dispensable or even pointless.

Atlantic Provinces ~ C

Beginning in 1993, the Atlantic provinces have developed a common science curriculum but it does not yet extend to all science courses. Many of the courses have an inadequate content, contain many errors, contain unsubstantiated dogmatic statements, often recommend dubious teaching methods, and offer a poor discussion of the nature of science. We considered that some sections of these curricula deserve a “D” or even an “F” rating. There are, however, some bright spots. The Prince Edward Island (P.E.I) Grade 11 and 12 biology program was judged to be very good or excellent and a P.E.I. Grade 10 science course (Science 431) was also judged to be excellent.

Discussion

The overall quality of the science curricula in different provinces varied rather widely. Alberta was judged to have the best overall curriculum; British Columbia was close behind; Saskatchewan, Manitoba, Ontario and Quebec received middling ratings; and the Atlantic provinces fared relatively poorly. The quality of the curricula appears to be related to measures of student achievement in standard tests. In the School Achievement Indicators Program (SAIP for 1999) for science assessment, Alberta students took first place among the provinces; British Columbia took second place; Saskatchewan, Quebec, Manitoba and Ontario ranked third, fifth, sixth, and eighth respectively; while Prince Edward Island, Nova Scotia, New Brunswick, and Newfoundland ranked fourth, seventh, ninth and tenth respectively. Rather similar results were obtained in the Third International Mathematics and Science Study (TIMSS, 1999) in which Alberta scored first and British Columbia second among the Canadian provinces.¹² The international comparisons show that Alberta elementary and secondary schools offer one of the best preparatory science programs in the world, ranking considerably higher than the average for the United States, Britain, Australia, New Zealand and the various European countries.

“The quality of the curricula appears to be related to measures of student achievement in standard tests.”

It would not be justifiable to conclude from these results that the quality of a provincial curriculum is necessarily responsible for the scores achieved by that province’s students. Although curriculum quality might be a factor in student achievement, there may be other unidentified factors that promote both a high quality curriculum and high levels of student achievement.

A major feature of Canadian elementary and high school science curricula is a heavy emphasis on a Rousseau-like approach to education. No evidence is ever presented to show that Rousseau’s methods actually work better than other methods: they are recommended solely on the basis of supposed novelty without any awareness that so-called “child-entered education” is hundreds of years old. In one of the most extensive field trials of pedagogical techniques ever carried out, Engelmann *et al* (1988) compared direct instruction (teacher-led instruction, correction of errors, high expectations, frequent tests) with 13 other pedagogical approaches, including child-centered teaching, as a means of teaching reading, arithmetic and language to children in kindergarten to Grade 3. The scale of the study was massive, up to 75,000 children/year over several years in 170 American communities. Independent evaluation by a private testing firm showed that direct instruction was far more effective than any of the other pedagogical techniques tested.¹³

Although different approaches to the teaching of science have never been tested on a large scale, it does not seem likely that learning science is radically different from learning language, reading or arithmetic. One might hope that science teachers, in particular, might take note of empirical studies of the effect of different teaching methods and be willing to question the continual ebb and flow of fads and quackery in education.





References and notes:

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4. McTaggart-Cowan, I. (1989) Room at the top? In: Hummel, M. (ed) *Endangered spaces: the future for Canada's wilderness*. Toronto: Key Porter Books, Ltd, pp. 249-266.
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7. It is important to recognize in this context that many cultures did, indeed, develop complex arts and crafts such as metallurgy and long-distance navigation but that this is not the same thing as developing theoretical science. For example, medieval European culture possessed a sophisticated metallurgy which permitted the manufacture of many useful and beautiful objects made from brass, bronze, copper, gold, iron, lead, silver, steel, tin and zinc but the only available relevant "science" of the day (alchemy) taught that all matter is made up of varying proportions of fire, water, earth and air. Some alchemists were of the opinion that all metals are composed of mercury and sulfur. Such "science" was of little assistance to practical metallurgy. [See: Holmyard, E.J. (1990) *Alchemy*. New York: Dover Publications (first published 1957)].

Much of traditional knowledge has the character of a cookbook recipe. If certain procedures are followed a desired result will be obtained, but there is no understanding of why the procedures work.
8. A recognition that science was produced largely by the male members of one particular cultural group does not justify a belief in any particular form of explanation of this, i.e., the facts available are not sufficient to demonstrate a predominant role of biological factors, environmental factors, cultural factors or any other factors that might be invoked. An excellent discussion of environmental factors that may have contributed to the world-wide dominance of European (or more loosely Western) culture in the past five centuries can be found in a recent book by Diamond, J. (1999), *Guns, germs and steel: the fates of human societies*, New York: W.W. Norton & Co.
9. Gross, P.R., Levitt, N., and Lewis, M.W. (Editors). The flight from science and reason. *Annals of the New York Academy of Sciences*, 1996, 775: 1-593.

10. The fashionable “intellectuals” who argue that there is no such thing as objective truth are generally regarded by scientists as figures of fun. An excellent brief commentary on this kind of imposture has been published by: Dawkins, R. (2003) *A devil’s chaplain*. Boston: Houghton-Mifflin, pp. 47-53. It is unthinkable that such ideas should influence teaching in science.
11. *Report on science assessment school achievement indicators program (SAIP)* (1999). Council of Ministers of Education, Canada.
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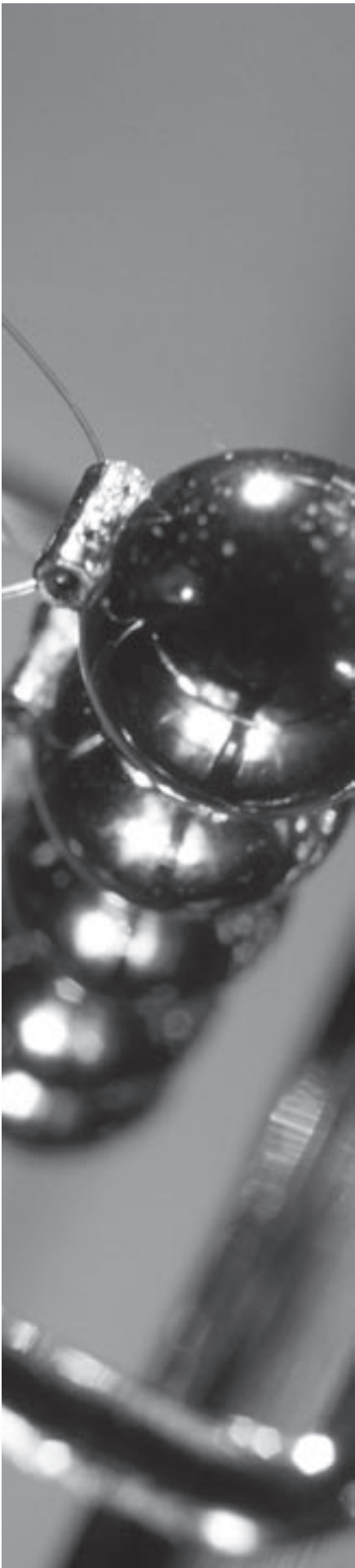
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