STS Education: International Perspectives on Reform

Published by Teachers College Press (New York) 1994

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Chapter 2

The Social Contract of Science: Implications for Teaching Science

Glen Aikenhead

In his 1939 book, The Saber-Tooth Curriculum, Harold Benjamin sketched a parable of stagnate curriculum reform. Let me quote a synopsis:

Three fundamentals marked the first educational curriculum: (1) catching fish with the bare hands, (2) clubbing tiny horses to death, and (3) frightening saber-toothed tigers with torches.

By studying those three subjects in their "schools" the stone-age people got along fairly well until there came a changed condition caused by the movement of ice from the north, the forerunner of the ice age.

The streams became muddied and fish could not be seen to catch with the bare hands, so someone invented the net, made of vines. The tiny horses fled and the antelope replaced them. The stone-agers invented antelope snares. The saber-toothed tigers died of pneumonia, but the big ice bear replaced them, and the stone-age men dug pits to trap them. So net-making, twisting antelope snares and digging bear pits became the three essentials of life.

But the schools continued to teach fish-catching with the hands, horse-clubbing, and tiger-scaring because they had taught them for years. Some "liberal" wanted to teach net-making, snare-making, and pit-digging but he was met with opposition. Some even wanted to do away entirely with the old subjects, but they aroused a storm and were called radicals.

The old subjects must be retained for their "cultural value," the school people contended. The proposed new subjects had no place in the curriculum.

The conservatives said: "Training to catch non-existent fish with bare hands is the best way to achieve muscular coordination and agility; training in clubbing horses that do not exist is an education in stealth and ingenuity; practising to frighten tigers that do not exist develops courage. Some things are fundamental and sacred in education and must not be changed." (Benjamin, 1948, pp. 53-54)

This chapter develops the argument that the high school science curriculum, as normally taught today, is a saber-tooth curriculum. Because the curriculum was established in the 19th century, and

although times have changed dramatically, the fundamental and sacred aspects of the 19th century science curriculum remain with us today.

The argument proceeds in two interconnected parts. The first part traces the evolution of science from its status as "natural philosophy" in renaissance society to its modern status in the 1990s. The evolution of science demonstrates how social events have shaped the very nature of science itself. This historical analysis establishes a framework for the second part of the argument which demonstrates how social events over the last three decades will likely reshape the high school science curriculum. The argument concludes that a science-technology-society (STS) science curriculum will replace the saber-tooth curriculum, for the same reason that over a hundred years ago science replaced natural philosophy.

The historical analysis explaining the evolution of science draws heavily upon a series of lectures given by Everett Mendelsohn (1975a, b, c, 1976), professor of history of science at Harvard University. This historical analysis of science provides new insights into today's high school science curriculum. The analysis gives a context for understanding why science teachers tend to teach as they do, why educators are calling for a change in this teaching, and why an STS curriculum is the natural focus for such a change.

The Evolution of Science

Over the past five hundred years, historical events have helped to shape the very nature of science itself (Cohen, 1960; Dampier, 1948; Elkana & Mendelsohn, 1981; Mendelsohn, 1975a, b, c, 1976; Middleton, 1963). Three instances will be examined:

1. How the social context of 17th century Europe, dominated by the Counter-Reformation, gave birth to the <u>institutionalization</u> of natural philosophy (the "science" at that time);

2. How the social context of 19th century Europe, dominated by the Industrial Revolution, precipitated the <u>professionalization</u> of science (when the term "science" came into common use);

3. How the social context of the 20th century, dominated by World War II, molded the <u>socialization</u> of science (the "science" of our everyday world today).

These three episodes caused mutations to science's fundamental characteristics. These critical episodes will be examined, one at a time, to see how they guided the evolution of science and how they profoundly altered science's social contract with society.

Our story begins with the Renaissance, a time when Aristotle's philosophy of the world governed people's conceptions of matter, motion, and the heavens. Some scholars added incrementally to Aristotle's intellectual heritage; for example, Bernard Sylvester (12th century), Roger Bacon (13th century), Nicole Oresme (14th century), Leonardo da Vinci (15th century), Copernicus (16th century), and finally, Johannes Kepler and Galileo Galilei (early 17th century). Their individual efforts began to define a new type of philosophy -- natural philosophy. Natural philosophy rejected authority based on scripture and old philosophers, in favor of authority based on one's empirical experience with nature.

The renaissance explorers of nature (da Vinci, Kepler, Copernicus, etc.) were unimpeded by any social contract with their society. They were only hobbyists enjoying intellectual diversion. Their musings were not seen initially as interfering with traditional philosophy. As the 17th century approached, however, the political climate changed. The Reformation led to the Counter-Reformation. A social contract would have to be negotiated between natural philosophy and society.

The Institutionalization of "Science"

During the first half of the 17th century, a number of natural philosophers worked towards organizing themselves into a politically acceptable public enterprise. Leaders in this effort included Mersenne, Descartes, Bacon, Huygens, Boyle, and Hooke. In 1662, British natural philosophers were formally incorporated into The Royal Society. They were followed in 1666 by the French natural philosophers who formed the Academie de Science in Paris. What content did they include in their new type of knowledge? What content did they leave out? What were the social forces at the time? How did these forces determine what would be included, and what would be excluded?

First, let us examine the social forces. Seventeenth century Europe was a time of insecurity and anxiety. People were coping with the Counter-Reformation, wars, fires, and epidemics. It was a period of instability -- social, intellectual, and political instability. Traditional sources of authority had been undermined. Natural philosophers of earlier generations had contributed to this revolution. Some had been condemned. Some had even been burned.

In 1660, however, a new social order was in place. Cromwell's rule had ended in England. The church and crown were reestablished. World exploration and colonialization had given rise to a new mercantile middle class.

What did natural philosophers offer this new society in return for allowing the natural philosophers to institutionalize their new way of thinking? What compromises did the natural philosophers have to make?

The promise that natural philosophy offered society is best summarized by Francis Bacon when he wrote about three kinds of ambition. The third and most noble ambition was for man "to establish and extend the power and dominion of the human race over the universe. ... We cannot command nature except by obeying her and understanding her" (quoted in Mendelsohn, 1975c, p. 9). In short, knowledge is power! "Scientia est potentia." Not only is knowledge power, but within the domain of Christendom, with its Judao-Christian ethic, you could exploit nature with a mood of indifference to the feelings of natural objects. Therefore, natural philosophers offered 17th century society three gifts: (1) a new way of knowing characterized by a new type of authority, an authority based on observation and rationalism, and not on scriptures and social position; (2) the goal and ability to achieve power and dominion over nature, and (3) a mood of indifference towards any responsibility to nature or to those who might be affected by the new rational knowledge.

But there was a compromise. In order to establish a niche in society, natural philosophers had to make peace with the newly established religious and secular authorities. The compromise was clear. Natural philosophers would avoid discussing religion, politics, and morals. These topics would be excluded, along with subjectivity and arational thinking. The public face of The Royal Society was therefore established. The social contract of natural philosophy was finalized: natural philosophy would deal only with objective rational knowledge acquired through direct experience with nature, and in return, natural philosophy would provide other social institutions with power and dominion over nature. Mendelsohn (1975b) calls it the positivist compromise.

Natural philosophy, as a social institution, was established across Europe. Its social contract with 17th century society kept natural philosophy out of trouble with the new authorities. Moreover, natural philosophy provided a new middle class with useful, practical knowledge which carried no moral responsibility. To be sure, discussions about moral responsibility were defined by the social contract to be beyond the scope of natural philosophy. In short, the precursor to science had been declared objective and value free, because its political survival depended on it.

The social and historical events of the 17th century helped to shape the characteristics and limitations of what we call science today. In the meantime, other historical events would reshape the nature of science.

The Professionalization of "Science"

The 17th and 18th centuries saw natural philosophers gain power and dominion over nature. By the end of the 18th century, their successful techniques and knowledge were redirected by others -- technologists -- towards power and dominion over human productivity itself. This gave rise to the Industrial Revolution and gave new power to the social institution of technology. Technology became so successful that it challenged the social niche that natural philosophy had gained 200 years earlier. Industrialists saw natural philosophy as the handmaiden of technology. Natural philosophers would have none of it.

They reacted to the attempted subordination in several ways: by retreating into the cloisters of the universities, by calling themselves "scientists" (to distinguish themselves from natural philosophers), by creating a public face of "pure science," by isolating themselves from the "vulgarities of practical knowledge," and by establishing a tight rein over who would have access to becoming a scientist and what standards would apply. Natural philosophy had evolved into a profession.

The Industrial Revolution caused natural philosophy to redefine its boundaries and to renegotiate its mission in society. By redefining its boundaries, what did science include? What did it exclude?

Science focused its efforts on intellectual curiosity and knowledge for knowledge sake, a marked departure from its Baconian tradition of practical knowledge. Moreover, science distanced itself further from value-laden discourse, from the consumers of its knowledge, and from social responsibility. Science eschewed its technological and social connections.

Scientists established a self-serving hierarchical position by defining technology as "applied science." The misconception continues to plague technology and science education today (Collingridge, 1989; Fleming, 1989; McGinn, 1991; Snow, 1987).

By 1860, a reshaped domain of knowledge had been constituted. Biology, chemistry, geology, and physics were enshrined as disciplines when they became new administrative units within the university. Natural philosophy had become professionalized science.

Coincidentally, the high school science curriculum was being introduced into public schools for the first time. The university's administrative model for science was copied by the high schools. Biology, chemistry, geology, and physics became the only valid ways to view nature. Like 19th century science, high school science eschewed practical knowledge and ignored values and social relevance.

A conclusion seems warranted. Similar to science itself, the high school science curriculum was shaped by the social forces that existed at the time of its inception. This happened to the high school curriculum when science was retreating into the universities to protect itself from a take-over bid by technology. As a consequence, the legitimacy of school science was defined by the 19th century professionalization of university science, and the purpose of school science was to prepare students for university science.

The Socialization of Science

The 20th century brought a host of new social forces. World War II likely reshaped science more than any other single historical event. World War II ensured the marriage of aloof scientific expertise with life-or-death practical problems of technology. This unlikely marriage irrevocably bound science and technology into a strong social unit called research and development (R & D). This marriage necessitated a new social contract between science and society.

The transformation of science during World War II is epitomized by one of the most dramatic events that occurred: the production and deployment of the atomic bomb. It was a corner around which humanity turned. Science constructed the corner and guided humanity around it. The splendid isolation, which scientists by and large enjoyed since the 19th century, was evaporated by a mushroom shaped cloud.

By the end of World War II, "small science" had become "big science" (Price, 1963). Big science had profound implications. It meant big budgets; large partnerships with government, industry, and the military; and a narrowed gap between "pure" and "applied" science. Big science meant the creation of national wealth and military superiority. As a result, scientific knowledge today has political currency on two levels: (1) internationally where it is traded in the diplomatic halls of foreign policy (Dickson, 1984), and (2) nationally where it sustains the dominant socio-economic intrastructure of that society (McGinn, 1991). For instance, governments support R & D in order to maintain that country's competitive edge in the world market place (Ziman, 1984).

Government, industry, and the military have become the dominant patrons of scientific activity. Science of the 1990s occurs in an interactive world of politics, economics, and war. Only a small minority of academic scientists undertake pure research. Even these scientists are mindful, however, of the political lobbying required to obtain funds. One conclusion seems inescapable: the social significance of scientific knowledge now takes on a new 20th century reality.

While World War II was having an impact on the interactions between science and society, a new academic discipline emerged -- the sociology of science (Layton, chapter 4; Ziman, 1984). Anthropological studies into the social construction of scientific knowledge (for example, Latour and Woolgar, 1979) described two types of science: "public science" and "private science" (Holton, 1978). Public science is the science reported in journals, at conferences, and in textbooks. Private science, on the other hand, is what actually occurs in labs. It is recorded in personal notebooks, conversations, e-mail, and letters. What did the anthropologists discover about scientists? In contrast to the public face of science -- that objective, rational, open-minded, free communication, and honest face, which we recall was established in response to the social demands of a 17th century Europe -- private science was found to harbor subjectivity, arational thought, closed-mindedness, secrecy, and behavior less than honest (Gauld, 1982).

Today we recognize two social contexts of science; an <u>external</u> context in which science interacts with technology, economics, politics, law, ethics, and other facets of society; and an <u>internal</u> context in which historical and social dynamics mediate the production of knowledge (Rosenthall, 1989; Ziman, 1984).

Science still strives for power and dominion over nature, but in the new context of research and development where technology, values, and social responsibility play an increasingly important role (Mendelsohn, 1976). Thus, a new social contract between science and society seeks a balance between, on the one hand, power and dominion over nature, including economic well being, and on the other hand, stewardship of the earth and quality of life.

Summary

Science today differs dramatically from the "science" of 1660 and 1860. Each stage in the evolution of science has been shaped and reshaped by social forces, both external and internal to science. This is schematically represented in Figure 2.1 by the arrows between "social forces" and "science." The social forces of 1600 gave birth to the institutionalization of science (box I). The social forces of 1800 precipitated the professionalization of science (box P). And lastly, the social forces of the 20th century molded the socialization of science (box S).

Figure 2.1 fits here

Figure 2.1 serves as a framework for the next section. The argument turns to the social forces of the last three decades, and the consequence of those social forces in reshaping the high school science curriculum.

The High School Science Curriculum

As described above, the social context of 17th century Europe shaped the institutionalization of science. Similarly the social context of the 19th century shaped the fundamental tenets of the high school science curriculum. Figure 2.1 depicts this influence by the arrow from box P (the professionalization of science) to triangle I/P (the institutionalization and professionalization of the high school science curriculum). Figure 2.1 provides a framework with which we can understand current practices and anticipate future changes.

What can we understand about the science curriculum given its 19th century origins? We can now recognize why today's curriculum includes pure abstractions that demonstrate the aesthetic unity of the disciplines, and why practical knowledge and social concerns are all but excluded. We can now see why the curriculum portrays science as a purely rational and objective inquiry into absolute knowledge. We can now recognize this portrayal as the public facade of 19th century science. We can also appreciate how the social upheavals of the 17th and 19th centuries shaped this facade.

Moreover, we can now recognize that this facade of school science -- 19th century academic idealism -- is inconsistent with the realities of post World War II science. In other words, school science is seriously out of date. Like the saber-tooth curriculum, the school science curriculum embraces outmoded content and values. No wonder we hear the criticism that school science is sterile, false and boring (Science Council of Canada, 1984).

Several serious attempts have been made to modify the high school curriculum in North America over the past 50 years (Hurd, 1986). Educators have tried to replace the curriculum's 19th century academic isolationism with a 20th century authenticity that reflects the humanization/socialization that science itself has undergone. But every attempt has failed (Hurd, 1986). Those "conservatives" (as Benjamin called them) with vested interests in the saber-tooth curriculum possessed greater political power than the "liberals" who tried to implement an up-to-date curriculum.

Nevertheless we have reason to be optimistic about the latest struggle to modify the science curriculum. During the past three decades a number of new social forces have become evident. Synergetically they may cause the extinction of the saber-tooth curriculum.

John Ziman explains in chapter 3 that student motivation in the sciences has decreased, as evidenced by a depletion in enrollment and an apparent attrition in academic achievement. Research tends to show that school science actually discourages imaginative and creative students, particularly women and minorities, from entering the profession (Bondi, 1985; Majumdar, Rosenfeld, Rubba, Miller and Schmalz, 1991; Oxford University, 1989). School science, therefore, undermines the development of future scientists and engineers. This is evident in the United States with its nation-at-risk crisis, in which the decline in both enrollment and student capabilities threatens to compromise that nation's place in the competitive market of our global village (Hurd, 1989; Majumdar et al., 1991). Industry and labor support science and technology education in order to maintain a sound economy (Bondi, 1985; De Vore, 1992).

The environmental movement has raised the public's consciousness concerning the stewardship of the earth. In ubiquitous conflicts between corporate profits and environmental agendas, scientists have been seen to participate on all sides of an issue (Globe & Mail, 1983; Jacobson, 1983). As a consequence, the attentive public has changed its perception of science from an image of objective isolation to one with social agendas.

Furthermore, two new academic fields have articulated the social nature of science. The social studies of science field explores the internal sociology of science, while the science policy studies field concentrates on social issues external, but related to science (Spiegel-Rösing, 1977). For instance, David Layton in chapter 4 discusses the social studies of science and how the "Social Responsibility in Science" movement activated STS programs at universities and colleges. In chapter 5, I show how the two fields help define STS teaching.

Concomitantly, a "science-for-all" education movement has surfaced in many countries (Fensham, 1992). The science-for-all impetus in Canada, for instance, took the unusual form of a national science education policy calling for a socially relevant science curriculum (Science Council of Canada, 1984). A science-for-all education contrasts with an elitist view of education -- science for the few. Joan Solomon traced the historical roots of this contrast in chapter 1. "The few" refers to students who prepare for, and survive, the university screening mechanism that artificially selects students who look very similar to the very academic scientists who sustain that screening mechanism (Tobias, 1990).

Practical capability (Harrison, 1980; Layton, 1991) is the most recent social issue to challenge science education, as described by David Layton in chapter 4. Today's pressure to synthesize science and technology education is not unlike the earlier 20th century pressure that merged science and technology into the institution we call research and development (R & D).

In summary, the past three decades have witnessed the emergence of substantial social forces: (1) a pervasive decline in the interest and understanding of science; (2) an awakening recognition of science as a human, social, and technological endeavor; (3) an egalitarian movement in public education; and (4) a proposal to synthesize science and technology education. Each country has its own unique set of social forces that impinge upon its 19th century school science curriculum. Many countries are beginning to change their traditional science curriculum.

When designing a new curriculum, countries share a common trend towards teaching science embedded in technological and social contexts familiar to students (Bybee, 1985a; Eijkelhof and Kortland, 1988; Fensham, 1992; Hofstein, Aikenhead and Riquarts, 1988; National Science Teachers Association, 1982; Piel, 1981; Ziman, 1980). This new curriculum movement advocates teaching science in a science-technology-society (STS) approach. An STS science curriculum conveys to students an image of science that honestly reflects science's social character -- the 20th century socialization of science.

This new curriculum is depicted in Figure 2.1 by the "STS" triangle. The socialization of science (box S) constitutes a pervasive pressure on today's school science curriculum. The arrow between box S and triangle STS represents this pressure. The triangle has broken lines, indicating a tentative status. Will the social forces of the past three decades, including the social nature of science itself, establish a "socialized" science curriculum -- an STS science curriculum? How much longer can 19th century school science masquerade as legitimate science?

Reform has already begun as evidenced by the successful initiatives discussed throughout this book. STS science educators are closing the gap between 19th century school science and 20th century authentic science.

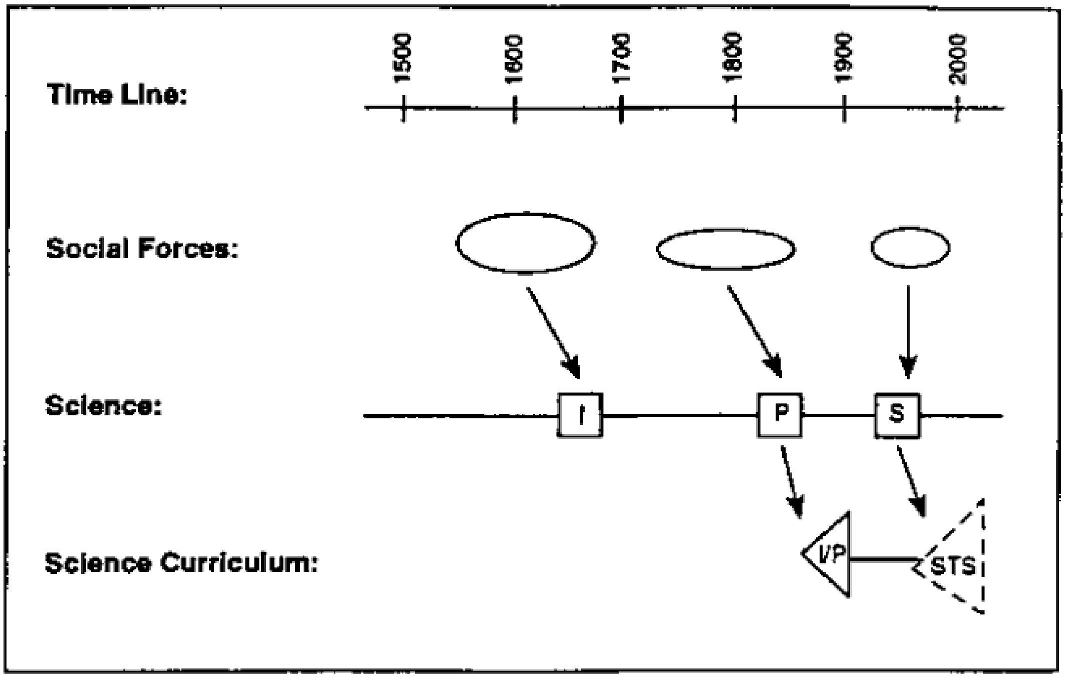

FIGURE 2.1 *The influence of social forces on science and the science curriculum*

Chapter 2

The Social Contract of Science: Implications for Teaching Science

Glen Aikenhead

In his 1939 book, The Saber-Tooth Curriculum, Harold Benjamin sketched a parable of stagnate curriculum reform. Let me quote a synopsis:

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By the end of World War II, "small science" had become "big science" (Price, 1963). Big science had profound implications. It meant big budgets; large partnerships with government, industry, and the military; and a narrowed gap between "pure" and "applied" science. Big science meant the creation of national wealth and military superiority. As a result, scientific knowledge today has political currency on two levels: (1) internationally where it is traded in the diplomatic halls of foreign policy (Dickson, 1984), and (2) nationally where it sustains the dominant socio-economic intrastructure of that society (McGinn, 1991). For instance, governments support R & D in order to maintain that country's competitive edge in the world market place (Ziman, 1984).

Government, industry, and the military have become the dominant patrons of scientific activity. Science of the 1990s occurs in an interactive world of politics, economics, and war. Only a small minority of academic scientists undertake pure research. Even these scientists are mindful, however, of the political lobbying required to obtain funds. One conclusion seems inescapable: the social significance of scientific knowledge now takes on a new 20th century reality.

While World War II was having an impact on the interactions between science and society, a new academic discipline emerged -- the sociology of science (Layton, chapter 4; Ziman, 1984). Anthropological studies into the social construction of scientific knowledge (for example, Latour and Woolgar, 1979) described two types of science: "public science" and "private science" (Holton, 1978). Public science is the science reported in journals, at conferences, and in textbooks. Private science, on the other hand, is what actually occurs in labs. It is recorded in personal notebooks, conversations, e-mail, and letters. What did the anthropologists discover about scientists? In contrast to the public face of science -- that objective, rational, open-minded, free communication, and honest face, which we recall was established in response to the social demands of a 17th century Europe -- private science was found to harbor subjectivity, arational thought, closed-mindedness, secrecy, and behavior less than honest (Gauld, 1982).

Today we recognize two social contexts of science; an <u>external</u> context in which science interacts with technology, economics, politics, law, ethics, and other facets of society; and an <u>internal</u> context in which historical and social dynamics mediate the production of knowledge (Rosenthall, 1989; Ziman, 1984).

Science still strives for power and dominion over nature, but in the new context of research and development where technology, values, and social responsibility play an increasingly important role (Mendelsohn, 1976). Thus, a new social contract between science and society seeks a balance between, on the one hand, power and dominion over nature, including economic well being, and on the other hand, stewardship of the earth and quality of life.

Summary

Science today differs dramatically from the "science" of 1660 and 1860. Each stage in the evolution of science has been shaped and reshaped by social forces, both external and internal to science. This is schematically represented in Figure 2.1 by the arrows between "social forces" and "science." The social forces of 1600 gave birth to the institutionalization of science (box I). The social forces of 1800 precipitated the professionalization of science (box P). And lastly, the social forces of the 20th century molded the socialization of science (box S).

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The High School Science Curriculum

As described above, the social context of 17th century Europe shaped the institutionalization of science. Similarly the social context of the 19th century shaped the fundamental tenets of the high school science curriculum. Figure 2.1 depicts this influence by the arrow from box P (the professionalization of science) to triangle I/P (the institutionalization and professionalization of the high school science curriculum). Figure 2.1 provides a framework with which we can understand current practices and anticipate future changes.

What can we understand about the science curriculum given its 19th century origins? We can now recognize why today's curriculum includes pure abstractions that demonstrate the aesthetic unity of the disciplines, and why practical knowledge and social concerns are all but excluded. We can now see why the curriculum portrays science as a purely rational and objective inquiry into absolute knowledge. We can now recognize this portrayal as the public facade of 19th century science. We can also appreciate how the social upheavals of the 17th and 19th centuries shaped this facade.

Moreover, we can now recognize that this facade of school science -- 19th century academic idealism -- is inconsistent with the realities of post World War II science. In other words, school science is seriously out of date. Like the saber-tooth curriculum, the school science curriculum embraces outmoded content and values. No wonder we hear the criticism that school science is sterile, false and boring (Science Council of Canada, 1984).

Several serious attempts have been made to modify the high school curriculum in North America over the past 50 years (Hurd, 1986). Educators have tried to replace the curriculum's 19th century academic isolationism with a 20th century authenticity that reflects the humanization/socialization that science itself has undergone. But every attempt has failed (Hurd, 1986). Those "conservatives" (as Benjamin called them) with vested interests in the saber-tooth curriculum possessed greater political power than the "liberals" who tried to implement an up-to-date curriculum.

Nevertheless we have reason to be optimistic about the latest struggle to modify the science curriculum. During the past three decades a number of new social forces have become evident. Synergetically they may cause the extinction of the saber-tooth curriculum.

John Ziman explains in chapter 3 that student motivation in the sciences has decreased, as evidenced by a depletion in enrollment and an apparent attrition in academic achievement. Research tends to show that school science actually discourages imaginative and creative students, particularly women and minorities, from entering the profession (Bondi, 1985; Majumdar, Rosenfeld, Rubba, Miller and Schmalz, 1991; Oxford University, 1989). School science, therefore, undermines the development of future scientists and engineers. This is evident in the United States with its nation-at-risk crisis, in which the decline in both enrollment and student capabilities threatens to compromise that nation's place in the competitive market of our global village (Hurd, 1989; Majumdar et al., 1991). Industry and labor support science and technology education in order to maintain a sound economy (Bondi, 1985; De Vore, 1992).

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Furthermore, two new academic fields have articulated the social nature of science. The social studies of science field explores the internal sociology of science, while the science policy studies field concentrates on social issues external, but related to science (Spiegel-Rösing, 1977). For instance, David Layton in chapter 4 discusses the social studies of science and how the "Social Responsibility in Science" movement activated STS programs at universities and colleges. In chapter 5, I show how the two fields help define STS teaching.

Concomitantly, a "science-for-all" education movement has surfaced in many countries (Fensham, 1992). The science-for-all impetus in Canada, for instance, took the unusual form of a national science education policy calling for a socially relevant science curriculum (Science Council of Canada, 1984). A science-for-all education contrasts with an elitist view of education -- science for the few. Joan Solomon traced the historical roots of this contrast in chapter 1. "The few" refers to students who prepare for, and survive, the university screening mechanism that artificially selects students who look very similar to the very academic scientists who sustain that screening mechanism (Tobias, 1990).

Practical capability (Harrison, 1980; Layton, 1991) is the most recent social issue to challenge science education, as described by David Layton in chapter 4. Today's pressure to synthesize science and technology education is not unlike the earlier 20th century pressure that merged science and technology into the institution we call research and development (R & D).

In summary, the past three decades have witnessed the emergence of substantial social forces: (1) a pervasive decline in the interest and understanding of science; (2) an awakening recognition of science as a human, social, and technological endeavor; (3) an egalitarian movement in public education; and (4) a proposal to synthesize science and technology education. Each country has its own unique set of social forces that impinge upon its 19th century school science curriculum. Many countries are beginning to change their traditional science curriculum.

When designing a new curriculum, countries share a common trend towards teaching science embedded in technological and social contexts familiar to students (Bybee, 1985a; Eijkelhof and Kortland, 1988; Fensham, 1992; Hofstein, Aikenhead and Riquarts, 1988; National Science Teachers Association, 1982; Piel, 1981; Ziman, 1980). This new curriculum movement advocates teaching science in a science-technology-society (STS) approach. An STS science curriculum conveys to students an image of science that honestly reflects science's social character -- the 20th century socialization of science.

This new curriculum is depicted in Figure 2.1 by the "STS" triangle. The socialization of science (box S) constitutes a pervasive pressure on today's school science curriculum. The arrow between box S and triangle STS represents this pressure. The triangle has broken lines, indicating a tentative status. Will the social forces of the past three decades, including the social nature of science itself, establish a "socialized" science curriculum -- an STS science curriculum? How much longer can 19th century school science masquerade as legitimate science?

Reform has already begun as evidenced by the successful initiatives discussed throughout this book. STS science educators are closing the gap between 19th century school science and 20th century authentic science.

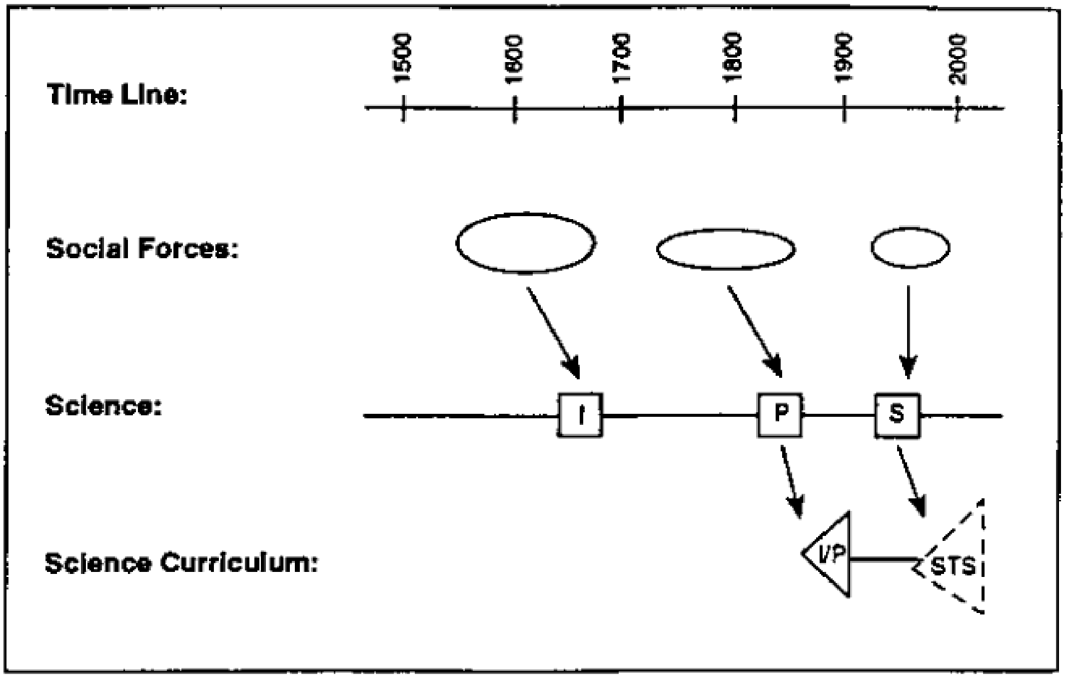

FIGURE 2.1 *The influence of social forces on science and the science curriculum*

Chapter 2

The Social Contract of Science: Implications for Teaching Science

Glen Aikenhead

In his 1939 book, The Saber-Tooth Curriculum, Harold Benjamin sketched a parable of stagnate curriculum reform. Let me quote a synopsis:

Three fundamentals marked the first educational curriculum: (1) catching fish with the bare hands, (2) clubbing tiny horses to death, and (3) frightening saber-toothed tigers with torches.

By studying those three subjects in their "schools" the stone-age people got along fairly well until there came a changed condition caused by the movement of ice from the north, the forerunner of the ice age.

The streams became muddied and fish could not be seen to catch with the bare hands, so someone invented the net, made of vines. The tiny horses fled and the antelope replaced them. The stone-agers invented antelope snares. The saber-toothed tigers died of pneumonia, but the big ice bear replaced them, and the stone-age men dug pits to trap them. So net-making, twisting antelope snares and digging bear pits became the three essentials of life.

But the schools continued to teach fish-catching with the hands, horse-clubbing, and tiger-scaring because they had taught them for years. Some "liberal" wanted to teach net-making, snare-making, and pit-digging but he was met with opposition. Some even wanted to do away entirely with the old subjects, but they aroused a storm and were called radicals.

The old subjects must be retained for their "cultural value," the school people contended. The proposed new subjects had no place in the curriculum.

The conservatives said: "Training to catch non-existent fish with bare hands is the best way to achieve muscular coordination and agility; training in clubbing horses that do not exist is an education in stealth and ingenuity; practising to frighten tigers that do not exist develops courage. Some things are fundamental and sacred in education and must not be changed." (Benjamin, 1948, pp. 53-54)

This chapter develops the argument that the high school science curriculum, as normally taught today, is a saber-tooth curriculum. Because the curriculum was established in the 19th century, and

although times have changed dramatically, the fundamental and sacred aspects of the 19th century science curriculum remain with us today.

The argument proceeds in two interconnected parts. The first part traces the evolution of science from its status as "natural philosophy" in renaissance society to its modern status in the 1990s. The evolution of science demonstrates how social events have shaped the very nature of science itself. This historical analysis establishes a framework for the second part of the argument which demonstrates how social events over the last three decades will likely reshape the high school science curriculum. The argument concludes that a science-technology-society (STS) science curriculum will replace the saber-tooth curriculum, for the same reason that over a hundred years ago science replaced natural philosophy.

The historical analysis explaining the evolution of science draws heavily upon a series of lectures given by Everett Mendelsohn (1975a, b, c, 1976), professor of history of science at Harvard University. This historical analysis of science provides new insights into today's high school science curriculum. The analysis gives a context for understanding why science teachers tend to teach as they do, why educators are calling for a change in this teaching, and why an STS curriculum is the natural focus for such a change.

The Evolution of Science

Over the past five hundred years, historical events have helped to shape the very nature of science itself (Cohen, 1960; Dampier, 1948; Elkana & Mendelsohn, 1981; Mendelsohn, 1975a, b, c, 1976; Middleton, 1963). Three instances will be examined:

1. How the social context of 17th century Europe, dominated by the Counter-Reformation, gave birth to the <u>institutionalization</u> of natural philosophy (the "science" at that time);

2. How the social context of 19th century Europe, dominated by the Industrial Revolution, precipitated the <u>professionalization</u> of science (when the term "science" came into common use);

3. How the social context of the 20th century, dominated by World War II, molded the <u>socialization</u> of science (the "science" of our everyday world today).

These three episodes caused mutations to science's fundamental characteristics. These critical episodes will be examined, one at a time, to see how they guided the evolution of science and how they profoundly altered science's social contract with society.

Our story begins with the Renaissance, a time when Aristotle's philosophy of the world governed people's conceptions of matter, motion, and the heavens. Some scholars added incrementally to Aristotle's intellectual heritage; for example, Bernard Sylvester (12th century), Roger Bacon (13th century), Nicole Oresme (14th century), Leonardo da Vinci (15th century), Copernicus (16th century), and finally, Johannes Kepler and Galileo Galilei (early 17th century). Their individual efforts began to define a new type of philosophy -- natural philosophy. Natural philosophy rejected authority based on scripture and old philosophers, in favor of authority based on one's empirical experience with nature.

The renaissance explorers of nature (da Vinci, Kepler, Copernicus, etc.) were unimpeded by any social contract with their society. They were only hobbyists enjoying intellectual diversion. Their musings were not seen initially as interfering with traditional philosophy. As the 17th century approached, however, the political climate changed. The Reformation led to the Counter-Reformation. A social contract would have to be negotiated between natural philosophy and society.

The Institutionalization of "Science"

During the first half of the 17th century, a number of natural philosophers worked towards organizing themselves into a politically acceptable public enterprise. Leaders in this effort included Mersenne, Descartes, Bacon, Huygens, Boyle, and Hooke. In 1662, British natural philosophers were formally incorporated into The Royal Society. They were followed in 1666 by the French natural philosophers who formed the Academie de Science in Paris. What content did they include in their new type of knowledge? What content did they leave out? What were the social forces at the time? How did these forces determine what would be included, and what would be excluded?

First, let us examine the social forces. Seventeenth century Europe was a time of insecurity and anxiety. People were coping with the Counter-Reformation, wars, fires, and epidemics. It was a period of instability -- social, intellectual, and political instability. Traditional sources of authority had been undermined. Natural philosophers of earlier generations had contributed to this revolution. Some had been condemned. Some had even been burned.

In 1660, however, a new social order was in place. Cromwell's rule had ended in England. The church and crown were reestablished. World exploration and colonialization had given rise to a new mercantile middle class.

What did natural philosophers offer this new society in return for allowing the natural philosophers to institutionalize their new way of thinking? What compromises did the natural philosophers have to make?

The promise that natural philosophy offered society is best summarized by Francis Bacon when he wrote about three kinds of ambition. The third and most noble ambition was for man "to establish and extend the power and dominion of the human race over the universe. ... We cannot command nature except by obeying her and understanding her" (quoted in Mendelsohn, 1975c, p. 9). In short, knowledge is power! "Scientia est potentia." Not only is knowledge power, but within the domain of Christendom, with its Judao-Christian ethic, you could exploit nature with a mood of indifference to the feelings of natural objects. Therefore, natural philosophers offered 17th century society three gifts: (1) a new way of knowing characterized by a new type of authority, an authority based on observation and rationalism, and not on scriptures and social position; (2) the goal and ability to achieve power and dominion over nature, and (3) a mood of indifference towards any responsibility to nature or to those who might be affected by the new rational knowledge.

But there was a compromise. In order to establish a niche in society, natural philosophers had to make peace with the newly established religious and secular authorities. The compromise was clear. Natural philosophers would avoid discussing religion, politics, and morals. These topics would be excluded, along with subjectivity and arational thinking. The public face of The Royal Society was therefore established. The social contract of natural philosophy was finalized: natural philosophy would deal only with objective rational knowledge acquired through direct experience with nature, and in return, natural philosophy would provide other social institutions with power and dominion over nature. Mendelsohn (1975b) calls it the positivist compromise.

Natural philosophy, as a social institution, was established across Europe. Its social contract with 17th century society kept natural philosophy out of trouble with the new authorities. Moreover, natural philosophy provided a new middle class with useful, practical knowledge which carried no moral responsibility. To be sure, discussions about moral responsibility were defined by the social contract to be beyond the scope of natural philosophy. In short, the precursor to science had been declared objective and value free, because its political survival depended on it.

The social and historical events of the 17th century helped to shape the characteristics and limitations of what we call science today. In the meantime, other historical events would reshape the nature of science.

The Professionalization of "Science"

The 17th and 18th centuries saw natural philosophers gain power and dominion over nature. By the end of the 18th century, their successful techniques and knowledge were redirected by others -- technologists -- towards power and dominion over human productivity itself. This gave rise to the Industrial Revolution and gave new power to the social institution of technology. Technology became so successful that it challenged the social niche that natural philosophy had gained 200 years earlier. Industrialists saw natural philosophy as the handmaiden of technology. Natural philosophers would have none of it.

They reacted to the attempted subordination in several ways: by retreating into the cloisters of the universities, by calling themselves "scientists" (to distinguish themselves from natural philosophers), by creating a public face of "pure science," by isolating themselves from the "vulgarities of practical knowledge," and by establishing a tight rein over who would have access to becoming a scientist and what standards would apply. Natural philosophy had evolved into a profession.

The Industrial Revolution caused natural philosophy to redefine its boundaries and to renegotiate its mission in society. By redefining its boundaries, what did science include? What did it exclude?

Science focused its efforts on intellectual curiosity and knowledge for knowledge sake, a marked departure from its Baconian tradition of practical knowledge. Moreover, science distanced itself further from value-laden discourse, from the consumers of its knowledge, and from social responsibility. Science eschewed its technological and social connections.

Scientists established a self-serving hierarchical position by defining technology as "applied science." The misconception continues to plague technology and science education today (Collingridge, 1989; Fleming, 1989; McGinn, 1991; Snow, 1987).

By 1860, a reshaped domain of knowledge had been constituted. Biology, chemistry, geology, and physics were enshrined as disciplines when they became new administrative units within the university. Natural philosophy had become professionalized science.

Coincidentally, the high school science curriculum was being introduced into public schools for the first time. The university's administrative model for science was copied by the high schools. Biology, chemistry, geology, and physics became the only valid ways to view nature. Like 19th century science, high school science eschewed practical knowledge and ignored values and social relevance.

A conclusion seems warranted. Similar to science itself, the high school science curriculum was shaped by the social forces that existed at the time of its inception. This happened to the high school curriculum when science was retreating into the universities to protect itself from a take-over bid by technology. As a consequence, the legitimacy of school science was defined by the 19th century professionalization of university science, and the purpose of school science was to prepare students for university science.

The Socialization of Science

The 20th century brought a host of new social forces. World War II likely reshaped science more than any other single historical event. World War II ensured the marriage of aloof scientific expertise with life-or-death practical problems of technology. This unlikely marriage irrevocably bound science and technology into a strong social unit called research and development (R & D). This marriage necessitated a new social contract between science and society.

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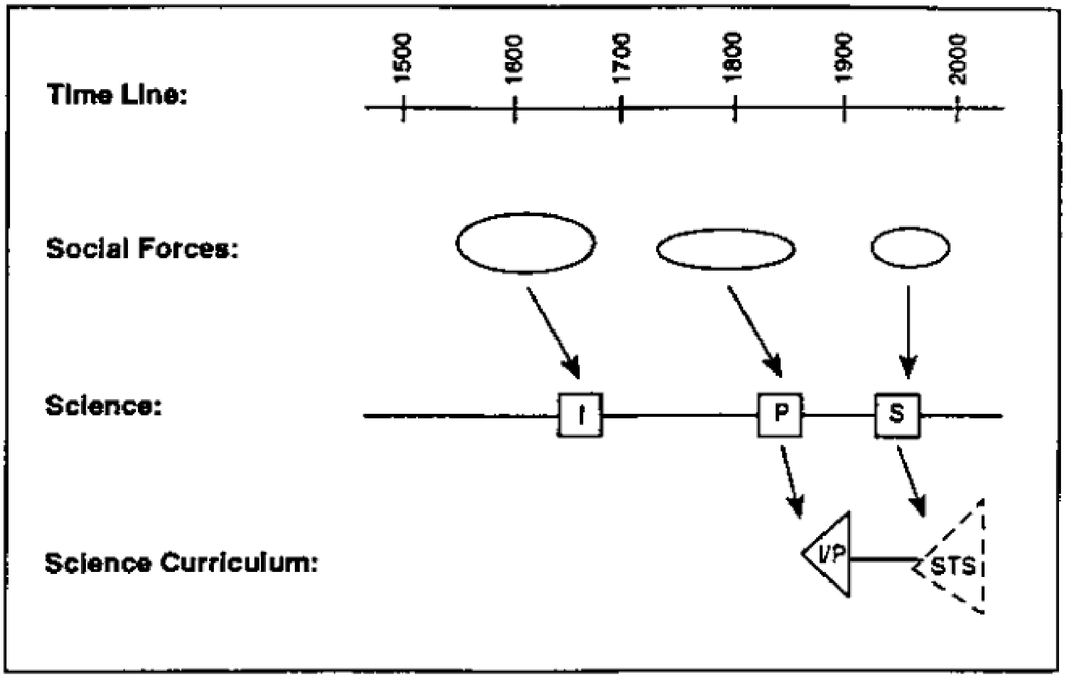

FIGURE 2.1 *The influence of social forces on science and the science curriculum*

Chapter 20

Collaborative Research and Development to Produce an STS Course for School Science

Glen Aikenhead

This chapter describes how a practical deliberative enquiry guided the development of an STS science textbook for the high school.

In its education study <u>Science for Every Student</u>, the Science Council of Canada (1984) called for a renewal of science education, advising educators to teach scientific concepts and skills embedded in social and technological contexts relevant to all students. Curriculum theorist Joseph Schwab (1974) had argued the need for educators (1) to engage in practical deliberative enquiry (as opposed to theory-generating enquiry), and (2) to pay closer attention to what happens with students in the classroom. Both Schwab's points define the present study: a practical deliberative enquiry <u>with students</u> to produce an STS science textbook commensurate with recommendations proposed by the Science Council of Canada.

Deliberative enquiry guided the Science Council of Canada's education study and influenced a subsequent science education study undertaken by the Saskatchewan Department of Education. Because both deliberative enquiries define the context of the present study, they are summarized briefly before addressing the present study.

National and Provincial Deliberations

The Science Council of Canada put Schwab's deliberative enquiry approach into action during a unique science education study that spanned five years, 1979-1984 (Orpwood, 1985). The study ensured that significant problems were identified, that appropriate data were collected, and that these problems and data were considered by the diverse stakeholders (including students) attending two-day deliberative conferences held across Canada in 1983. The deliberative conferences unfolded as Schwab (1978) had predicted:

> Deliberation is complex and arduous. ... It must try to identify the desiderata in the case. It must generate alternative solutions. ... It must then weigh alternatives and their costs and consequences against one another, and choose, not the <u>right</u> alternative, for there is no such thing, but the <u>best</u> one. (pp. 318-319)

This "best" solution included the following recommendations (Science Council of Canada, 1984). Along with scientific concepts and skills, students should learn an appreciation for: (1) authentic science -- the nature of science and scientists, including the way science generates and uses its knowledge; (2) technology in Canada; and (3) the interrelationships among science, technology and society.

These recommendations, as well as the process of deliberation itself, greatly influenced a provincial project that was designed to change the science curriculum in Saskatchewan (Hart, 1989). In the Saskatchewan science study, conducted between 1986 and 1987, an overwhelming 92% of Saskatchewan science teachers participating in the deliberative inquiry endorsed the goal of "scientific literacy" defined as a <u>balance</u> among seven subgoals:

1. the nature of science itself
2. the key facts, principles and concepts of science
3. the intellectual processes used in doing science
4. the interactions among science, technology, society, and the environment
5. the values that underlie science
6. the manipulative skills required for doing science
7. personal interests and attitudes toward scientific and technological matters.

Although 88% of the teachers believed that a science-technology-society-environment (STSE) emphasis to the curriculum should be adopted (the Saskatchewan equivalent of STS), teachers expressed many concerns about: (1) the balance between an STSE emphasis and other emphases; for example, a solid foundation for the next level of science study (Roberts, 1988); (2) the evaluation of students with respect to STSE goals; (3) the availability of appropriate teaching materials; and (4) the need to teach controversial issues. In other words, teachers were positive but certainly cautious about changing their science curriculum towards an STSE approach.

The Saskatchewan study had established the goal of "scientific literacy" and a curriculum emphasis on STSE. Saskatchewan science teachers expressed, among other things, a need for classroom materials -- such as a textbook -- to support them in their efforts to implement a new science curriculum.

The Study: Definition and Purpose

A curriculum exits in three different phases or forms: (1) the <u>intended</u> curriculum developed by curriculum specialists or committees authorized by governments; (2) the curriculum as <u>taught</u> by classroom teachers, the translation of the intended curriculum by teachers when they prepare and teach lessons; and (3) the curriculum as <u>learned</u> by students. Ideally, the intended, taught, and learned curricula should be similar. In reality, however, they differ widely (Cronin-Jones, 1991).

The similarity among the intended, taught, and learned curricula may be strengthened by using classroom materials -- for instance, a textbook -- designed to give students experiences that clearly convey the intended curriculum (Aikenhead, chapter 16) A textbook influences the content of the taught and learned curricula whenever the textbook is a teacher's primary resource, a condition found in most North American high school science classes (Gallagher, 1991).

In Saskatchewan's deliberative meetings, curriculum developers and classroom instructors discussed what ought to be taught in science classes. Although the perceived needs and interests of students were given high priority, students were not involved in the provincial process of curriculum deliberation.

However, students can play a significant role in determining the quality of the <u>learned</u> curriculum (Aikenhead, 1982; Eijkelhof, chapter 19; Kortland, 1992; Solomon, 1983). This role was explored in the present study by involving students in a new type of deliberative process: a collaboration with textbook authors to produce classroom materials that strengthen the similarity among the intended, the taught, and the learned curricula.

In the study, the textbook developer (Glen Aikenhead) consulted and negotiated with students and teachers. Students worked through, and deliberated over, draft versions of the textbook. Students offered concrete guidance on how to achieve the intended curriculum. As described below in the Results section, students contributed significantly to the textbook's content, structure, and language.

The study was primarily concerned with students learning a curriculum that had been rationalized by two successive Schwabian deliberations. The study, however, went beyond practical enquiry characterized by defensible decision making. The study included research and development that led to the publication of an academic STS textbook and teacher's guide, Logical Reasoning in Science & Technology, LoRST (Aikenhead, 1991a, b). The study not only focused on the classroom experiences of students (the learned curriculum) but also collaborated with those students and their teachers in a type of practical enquiry to produce classroom materials that were: (1) in harmony with the intended curriculum, (2) usable by teachers with limited inservice training, and (3) consistent with students' views on relevancy and practical appropriateness. This chapter describes this deliberative research and development process.

Overview of the Study

The research and development of LoRST followed a three-stage sequence that took advantage of the classroom realism well known to teachers and students. These phases are summarized here. In phase 1 (an eight-week project), I wrote and taught draft #1 in a local high school in 1987. Based on this classroom collaboration with students, the text was modified and expanded to yield draft #2. By initiating the project in a classroom setting: (1) the classroom materials evolved on the spot with average grade 10 students, (2) appropriate teaching strategies were identified (Aikenhead, 1988b), and (3) a rough draft of the teacher's guide was written. This second draft of LoRST was used in 1988 (phase 2, a twenty-week project) by three volunteer teachers who received no inservice training. The teachers taught in three different schools, representing a full cross section of student background and abilities. Classes were observed daily as teachers used draft #2 of the text and teacher's guide. This collaboration with students and teachers led to another revision of the student materials and teaching strategies. As a result of this closely monitored project, LoRST was polished into draft #3. In 1989-90 (phase 3), draft #3 was field tested across Saskatchewan and evaluated by 30 teachers both sympathetic to, and critical of, an STS approach to teaching science. Teacher feedback resulted in further revisions to LoRST. The resulting material (student text and teacher's guide) was published in 1991 and adopted by Saskatchewan as a principal textbook for grade 10. Two other provinces adopted LoRST in 1993.

The former grade 10 syllabus in Saskatchewan had been a traditional physical science course with an emphasis on chemistry. The LoRST project was initiated with the assumption that a similar content would be the basis of the new curriculum (a false assumption, as it turned out).

The three-phased research and development process that produced LoRST will be much easier to understand if one has an idea of the product of the study -- the textbook.

Product of the Study

LoRST teaches scientific content in conjunction with critical reasoning skills to a target audience of grade 10 students of average (or above average) academic ability. (For a detailed description of LoRST see Aikenhead, 1992b.) Students learn scientific facts, concepts and principles from physics, chemistry and biology in a way that connects those facts, concepts and principles with the students' everyday world. The interdisciplinary nature of LoRST places it in category 5 of the STS science scheme presented as Table 5.1 in chapter 5.

The textbook begins with courtroom testimony by scientific experts -- a social context familiar to students. This creates the need to know a host of science concepts and logical reasoning skills. In LoRST, the social issue of drinking and driving creates the need to know (1) the technology of the breathalyzer; (2) how science and technology interact with each other, and how they both interact with various aspects of society; and (3) scientific content such as mixtures, concentration, chemical reactions, photometry, electrical circuits, and the biology of body cells and systems. While the content is "driven by" the social issue of drinking and driving, the content is not limited to that social issue. For instance, students solve concentration problems in the world of recipes, false advertising, toxic chemicals, and farm fertilizers. Classification of mixtures is introduced in the context of the Red Cross and is developed via the technology of salad dressings. Electricity concepts are learned in order to bridge the gap between atomic theory and the household appliances familiar to adolescents (both female and male). Heat and temperature are taught in an historical context, accompanied by inquiry labs requiring students to construct relevant concepts.

LoRST's emphasis on logical reasoning reflects the mandate to improve students' critical thinking skills (Aikenhead, 1990; Byrne & Johnstone, 1978; National Science Foundation, 1990). Specific critical reasoning skills are taught in Unit 3, "Science & Critical Thinking: The Logic Game." These skills are then applied throughout the book. More important than the individual reasoning skills themselves is the increase in students' predisposition (habits of the mind) to analyze, to question, and to articulate a reasoned argument (McPeck, 1981).

Results

This section describes specific instances of collaboration in which students and teachers contributed to the content, structure and language of the final product -- Logical Reasoning in Science & Technology. While each page in the textbook has a unique story to tell about how it evolved over the three phases of the study, only a few typical examples are described here. (More details are provided by Aikenhead, 1991c.)

The examples address four topics: selection of the content, structuring the content, students "editing" the language of the textbook, and lastly, contributions by teachers.

Selection of Content

The social issue of drinking and driving was selected as an organizing STS theme in LoRST. The issue is of critical importance to every community. Alcohol is the most fatal toxic chemical in the environment when it pollutes a driver's body. The issue of drinking and driving also demands particularly realistic decisions by students, rather than the more idealistic, hypothetical decisions sometimes associated with global issues (Carter, 1991). Students in grade 10 know that they will soon take personal action based on their own decisions about alcohol and driving. Thus, an action orientation to decision making is particularly realistic for students (Rubba, 1991). Questionnaire feedback from 91 students participating in phase 2 indicated that most (83%) found the issue of alcohol and driving to be relevant and enjoyable, though they would have preferred studying science via the issues of sex and drugs.

During phase 1 of the R & D study, students vigorously quizzed me about facts and principles related to how alcohol would affect their bodies. This was science content not found in the old curriculum and therefore not intended for LoRST. (It is now part of the new curriculum.) Students' interest and curiosity convinced me to compose a new unit, "How Alcohol Affects the Body." It was added to the end of LoRST version #1. I designed this new unit in a way that systematically addressed students' questions, but also applied previously learned physical science content to biological systems; for instance, concepts such as diffusion, chemical changes, and parallel and series circuits.

To provide practice at applying physical science content to the everyday world, some decision-making activities were developed in version #2. Students fell short of my expectations on how easily they could reach a decision. When I clarified these expectations (the intended curriculum) during a class discussion, students pointed out that more guidance was needed to lead them through what they perceived to be unfamiliar territory. In other words, students suggested how the learned curriculum could be more consistent with the intended curriculum. As a consequence, another unit, "Decision Making," was tacked on to the end of LoRST version #2. It described a ten-step sequence to follow when making a decision (Aikenhead, 1985a).

Not only did students initiate the development of these two new units, they contributed to the content of other units. In a section on electricity, for instance, students were the source of questions that now appear in the text. During phase 1 of the study, I overheard a conversation between two girls about accidentally plugging a hair dryer into a 220 volt source. "It killed my hair dryer", one said. Version #2 of LoRST incorporated her story into a question that asked why 200 volts would "kill" a hair dryer.

Structuring the Content

Three examples of structuring the content in LoRST will further clarify the deliberative process that characterized the research and development study.

A post-lab discussion of an activity called "Experimenting with Mixtures" provided a forum for identifying the activity's successes and difficulties. Students expressed frustration over my expectation that they could inductively derive a distinction between homogeneous and heterogeneous mixtures. Students' preconceptions of mixtures were far <u>richer</u> and more complex than the scientific dichotomy of homogeneous/heterogeneous. "Why couldn't we just read about it before the activity?" they asked. The section was revised accordingly.

The second example of structuring content in LoRST deals with a section on electricity. In version #1, students were given the challenging task to explore electricity ("bulbs and batteries" revisited) and to write up what they discovered. This approach was fashioned after the Nuffield science projects in the U.K. in which students learned almost all their science content from lab activities. The expectation of the LoRST research and development project, however, was to turn the students' work produced during version #1 into an activity for version #2. With appropriate editing, version #2 incorporated the students' work into a single activity comprised of five interconnecting parts that took about five hours to complete. The students who studied version #2 did not like this long and involved activity. Instead, they wanted an activity to be more focused on one particular topic. Therefore, the five-part activity of version #2 was restructured into four activities embedded in didactic text that introduced or reinforced the four activities. In doing so, the topic of electricity was reorganized around two themes: scientific theory and scientific law. These themes reinforced the textbook's epistemic distinction between theories and laws.

The third illustration of students structuring text content occurred when one of LoRST's activities failed. I wanted students to analyze a current article from the New England Journal of Medicine to see a 1990 example of the tentativeness of science, and learn more about scientists participating in consensus making. I wrote a synopsis of the article. The first time students read it, they could not decide whether the conclusion reached was logical or not. (The conclusion was somewhat controversial within the scientific community.) During a classroom discussion of the article, I acknowledged the impasse the class had come to, and wondered aloud how the impasse might be resolved. One student pointed out that there were actually two main conclusions to the article, not one; and that one conclusion was logical while the other one was not. Her analysis was written into the next version of LoRST. Now students are given two conclusions and asked to comment on the logic of each conclusion. Difficult science content can sometimes be clarified by students themselves, and then be restructured to conform with an adolescent logical perspective.

Teachers were often helpful at identifying student problems and at articulating student concerns. Throughout phase 2, students' problems and preconceptions led me to reformulate the content and to restructure the text. In other words, collaboration with students and teachers identified problems, generated alternatives, and the best solutions were chosen. A Schwabian type of practical enquiry was working.

Students "Editing" the Textbook

Students will gladly express confusion or frustration over something they do not understand. By sitting in their classroom day in and day out, one can detect not only their confusions or frustrations, but also how they spontaneously clarify or correct the problems. Typical examples will illustrate the point.

Lab instructions were modified when I observed students making "errors" or making impromptu improvements to the instructions. The intent of LoRST was to have students <u>reason</u> with scientific ideas rather than simply memorize them. Consequently, the LoRST lab instructions were written much differently than lab instructions designed to have students verify facts. Teachers' extemporaneous modifications to labs (in phase 2) also contributed to the clarity and efficiency of LoRST's lab instructions.

Another issue (related to the language in LoRST) deals with the text's writing style. Young, Ruck and Crocker (1991, p. 46) claim, "Science texts violate students' expectations because the language is unlike anything they have previously encountered. The way science books present ideas is a discrepant event in the students' experience." The traditionally formal, succinctly dense, science language makes textbooks science-centered, not student-centered. Rather than requiring students to completely change their reading style in order to understand the science text language, one can modify the text's language to conform more with student expectations. This has been achieved in LoRST. The text is unusually narrative (sometimes even chatty), filled with visual imagery, and structured from a student's perspective. Thus, students indirectly influenced the writing style of LoRST because of the student-centered approach to the use of language.

However, students had a direct effect on the writing style as well. Occasionally, the text is literally interrupted by a comment from a student, usually at some key point in the development of an idea. For instance, the water content of body tissue is studied in LoRST. The textbook points out that a 70 kg female athlete (high muscle content) would be less affected by an alcoholic beverage than a 70 kg pot-bellied male (high fat content), all other variables being equal. Then a cartoon-like balloon interrupts the paragraph and points to a silhouette of a student's head in the margin. Inside the balloon the following passage appears:

"That can't be true," he protested. "I read in a book that women are more affected by alcohol than men" (Aikenhead, 1991a, p. 223). The text then responds in a dialogue fashion and introduces students to the idea of a statistical fact, the type to which the student was referring. This dialogue between student and textbook paraphrases an actual classroom interaction. The dialogue emphasizes a discrepancy between a student's preconception about scientific facts (they are either true or false) and the curriculum's conception of scientific facts (they are context dependent and probabilistic). This style of highlighting discrepancies between the intended curriculum and students' preconceptions was inadvertently suggested to me by the poignancy of certain key student/teacher exchanges that took place in the classroom. These exchanges are recaptured in LoRST as a dialogue between the student and the textbook. The practical enquiry of collaborating with students allowed me to build on students' natural reaction to classroom events, and to judiciously incorporate some of those reactions into the text.

The informal, unorthodox, narrative writing style in LoRST received strong endorsement from the 91 students surveyed in phase 2. Ninety-two percent thought the style made the textbook easier to understand, while five percent thought it made it more difficult.

Teacher Contributions

It is evident from the examples cited above how the three teachers in phase 2 of the study contributed to the development of LoRST. Their contributions normally arose spontaneously during classroom action, where idiosyncrasies and constraints abound. Helped only by a rough draft of the teacher's guide for LoRST, these teachers explored new territory of STS instruction. By observing each lesson (the taught curriculum) and by listening to a teacher's out of class comments, I modified the teacher's guide in several ways: by clarifying directions, by adding specific teaching suggestions, and by writing background information. Day by day the teachers also identified problems for me to solve in the student text.

The revision of LoRST at the end of phase 2 would certainly have been suitable for most grade 10 students. After all, students themselves had contributed to its content, structure and language. But would LoRST work with other teachers? Critics of STS claim it would not (Walberg, 1991).

Phase 3 of the study, a province-wide field test of manuscript version #3, involved 30 teachers chosen by Saskatchewan Education, some of whom were supportive but others who were sceptical or even critical of an STS approach. Phase 3 was <u>not</u> an investigation into teacher implementation of LoRST nor an evaluation of LoRST. Rather, it was a practical enquiry into developing LoRST further. A few examples of collaboration in phase 3 will illustrate how LoRST was improved.

Unlike the day-to-day collaboration with students and teachers in phases 1 and 2, in phase 3 teachers only identified problems. (Financial and human resources were limited.) The solutions to these problems were left for me to engineer. A short case study about the topic of heat will illustrate typically what happened in phase 3.

A workshop had been organized to help teachers with some "new" content in LoRST -- the explicit treatment of critical thinking in a unit called "The Logic Game." The teacher's guide suggested that students read, analyze, and discuss. This logic game unit had been very successful in another project with average students (Aikenhead, 1979a). That success had been attributed to the fact that the logic content that students read, analyzed, and discussed, did not come from science but from the everyday world of adolescent experience. At the workshop, however, one teacher emphatically explained his class's negative reaction to this logic content, "When my students come into science class, they want to light bunsen burners and get the right answers." Because the teacher was conscientiously implementing the new curriculum, and because he likely represented a prevailing view among science teachers, his comment was taken seriously. Thus, my objective was to design:

1. Activities in which students light bunsen burners and get the right answers.

2. Activities that correlate with the content in "The Logic Game" unit, but could also function independently of this content in case teachers do not teach the logic unit.

3. Activities that reflect a constructivist and STS perspective.

4. Activities that correspond to the emerging curriculum.

One new activity, "The Law of Heating (and Cooling) Bodies," was designed according to the four specifications stated above. The activity extrapolates from the student's everyday world of temperature changes in syrup, cooking oil, and water, to the realm of scientific thinking about specific heat capacities. Students, acting as research teams, explore the variables that seem to affect heat transfer. (Exploration rather than verification occurs.) Bunsen burners are lit! Each research team works on one of the variables. Then all teams get together at an "international conference" where the class reaches a consensus on what to believe about which variables affect heat transfer. To prepare for their conference, students analyze the heat data. Students must reason on the basis of the assumption: "One gram of substance rising one degree Celsius takes in a certain number of joules of heat." After reaching a consensus, students are introduced to the term "specific heat capacity." Next, the heat transfer equation is presented as a mathematical wording to the Law of Heating (and Cooling) Bodies. Finally, several math problems are solved to gain a facility at using the heat transfer equation. Students get right answers! The teacher who wanted students to light bunsen burners and get the right answer had his specifications met.

Two further activities on heat were developed and cycled through the three phases of the deliberative enquiry process in order to complete a systematic treatment of heat and temperature (Aikenhead, 1992a). The phase 3 collaboration with the 30 teachers led to the production of several other activities that would not have otherwise been developed. The collaboration also resulted in LoRST looking more like a traditional science text (for example, chapter titles were changed to conform to traditional expectations) but without compromising the harmony between the intended and learned curricula achieved in phases 1 and 2. None of the changes undermined the book's relevancy and practicality to students.

Conclusions

The ultimate purpose of the LoRST research and development project was to strengthen the cohesion between (1) the <u>intended</u> curriculum, advocated by the Science Council of Canada and defined by Saskatchewan's Department of Education, and (2) the curriculum <u>learned</u> by students. Accordingly, LoRST was developed to help teachers translate (modulate) the intended curriculum into a taught curriculum, in a way that more accurately portrays the intended curriculum (Roberts, 1980).

The practical enquiry demonstrated that students can contribute significantly to a textbook's content, structure, and language. By engaging students in tasks in the natural setting of their classroom, an author can attend to information that spontaneously emerges during instruction or to information that thoughtfully evolves from informal discussions with students. Students were most helpful in (1) reflecting on how well the tasks met the provincial curriculum's objectives (that is, the consistency between the learned and intended curricula), and (2) suggesting, indirectly or directly, how to improve on the text material. In a somewhat similar fashion, Kortland's (1992) environmental education project also demonstrates how student interviews and classroom observations can judiciously guide the development of instructional materials.

Further research is needed to shed more light on the learned curriculum that results from using STS materials such as LoRST. One promising avenue of research is the systematic identification of classroom events that appear to have an impact on students' reconceptionalizations of science and STS content. Case studies of a small number of students can clarify the classroom events that affect their understanding of, for instance, the nature of heat, the role of assumptions in scientific thinking, or the nature of scientific decision making. (See, for example, studies by Larochelle and Désautels, 1991; Roth and Roychaudhury, 1993; and Shapiro, 1989.) A case study of students learning science can portray the different ways in which students' feelings, world views, and preconceptions interact with the teacher's taught curriculum, fellow students, and the classroom events supplied by a textbook. These interactions provide rich data for better understanding the learned curriculum of an STS science course.

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