

Science Education and Textbook Science

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The Science and Education Study conducted by the Science Council of Canada, 1980–84, included a descriptive analysis of 32 science textbooks from among those most widely used in Grades K–12 in Canadian schools. From this descriptive analysis some characteristics of a representation of science emerged that will be referred to as *textbook science*. This paper attempts to clarify the concept of textbook science, discusses the methodology used to identify it, and illustrates some of its various aspects. It is then suggested that further research be undertaken on the validity of the science represented in textbooks with regard to recent advances in disciplines such as the history and the epistemology of science.

L'étude sur l'enseignement des sciences dans les écoles conduite par le Conseil des sciences du Canada en 1980–84 comprenait une analyse descriptive de 32 des manuels de sciences les plus utilisés dans les écoles canadiennes, de la maternelle à la 12^e année. Des conclusions de cette analyse descriptive, on a pu tirer certaines caractéristiques d'une représentation de la science qu'on pourrait appeler la "science des manuels scolaires." La présente communication se propose de clarifier cette représentation, d'examiner la méthodologie employée pour arriver à la cerner, et d'illustrer certains de ses nombreux aspects. L'auteur suggère d'entreprendre des recherches plus poussées sur la validité de la science représentée dans les manuels scolaires en regard des progrès récents dans d'autres disciplines, telles que l'histoire et l'épistémologie des sciences.

Science curriculum guidelines published by the ministries of education in Canada list a wide variety of aims for science education. One of the most frequently encountered is that students should know, understand, and in various ways be able to manipulate the substance of scientific knowledge. Such an aim stresses learning the *content* of science – its facts, relations, laws, and theories. At school, this content is embodied in science textbooks which will be used by teachers to prepare for instruction and by students who will read some passages, follow the written instructions to carry on experiments, and solve the problems and exercises found at the end of each chapter.

The scientific content of science textbooks varies very little, if at all, from one text to the other. By its consensual nature, the scientific knowledge of a given period is fixed, at least as long as the leading paradigm prevails. For example, one would be rather surprised to find conflicting statements of the law of gravity. However, this scientific content is embedded in a context, a mass of information *about* science

which indeed teaches something about science whether the authors realize it or not. This context is referred to by Roberts as a *curriculum emphasis*.

A curriculum emphasis in science education is a coherent set of messages to the student *about* science (rather than within science). Such messages constitute objectives which go beyond learning the facts, principles, laws and theories of the subject matter itself – objectives which provide answers to the student question: “why am I learning this?” (1982, p. 245)

If the scientific context is rather fixed, the choice of a context or emphasis is very wide. Hence, depending on the set of messages about science offered to the student in a particular textbook, that student will likely develop one of several corresponding images of science. This can be illustrated by an example from a physics textbook.

Issac Newton, so the story goes, discovered gravity one afternoon while sitting under an apple tree. An apple fell and struck him on the head. All at once he realized that the Earth was pulling down on the apple, and that that was why it fell. Before Newton made his discovery, fall was considered just another “natural” motion that needed no explanation. Apples fell, smoke rose, and the moon circled the Earth, because of their natures.

Newton suggested that the Earth, because of its great mass, exerted a strong inward pull on all nearby objects, such as apples and moons. This inward force he called the force of gravity.

Aristotle wrote, about 350 B.C., that the speed of a falling body is proportional to its mass. In other words, a 2 kg rock should fall twice as fast as a 1 kg rock. This was generally believed for nearly 2000 years, until Galileo, in 1590, suggested a simple experiment which you can try. Drop two objects of equal mass and similar shape side by side. They will fall at the same rate. Now, tie the two objects together with a short length of string. This gives you a single object with twice the mass of either of the original objects, and it will fall at the same rate as either of the original objects. This is how Galileo concluded that all freely falling objects fall at the same rate. You can test Galileo’s theory of gravity by doing the following investigation. (Heath, MacNaughton, & Martindale, 1979, p. 59)

Reading this, the student can assume that one can discover things at once, one does not try to explain that which is considered natural, one experiment is enough to contradict a belief held for 2000 years, one can test a theory by doing *one* scientific investigation, and two objects tied by a string *do* make one object. This student, then, can be expected to add these assumptions to those already learned and subsequently build a personal representation of science. Indeed, such a representation will not come solely through reading science textbooks. It will likely result from repeated exposure to the teacher’s own images of science and those projected by the media and popular literature. However, the textbook

is still a very major component of science teaching in Canada: at the secondary level, the science textbook is considered by teachers as the most useful means to prepare for instruction, and it is still widely used by students (Orpwood & Alam, 1984, p. 63). So, one can assume that the representation of science by science textbooks is crucial to the image of science formed by students during their formal education and, as such, deserves careful consideration.

The science textbook analysis performed within the Science and Education Study helps identify the representation of science by science textbook writers. This paper will summarize this descriptive analysis to see how it helps in identifying *textbook science* and to suggest ways to improve our knowledge of textbook science.

ANALYZING TEXTBOOKS FOR WHAT AIMS?

The Science and Education Study was concerned with the aims of science education and with the provisions being made in the schools to reach them. More precisely, the research phase focussed on the gap revealed between goals and practical achievements. The use of textbooks is considered by education authorities as one principal way to practically implement the aims of a science program.

It is important, therefore, that the *explicit* aims of frequently used textbooks be determined together with the actual curriculum emphases embodied, from which we may infer the *implicit* aims of the books. A comparison may then be made among three versions of science education aims: the official version (from the ministry guidelines), the textbook writer's version, and the implicit version revealed by the analysis. From such a comparison, the practical realization of these aims stated for teaching science can be assessed. The selection of aims for which this analysis was to be undertaken was done in two stages. First, we selected the two aims (other than learning scientific content) most popular among provincial educational authorities – acquisition of scientific skills, and learning about the interactions among science, technology, and society. Second, we selected three other aims claimed by critics of science education in Canada as unrealized in the classrooms:² learning science in a Canadian context, acquiring an authentic image of science, and developing an interest in the careers in science and technology.

Methodology

The analysis revolved around six themes: the explicit intentions of science textbook writers, the acquisition of scientific skills, the development of an

awareness of the interaction between science, technology, and society, the Canadian context in the teaching of science, the image of the scientific activity conveyed by science textbooks, and the encouragements to pursue careers in science and engineering. The original analytical schemes were designed for five of these themes (Orpwood & Souque, 1984, pp. 199f.). The construction of one will be described later. For one theme (acquiring scientific skills), we used an existing instrument (the LAI Instrument) developed by Fuhrman, Lunetta, Novick, and Tamir (1978), whereby the tasks students must perform during laboratory sessions (according to the laboratory manual) can be classified according to the degree of complexity. The other schemes were appraised by independent experts and were tested before use.

The selection of the 32 textbooks to be analyzed was based partly on the results of the Science and Education Study survey of science teachers, which listed the most widely used science textbooks in Canada, and partly on geographical and linguistic considerations (Orpwood & Souque, 1984, pp. 94f.). The task of examining such a large number of textbooks, intended for different populations and from so many different viewpoints far surpassed the capacity of a single individual. For this reason, the Science Council appointed a team of 18 science teaching specialists who, following an intensive training period, examined the textbooks from April to June, 1982.

The Design of Analytical Frameworks

This paper which focuses on textbook science will consider only one framework which gives helpful information about textbook science: the Science-Technology-Society (STS) Interactions in Science Textbooks.

Most of the ministries and departments of education in Canada believe that one aim of science teaching is to make students aware of the social implications of science and technology. Two examples illustrate this: (a) *aims of the teaching of natural sciences (Québec, elementary level)*, which are "to enable pupils to develop as autonomous and creative individuals in a scientific and technological society" (Gouvernement du Québec, 1984, p. 8), and (b) *goals of the chemistry program (Nova Scotia, senior-high level)*, which require

students to acquire the basic chemical knowledge in making decisions required of *participating citizens of a technological nation*. They will develop a realistic as opposed to a hostile or fearful attitude to chemistry.

This will be accomplished through an understanding of the influences of chemistry and chemistry technology on our society, our everyday life and our environment. By becoming aware of the potential uses and abuses of chemical

knowledge, students will question the uses to which chemistry and chemical technology are put (Nova Scotia Department of Education, 1977, p. 7).

Both aims stress a *personal* dimension. The second not only suggests learning facts about science, technology, and society; like the first, it suggests reinvesting this knowledge in the personal decisions of a citizen in our modern society. While examining science textbooks in order to find messages about STS, we had, then, two broad categories in mind: knowledge about science and technology and utilization of scientific knowledge for personal decision making in society. The former, in turn, was broken down in three subcategories taken from the field of science policy analysis: the impact of science and technology on society, the use of science and technology for social purposes, and the social responsibility of science and technology. Taking as a basis the works of Aikenhead (1981), Ziman (1980), and Orpwood and Roberts (1980), we finally opted for four categories that seem to constitute the essentials for STS interaction for the primary and secondary levels and that would help classify the messages about STS interaction:

- (a) *Application of knowledge* is defined by messages that invite students to use their scientific and technical knowledge to benefit themselves or their community.
- (b) *Socioeconomic category* is defined by messages that describe the beneficial or detrimental effects of scientific and technological activity for society at the national and international levels.
- (c) *Political category* is defined as messages dealing with the ways in which a society exploits scientific and technological knowledge to solve national or international problems.
- (d) *Scientific responsibility* is defined as messages dealing with the ethical and legal aspects of scientific and technological activity.

Provided with this analytical framework, each analyst undertook, page by page, the search for messages about STS interaction. A summary of the results will follow later.

DESCRIPTIVE ANALYSIS

For the purposes of this paper, we will summarize only those results of the analysis that help identify a representation of science in textbooks: the STS interaction, the acquisition of scientific skills, and the nature and history of science.³

STS Interaction

The first category of messages concerning STS interaction concerned the application of knowledge. The results show that science textbook authors provided few or no activities involving the application of scientific or technological knowledge in society. When such activities were requested, they were mainly reflective in nature. Invitations to direct action were addressed chiefly to junior-high students. In general, students were asked to conduct these activities at home and in the community rather than at school, and these activities tend to be individual rather than collective.

Messages in the second category, socioeconomic, were most numerous (230 messages taken from the 32 textbooks and two supplementary booklets). They fell within five groups of varying size, and each group is characterized by one message, representative of the group.

Group A (98 messages): Growth or progress resulting from science and technology creates pollution, causes illness, and disturbs the ecosystem.

Group B (55 messages): Science and technology have created medicines and techniques for improving public health and combatting malnutrition.

Group C (27 messages): Science and technology have created machines or processes to facilitate work or increase the well-being of the population.

Group D (23 messages): Science and technology have made possible the creation of beneficial new materials and new sources of energy.

Group E (20 messages): Growth or progress resulting from science and technology entails the squandering of energy and resources and gives rise to problems of waste management.

Group F (7 messages): Science and technology, by their effects on society, are inducing people to conserve resources and energy and to take action against pollution.

According to our sample of textbooks, pollution and the waste of resources were the most important consequences of science and technology. This conforms fairly well to the temper of the times during the 1970s. The benefits of science and technology appeared to come exclusively from medical research. Finally, the effects of data processing and telecommunications, phenomena that likely will change the society of the 1980s, were conspicuous by their absence in the physics, general science, and physical science textbooks examined.

In the political category, our analysis found scattered throughout our sample of textbooks about 130 messages concerning social problems which science and technology can be called upon to solve: world hunger, diseases, and problems caused by science and technology such as pollution or the increased need for new sources of energy.

Finally, in the category of the scientific responsibility, about 65 messages concerned the moral and legal dimensions of the scientific and technological activity. The moral problems were: personal attitudes to pollution and waste, questions concerning life in society (such as the use of drugs), genetic engineering, and genetic counselling. The legal problems again concerned pollution and waste.

Scientific Skills

The analysis of about 1000 instructions for laboratory work from elementary to senior high levels with the LAI instrument yielded the following results: the laboratory exercises were almost always highly structured and only low-level tasks were required from students. Out of the 32 textbooks examined, 28 of them never asked the student to formulate a question or define a problem, and the student was only rarely asked to plan the observation or measurement procedure or determine the accuracy of the results, and even more rarely to plan the experiment.

Nature of Science and History of Science

The analytic framework concerning the nature of science and the history of science and technology helped complete the picture of science as represented in textbooks. It allowed the analysts to gather messages about the nature of science: how science works, what method it uses, how scientists carry on their tasks, how the scientific community behaves, and so on. The history of science was included in the analysis because most textbook writers introduced a historical component to illustrate the nature of science.

Messages about the nature of science often appeared in the form of definitions of science as a product and a process and of the scientific method. With little variation and a caveat here and there, the scientific method is described as empirico-inductivist and generally presented as a series of steps: definition of the problem, observation, gathering of information, formulation of a hypothesis, designing of an experiment with controlled variables, verification, and communication of results.

Defining science as both product and process has two aims: first, to teach the facts, laws, and theories and, second, to show the student how to

work and that scientists actually work this way themselves. However, as we have already seen from analyzing laboratory exercises, the entire range of skills involved in the scientific method is seldom considered. One might also ask to what extent textbooks demonstrate that science does, in reality, conform to the procedural description given in the initial chapters. On the whole, authors attempt to prove this claim, though never compromising on the amount of content to be covered for a school year. This explains why theoretical entities are introduced in textbooks as if their discovery were self-evident: "Then in 1932 the neutron was discovered. This is a particle with a mass almost the same as that of the proton (actually it is just slightly heavier, but it has no electrical charge)" (MacLachlan, McNeill, Bell, & Spencer, 1977, p. 282).

Other characteristics of science that authors included were co-operation and communication among the scientific community. From examining science textbooks, it was obvious that, on the one hand, the only act of communication asked of the student was the submission of a laboratory report; on the other hand, the student was never asked to examine or discuss any original publication as evidence of scientific communication. We also found it curious that textbooks, as examples of scientific communication, rarely, if ever, acknowledge their sources.

The use of the history of science in textbooks was particularly interesting for, although history objectives have no apparent importance for either ministries of education or teachers, very few textbook authors chose to disregard the history of science completely. Historical messages ranged between two extremes: the first consisted only of the names of scientists and dates of their discoveries; the second featured detailed case studies from the history of science. The information we sought centred both on these two extreme cases and on examples in between.

Most textbooks used names of scientists merely to identify a fact, law, or theory. In only 5 textbooks (from a sample of 28) was the proportion of scientists whose work was described according to a systematic account of the scientific method greater than 50%. Most often, the student was told of scientific discoveries but not why scientists were studying the particular phenomenon. Moreover, these scientists generally were not placed in any historical or social context.

Finally, the history of the evolution of the atomic model as related in some science textbooks constituted a good example of textbook science. As we mentioned earlier, textbook writers commonly claim that open communication and teamwork are two values associated with the scientific enterprise. However, the accounts of the development of the atomic model given in five chemistry textbooks at the senior-years level⁴ failed to conform to this expectation. In each book, the student sees the

development of this model from J. J. Thomson to Niels Bohr and the corrections made by Ernest Rutherford and James Chadwick. At no time are the students given any indication that these men knew each other or that the atmosphere at the Cavendish Laboratory at Cambridge University contributed to these achievements. (In reality, J. J. Thomson was director of the laboratory from 1884 to 1919, and Rutherford, his student as of 1895, replaced him as director in 1919. And Niels Bohr had been a student of Thomson at Cambridge and of Rutherford at Manchester, while Chadwick had worked under Rutherford at Cambridge.) Very occasionally, one may read: "Rutherford, under Thomson's supervision ..." or the like. Yet, there must have been a certain "chemistry" (if I may say so) at the Cavendish laboratory, a social and intellectual climate that made the development of the model possible there rather than elsewhere. In 1906, Thomson was awarded the Nobel Prize in physics, and subsequently seven of his research assistants were to win Nobel Prizes. The history of this period of science as it is related in textbooks conveys very little of the social and intellectual context that could explain all these achievements. The scientist is often portrayed as the solitary genius who has the right idea at the right time: "The time was ripe for someone of great vision and imagination to provide an explanation for these facts. The Danish physicist Niels Bohr was such a person. He proposed a model that stretched the minds of scientists" (O'Connor, Davis, Haenisch, MacNab, & McClellan, 1981, p. 164).

This example raises another issue: the standardization of textbooks.⁵ None of the five textbooks differed significantly in describing the development of the atomic model. Moreover, some claims that are made in all the textbooks are open to question. The five textbooks claim that, following the experiment of Rutherford and/or Geiger and Marsden (in 1911), Rutherford postulated that the nucleus was small, positively charged, and contained all the mass of the atom. However, in his now famous article, Rutherford said: "The main results of large scattering are independent of whether the central charge is positive or negative. It has not yet been found possible to settle this question of sign with certainty" (Rutherford, 1911, p. 20).

Indeed this question was to be settled, but only a few years after the experiment. Another claim shared by textbook writers is that Thomson's model was a "plum-pudding" one. We have not been able to find the origin of this culinary metaphor. However, Rutherford, in 1914, gives a different account – and a different culinary metaphor:

In this type of atom (first suggested by Lord Kelvin, and afterwards modified and examined in great detail by Sir J. J. Thomson) the positive electricity is supposed

to be uniformly distributed throughout a spherical volume of dimensions comparable with that of the atom itself as ordinarily understood. Negative electrons are supposed to be distributed through this volume either in one plane in concentric rings or in concentric spherical shells like the coats of an onion. (Rutherford, 1914, p. 342)

Finally, in the same article, Rutherford discusses the external structure of the atom. As Rutherford is considered in science textbooks as the father of the planetary model, it is interesting to read that: "We have so far not discussed the distribution of the external electrons which make the atom electrically neutral. This is an exceedingly involved problem and any attempt at its solution at once raises many difficulties" (Rutherford, 1914, p. 351).

In their attempt to represent science as a road to discovery devoid of major obstacles, most textbook writers misrepresent science. The problem is not new. In 1951, Conant wrote:

The stumbling way in which even the ablest of the scientists in every generation have had to fight through thickets of erroneous observations, misleading generalizations, inadequate formulations, and unconscious prejudice is rarely appreciated by those who obtain their scientific knowledge from textbooks. (Conant, 1951/1974)

Except for the Project Physics writers, it seems that Conant's comments have had little impact on science textbook writers.

THE DIMENSIONS OF TEXTBOOK SCIENCE

The Science and Education Study has revealed some features of textbook science. As any representation of science, it is composed of several elements: epistemological (a model of scientific knowledge), historical, and social. But the question is: is this representation valid? In other words, would this representation satisfy the epistemologists of science, the historians of science, and the sociologists of science? This is a further dimension: a different question from that of accuracy, although our previous examples may have led the reader to think the opposite. For instance it is accurate that Galileo suggested the simple experiment described in the textbook quoted at the beginning of this paper. However, the image of science conveyed here entails a strongly rationalistic view of theory building. Galileo's conjecture about the free fall of objects rests strictly on the power of reasoning, without reference to any actual experiment. In fact, Galileo had good reasons for not basing his hypothesis on experimental data: the vacuum technology needed for the experiment did not exist and the experimental tools then available would

not have allowed him to gather significant results. This image of science as producing theories from pure rational activity has been challenged for centuries in the Western world by empiricists, who put a premium on experimentation as the source of knowledge. This philosophical debate is still alive (Thuillier, 1983), but, because the image of science conveyed in most North-American textbooks is heavily biased towards empiricism, students and teachers alike fail to appreciate a more valid account of the scientific activity generated by this debate (Orpwood & Souque, 1984, p. 136; Souque, 1985, p. 497). As a first step, writers of science textbooks could at least clarify for the students the philosophical perspective behind particular statements of how science works. This might help convey an image of science that is more complete, more challenging, and certainly more valid than at present.

To conclude, if we want to look for the validity of textbook science, we must first find analytical frameworks to identify all its features. This means drawing from philosophy, epistemology, history, and sociology of science to examine the textbook context within which science is placed. This line of research is promising and has already brought interesting results (Kilbourn, 1980). With better knowledge of textbook science, we will become able not only to measure the degree of its validity but also to design textbooks that present a valid image of science.

NOTES

- ¹ An earlier draft of this paper was read at the annual meeting of the National Association for Research in Science Teaching held in New Orleans, April 28–30, 1984.
- ² See, for example Symons (1975, p. 1962) or Désautels (1980, p. 123).
- ³ The publications of the Science Council Study may be obtained from the Publications Office, Science Council of Canada, 100 Metcalfe, Ottawa, Ontario, K1P 5M1. These include discussion papers, workshop proceedings, a three-volume background study, *Science Education in Canadian Schools*, edited by Graham Orpwood and Jean-Pascal Souque, and the Council's final report, *Science for Every Student: Educating Canadians for Tomorrow's World*. All publications are available in English and French.
- ⁴ The textbooks examined were O'Connor, Davis, Haenisch, MacNab, and McClellan (1981), Toon and Ellis (1973), Turner and Sears (1977), Parry, Dietz, Tellefsen, and Steiner (1975), and Lahaie, Papillon, and Valiquette (1976).
- ⁵ The question of the standardization of the scientific content of college chemistry textbooks has been documented by Factor and Kooser (1981) and Kooser and Factor (1983).

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Die "Science and Education Study" (Wissenschafts, Erziehungs und Ausbildungs Untersuchung) welche in den Jahren 1980–84 von dem Science Council of Canada durchgeführt wurde, enthielt eine beschreibende Analyse von 32 Wissenschafts-Lehrbüchern die allgemein in kanadischen K-12 Schulen gebraucht werden. Die Analyse erbrachte einige Charakteristiken zur Darstellung der Wissenschaft die als "textbook science" (Lehrbuchwissenschaft) bezeichnet werden soll. Diese Abhandlung erklärt den Begriff "textbook science," erläutert die Methodik die angewendet um sie zu identifizieren und beschreibt einige seiner Aspekte. Es wird dann vorgeschlagen, daß im Hinblick auf neueste Fortschritte in den Disziplinen der Geschichtslehre und Epistemologie der Wissenschaft, weitere Untersuchungen in die Gültigkeit der in Lehrbüchern dargestellten Wissenschaft, unternommen werden.

El estudio de la documentación para la enseñanza de las ciencias, realizado por el Science Council of Canada (Concejo de Ciencias de Canadá) en 1980–84 incluyó un análisis descriptivo de 32 textos de ciencia de entre los más usados en las escuelas canadienses, desde jardinería hasta el final de la secundaria. Algunas características se hicieron claras del resultado de este análisis descriptivo, que se podrían denominar "ciencia de los textos." Esta comunicación tiene por objeto aclarar tal concepto de ciencia, examinar la metodología usada para identificarla, e ilustra algunos de sus aspectos. Luego se sugiere entablar investigación adicional sobre la validez de las ciencias tal como se representan en los textos, respecto a los más recientes adelantos en disciplinas tales como la historia y la epistemología de las ciencias.

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