# Science, Technology, and Society: Some Philosophical Reflections on a Grade 11 Course

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In 1984 the Ministry of Education in British Columbia decided to introduce a *Science and Technology* course at Grade 11. The course focuses upon the relationships among science, technology, and society. Its introduction accompanied a policy decision mandating all Grade 11 students to take some science; about a fifth of Grade 11 students in the province take the course. Previous researchers have reported that the course suffers from a lack of academic status. In this paper I speculate that a contributing factor may be a deeply ingrained cultural one, namely that Aristotelian conceptions of the superiority of pure science over practical knowledge continue to affect the status of school subjects. I also question whether the course presents an accurate portrayal of the nature of technology and of the relationship between technology and science.

En 1984 le ministère de l'éducation de la Colombie Britanique a introduit un cours de science et technologie en onzième année. Le cours veut préciser les relations entre la science, la technologie, et la société. Une décision exigeait que tous les étudiant-es de la onzième année prennent une partie de science. Environ un cinquième des étudiant-es de la onzième année de la province suit ce cours. Des recherches précédentes ont montré que ce cours manquait de statut académique. Dans cet article, je soutiens que la cause de cela pourrait être un facteur purement culturel, c'est-à-dire que la conception aristotélitienne qui croit en la supériorité des sciences pures sur les sciences appliquées continue d'influencer le statut des matières scolaires. Je me demande également si le cours présente un profil adéquat de la nature de la technologie et des relations entre la technologie et la science.

Curriculum evaluation can be done in many different ways. One could administer instruments to assess the objectives of a course and then interpret the findings. One could observe classrooms in action, talk with teachers and students, and record impressions. One might adopt a historical approach, in order to trace the development of ideas in the minds of those who initiated and implemented the curriculum. In this paper, however, I utilize none of these approaches. I exemplify the least expensive form of curriculum evaluation there is: armchair philosophizing. The focus of my enquiry is the Grade 11 *Science and Technology* course in British Columbia; my research method has been to look at curriculum documents, read papers by other researchers, talk with people who know something about the course, and then think.

Philosophical enquiry can take many forms. Normative philosophy is concerned with questions of value; analytical philosophy, with meaning. Ontology asks about the nature of things; epistemology inquires into how we know what we know. These philosophical areas generate questions for educators interested in science and technology. Some are ontological: What is science, what is technology, and how do they differ? Some are epistemological: How do we gain scientific knowledge and technological capability? What is their relationship: Is technology an outcome of science, or vice versa, or is the relationship more complex? Others belong to the normative school: What is the relative value of science and technology? Are they of equal value? Is technology more valuable because it generates solutions to practical problems? Or is science more valuable because it is in some way intellectually more powerful than technology? Perhaps the earliest known work in this field is the book of *Ecclesiastes*, attributed to King Solomon (although it may have been written centuries later), in which the author describes the pursuit of knowledge and the pursuit of human comfort as equally futile ("Vanity of vanities") and recommends the religious life instead.

Frankena (1970) observes that epistemological theories are neither necessary nor sufficient to establish conclusions about education; these must be derived from normative or value premises. He notes Aristotle's argument that ethics and politics, not epistemology, determine what is to be studied, by whom, and to what extent. Nevertheless, one can find examples of curriculum writers using epistemological positions to defend normative positions. An illustration in the science/technology field can be seen in the writings of Professor Eric Rogers, director of the Nuffield

Physics Project in the 1960s. Rogers is discussing the education of the technologist; from the context, he appears to be using the term to mean engineers.

> The technologist must have a tremendous knowledge of science; and he must understand that science which he puts to such good use. He too needs an early beginning in understanding and much study of pure science — study with real delight if he is to keep and use it. Furthermore I fear the technologist is sterile: One generation of technologists cannot breed the next generation — for the latter will be far behind the frontiers, and will lack the deeper understanding which is part of their preparation. It is the pure scientists who must give the next generation of technologists essential training. (McCulloch, Jenkins, & Layton, 1985, pp. 96-97)

The epistemological position here is quite explicit: Technology depends upon science; therefore learning science must precede the development of technological capability. Rogers defends this position with a normative argument: Scientific knowledge is more useful than technological skill, at least at the earlier stages of education, because of its greater power or fertility. Not surprisingly, the physics course developed under his direction emphasized "pure" academic physics, virtually unrelated to technological issues.

### *The Introduction of STS-Based Curricula*

*International Trends.* The introduction of a science-technology-society (STS) based course into the British Columbia (BC) curriculum during the mid-1980s was part of an international movement that had been under way for many years. As early as 1957, the Science Masters Association in England had recognized that science was a humanitarian and philosophical study which ought to provide "knowledge of modern scientific and technological developments and their implications for society now and in the future" (McCulloch, Jenkins, & Layton, 1985, p. 36), but this statement remained as a platitude for more than a decade.

During the early 1970s, the Schools Council Integrated Science Project in England developed a course in which STS ideas were included, and within a few years, a conference in the Netherlands received reports from numerous countries indicating widespread implementation of similar developments (Haggis & Adey, 1978). Various factors influenced the uptake of STS: The recognition that science and technology were now interwoven into the economic, political and ethical problems of the time, and that curricula ought to reflect this (Layton, 1972); the effects of increased school retention rates, the challenge of designing curricula suitable for a wider range of student ability; the problem of declining student interest in science and science enrollments not keeping pace with rising school enrollments.

*STS in British Columbia.* In the mid-1970s, BC introduced provincial assessment programs in which a sample of students was tested every four years in various subjects at selected grade levels, and the data reviewed by Interpretation Panels. The Science assessments in 1978 and 1982 included questions testing student understanding of science and technology issues. The 1978 panel recommended that junior secondary science curricula be revised to "help students relate science to current issues and practical applications" (Hobbs et al., 1978, p. 44). The 1982 panel (Taylor, 1982) expressed a similar view. Gaskell (1982) regards these views as a response to a perceived crisis in science education, due to societal concern about science and declining public interest in school science programs. Two years later, STS made its way onto the national agenda, when the Science Council of Canada (1984) issued a report calling on science educators to provide a more accurate view of the practice, uses, and limitations of science.

## *Science and Technology 11*

A committee to develop an STS-based course known as *Science and Technology 11* (SAT11) was formed by the BC Ministry of Education in 1984. Gaskell (1989) has described the origins of the course; in addition to the influence of international trends, there was also a significant local factor, namely the decision by the government in 1984 to require that some science (and mathematics) be taken by all Grade 11 students in order to qualify for high school graduation in Grade 12. Prior to this, only English and Social Studies had been compulsory; about 30% of the graduating class had taken no science beyond Grade 10. Gaskell notes that the Ministry had indicated that

> the course would be designed for students who were not proceeding to university and the course was not on the list of acceptable courses for students in the top stream of a proposed three tier structure. While the proposal for streaming was eventually dropped, the course has continued to be perceived as one intended for less academically able students — indeed, the provincial universities have refused subsequent Ministry of Education requests that the course be accepted as fulfilling university entrance requirements for a grade eleven science. (p. 3)

The SAT11 committee consisted of teachers with backgrounds in science, industrial education, home economics, and physical education, with some input from university scholars. It developed a curriculum guide and an *Instructional Resources Manual* (Ministry of Education, 1986a,b) and 16 *Teacher Resource Modules* containing instructional materials. Of these, five were designated as core modules, requiring about 60 hours of class time. Teachers were free to select four further options, totalling another 40 hours of class time, from the remaining modules. The modules were classified according to their context under three headings (see Box 1). The curriculum guide lists three major goals, sub-divided into a total of thirteen intended learning outcomes, and also identifies between four and six major objectives for each module.

**BOX 1 — Teacher Resource Modules for Science and Technology 11 (Ministry of Education, 1986a, p. 6)**

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| Module 1 | Introduction to Science and Technology 11 (core module) |
| **Personal Connections** | |
| Module 2 | Health Technologies (core module) |
| Module 3 | Recreational Technology |
| Module 4 | Shelter — Technology of the Home |
| Module 5 | Technology for the Home |
| **Local/Vocational Connections** | |
| Module 6 | The Computer in the Workplace (core module) |
| Module 7 | Forestry |
| Module 8 | Resource Management* |
| | *This module differs from the others in that no teacher materials are provided; instead, teachers are expected to build their own module, centred around a local resource industry. |

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| **Global Connections** | |
| Module 9 | Telecommunications (core module) |
| Module 10 | Transportation |
| Module 11 | Military and Defence Technology |
| Module 12 | Energy and Environmental Trade-offs |
| Module 13 | Waste - Technology's by-product |
| Module 14 | Food Production and Distribution |
| Module 15 | Space |
| Module 16 | The Future (core module) |

*Some positive features of the course.* SAT11 attempts to link science with the world in a meaningful way, an emphasis that most modern science educators would applaud. The course reflects a reaction against courses which have presented science as a set of "academic" topics whose interconnections and relationships with the student's world are only dimly perceived. A significant strength of the *Instructional Resources Manual* is that the curriculum is viewed as encompassing an approach to teaching and learning, and not simply as a body of subject matter content. The *Manual* is essentially a book of advice to teachers about how to establish classroom conditions which are intended to promote meaningful learning, group discussion, and exploration of complex issues which may have open-ended answers. It emphasizes the value of developing a cooperative classroom environment; it suggests approaches designed to help both lower- and higher-achieving students; it advocates continuous, descriptive student assessment. The *Manual* outlines procedures which could be used in the classroom to deal with STS issues (e.g., brainstorming, group discussion, oral presentations by students, debating, research projects, role playing, media analysis, field studies, computer conferencing, and computer simulations).

The curriculum was put together quickly, and was ready for implementation in 1985-86. Within a year, almost 20% of Grade 11 students in the province were taking the course; these were generally students who previously would have taken no science at all at that level.

*Gaskell's Evaluative Study.* Given all these positive features, one might have hoped that this curriculum innovation would have met with considerable success; unfortunately, there have been some difficulties with its implementation. In a nutshell, the problem is that the course suffers from a lack of academic status and resources. Part of the problem is that SAT11 does not lead to any corresponding Grade 12 course, unlike the traditional separate science subjects (physics, chemistry, biology and geology). One Vancouver school refuses to offer the course, for fear that it will weaken enrollments in its Grade 11 Earth Science course, which might in turn make its Grade 12 Geology course unviable. Another part of the problem is the refusal of the three BC universities to recognize it as an acceptable science for their admission requirements. The future scientist or science teacher is therefore virtually excluded from taking the course. (This would not matter if such people studied STS issues in their specialist science courses at school or university, but it is doubtful whether they do.)

Gaskell (1989) studied the implementation of SAT11 in one urban school district, and found little support for it. Few resources were allocated to the course; most science teachers preferred to continue to teach their specialties to academically able students. These students were encouraged to take the specialist sciences; mandatory graduation requirements left little space in the timetable for elective courses, and it was therefore difficult for an able student taking a specialist science to take SAT11 as well. The course was rarely taught by teachers with a science background; it was often allocated to teachers of other subjects to make up their workload.

No cohesive and influential professional group that cares deeply about the maintenance and development of the course therefore exists. Gaskell refers to an "ironic paradox": A central argument for introducing the course was that the critical nature of the science-related issues facing societies requires that all students must take some senior high school science, but this mandatory requirement, coupled with a policy which excludes specialist science students from the course has actually led to a situation where the course may not survive because of the lack of support for it.

*Some Philosophical Issues*

My purpose in this paper is to explore three philosophical issues — one normative and two epistemological — related to the course. The normative issue involves the problem uncovered by Gaskell, namely the low academic status of the course. The epistemological issues are whether the course provides students with a valid introduction to the nature of *technology* and whether it presents an accurate portrait of the science/technology relationship.

*SAT11 is "Pseudo-Science."* Let us examine the status issue first. A comment made by a science department head in the Gaskell (1989) study provides a fruitful starting point for the discussion. It encapsulates the conclusion that Gaskell reached, namely that the course suffered from a status problem among teachers. "We tried to make the implementation of this program as painless as possible so that Science and Technology doesn't take up any of the science rooms ... it's sort of a pseudo-science really" (p. 5).

Various metaphors can be used to describe the school curriculum. One is to see it as a type of Testament, a document handed down by a powerful Authority. Another is to regard the curriculum as a filter for letting through selected content from the vast body of available organized knowledge. Perhaps a more apt metaphor here is to view the curriculum as an arena where contending social and political forces do battle. Hargreaves (1989) notes that school subjects are "more than just groupings of intellectual thought. They are social systems also. They compete for power, prestige, recognition and reward within the secondary or high school system" (p. 56).

McCulloch, Jenkins and Layton (1985) make a similar point; some areas of the curriculum, and some forms of knowledge, are regarded as more worthwhile than others. The science head's comments illustrate this: The science rooms are for the (more valued) "real" sciences, a club to which SAT11 does not belong (and probably will not be allowed to belong). The "painless" introduction of SAT11 is almost certainly a reference to the feelings of the science staff *not* involved in teaching the course, rather than to the feelings of those teachers attempting to introduce the new program.

Since the comment is not amplified, we have no way of knowing the head's reasons for his designation of SAT11 as a "pseudo-science," but we could speculate that it might mean one of three things: SAT11 is not based on any "genuine" scholarly discipline; it is a genuine scholarly discipline, but not a science (e.g., it is about science, but not a science itself); it is a science but an "inferior" one. The first connotation, although logically possible, seems implausible. It would mean that the knowledge base of SAT11 was illegitimate, akin to creation science or astrology, and therefore had no place at all in an institution abiding by the usual canons of scholarship. There is no reason to suspect that this is what the science head meant: If he did, he would probably have argued for the course's elimination, not for its painless introduction.

The second connotation is that SAT11 is a respectable area of study, but not a *science*. Perhaps it is a kind of social studies course, which assumes that students have gained sufficient scientific knowledge from their earlier secondary school science courses, and which focusses upon social issues in which science and technology play a central role. If so, this might justify the universities' refusal to accept the course as meeting minimal science requirements. Doubt would then also be cast upon the Ministry's justification for classifying SAT11 as a *science* course for graduation purposes. Since, as we have already noted, the course appears to be poorly resourced, the interpretation that SAT11 is not real science could become self-fulfilling and lead to the demise of the program. Curriculum innovation is unlikely to become secure in a climate which labels a course as a science but fails to convince people that it really is one.

There is a third possibility: That STS is intellectually respectable and contains genuine science, but that it is less valuable, "tainted" in some way, because of its link with the world of industry and the everyday world of the learner. At first sight, this might seem a ludicrous interpretation, yet it reflects an attitude which is founded upon some very ancient normative underpinnings, and has remained deeply ingrained in powerful sectors of various Western societies.

*Technology and Science: A Conflict of Values.* Almost 2500 years ago, Aristotle, in his *Nicomachean Ethics* (Book I, Chapters 1-2) argued that science was pursued for its own sake, while techne — art or skill based on knowledge — was a means to an end, knowledge whose purpose was to improve human comfort or survival. For Aristotle, knowledge which was an end in itself (e.g., science or philosophy) was to be valued over knowledge which was a means to an end. This was an elaboration of the Platonic distinction between the work of the mind and the work of the hand, the former possessing higher status. Two millennia later, Francis Bacon in his *Novum Organum* (1620) would reject this view, arguing that material goods were more effective than abstract knowledge in advancing social progress.

The tension between these two philosophic positions has continued through the centuries. Echoes of the conflict can be heard in discussions of the esteem of various careers and of the educational programs that lead to them, up to the present day. McCulloch, Jenkins and Layton (1985) argue that conflicts over status, resources, and territory have usually been won by academic disciplines at the expense of utilitarian concerns; abstract, theoretical knowledge is held in higher esteem than knowledge about industry or the everyday world of the learner. They note that, while

> the politics of school science and technology has been influenced mainly by national concerns, it has been particularly stimulated by a continuing debate over the relationship of 'science' and

> 'technology'. For at least the past century and a half, academic and theoretical 'pure' science has generally taken precedence over applied science and technology in terms of status and resources, and this has been reflected at the school level. (p. 6)

They mention the growth of associations of engineers in the 19th century, and comment that "both the professional and academic status of engineering were damaged by its close links with industry. Within the scientific community, engineers tended to be regarded as 'tinkers' rather than 'thinkers', and were downgraded accordingly" (p. 14). This attitude has persisted in the 20th century; they cite Sir Eric Ashby's 1958 essay which had argued that the development of science and technology in English universities had suffered partly because traditional academics were unwilling to admit that technologists had anything of value to contribute to academic life. Not much has changed in the three decades since; the Confederation of Design and Technology Associations in the UK recently commented that

> there is a pervasive misconception that the useful arts of manufacture are derivatives of science, and that as such they are worthy of less dignity and respect than science itself. As a result, the education of engineers has regrettably come to be regarded as a down-market form of science rather than as a culture in its own right. (Williams, 1990, p. ix)

It seems possible, therefore, that the view that STS subjects are somehow made inferior by their contact with the technological world could be contributing to the status problem afflicting SAT11.

*Is the Course a Valid Introduction to Technology?* We turn now to an epistemological issue: What view is presented to students about the nature of technology in the SAT11 course? Does the course provide a faithful introduction to technology? (There is of course a hidden normative assumption underlying this question, namely that school subjects *ought* to provide an accurate picture of the field of human endeavor whose names they bear.)

The term *technology* embraces a wide range of meanings. First, it can refer to artefacts (i.e., physical objects); we may describe the latest answering machine which uses computer chips instead of audio-tape as "a new piece of technology." Second, it can refer to technique, to the set of skills, resources, and procedures required to make an artefact; thus Wilkinson, the 18th century English cannon ball maker, had accurate lathes and therefore "had the technology" to help James Watt build his steam engine. If one adopts this view, the lathe-operators who made the cannon-balls or pistons were technologists. Some would reject this interpretation and say that the designer of the accurate lathe was a technologist, but the craftsmen who operated it were not. Thus, a third usage adopts more rigorous criteria: Technology is a process of change. It requires more than technique: It also involves invention, design, innovation, dissemination, evaluation; the technologist is a person who improves technology. Fourth, there is the phrase "technological system" which refers to a complex network of artefacts, processes, and people. A telephone company, for example, may employ technologists who design novel products, but the running of the entire system also requires telephone operators, repair personnel, accountants, and many other workers who would not describe themselves as technologists although they are certainly part of the technological system. Finally, *Technology* (with a capital T) also serves to describe a subject area, a field of specialization, a segment of the school, college, or university curriculum. Even this small umbrella provides various shades of meaning: The industrial arts teacher offering a course on automotive repair, the science-technology-society teacher discussing the environmental impact of logging and the university scholar writing essays on the history of the science-technology relationship can all legitimately claim to be interested in Technology.

These differing views about the meaning of the term may lead to differing views about the nature of technology education. Industrial arts courses, for example, have traditionally emphasized technique. Recent writing on technology education, much of it emanating from Britain, has focused on design, on technological capability: a marriage of thought and action, the ability to conceive of a product or service, and then to design, make, use, disseminate, and improve it. Technology has been described as

> the practical method which has enabled us to raise ourselves above the animals and to create not only our habitats, our food supply, our comfort and our means of health, travel and communication, but also our arts — painting, sculpture, music and literature. These are the results of human capability for action. They do not come about by mere academic study, wishful thinking or speculation. Technology has always been called upon when practical solutions to problems have been called for. Technology is thus an essential part of human culture because it is concerned with the achievement of a wide range of human purposes. (Black & Harrison, 1985, p. 5)

The notion of capability underpins several recent curriculum developments in various parts of the world. The *Design and Technology* program, recently introduced as part of the National Curriculum in England and Wales, provides a clear illustration. David Layton (1990) notes that what is intended is a

> freshly-conceived, broad, balanced and progressive set of experiences designed to empower students in the field of practical capability and enable them to operate effectively in the made world. The rhetoric often has some economic overtones to it, but the relationship between education and national economic performance is far from simple and these should be viewed with caution. The bottom line is about "privileging the practical" ... those realms of practical action where there are no right answers; where decisions have to be made on a basis of insufficient evidence; where requirements often conflict; and where compromise is endemic. And it is about acknowledging that competence in these areas — the ability to use knowledge and skills effectively, creatively and confidently in the solving of practical problems and the undertaking of tasks — is as significant an educational outcome as any other in more formal and academic realms. (p. 10)

There is little evidence in the SAT11 documents of such a view of technology. The language of the intended outcomes of the various modules is densely packed with verbs like describe, outline, identify, discuss, list, analyze, relate, explain, and discriminate. These reflect verbal skills common to most academic subject areas. A technology curriculum which emphasized capability would use such verbs as conceive, design, make, try out, and improve, but in SAT11 these are notable for their almost total absence. Students do not seem to be expected to engage directly in technology as a process of problem identification, design, and practical solution, or even to study that process vicariously.

The Health Technology module does specify as an objective the ability to "suggest or create a possible technological solution to a medical problem" (Ministry of Education, 1986a, p. 7), but no other module makes any reference to a comparable design component. The *Instructional Resources Manual* tells teachers, "Many of you may not have taught a science course before, and those that have may not have taught material that deals with technology and society." Since this is explicitly recognized, one might therefore have expected to see the inclusion of material to help teachers develop their understanding of technological processes, yet such material is nowhere to be found. The emphasis seems to be upon the external relations of technology with science and other sectors of society, and not upon the internal dynamics of the technological process, on the development of (or the study of) technological capability.

The criticism implied here flows from a definition of technology which emphasizes capability. The curriculum developers could quite reasonably respond that *their* definition is a narrower one, and that technological capability was simply not one of their central goals. If, however, the development of technological capability is seen as an important objective for at least some students in the BC education system, then there is no reason to expect that the SAT11 course will make a major contribution towards that goal.

*The Relationship Between Science and Technology.* The second epistemological issue is concerned with the view presented in the curriculum documents of the relationship between science and technology. The first of the three major goals of the course (Ministry of Education, 1986a, p. 4) states that "Science and Technology 11 will provide students with opportunities to gain knowledge of technologies as applications of science." This general statement is expanded into four more specific outcomes, the first of which states that students should be able to "understand that technology is an application of the concepts and principles of science."

This epistemological position has a distinguished ancestry and many powerful supporters, and it is not at all surprising that it reflects a commonly-held view. Nevertheless, I want to argue that such a position at best oversimplifies and at worst seriously distorts the nature of the relationship between technology and science. My argument is not a particularly novel one: Eminent scholars in the field of history and philosophy of science and technology were already calling the technology-as-applied-scienceview naive more than twenty years ago. What I am trying to do is to move their arguments out of academic journals into school curricula.

We have already noted that scholarly debate about the distinctions between technology and science and their relative value can be traced back to Aristotle. Francis Bacon in his *Novum Organum* was perhaps the earliest to discuss the epistemological relationship between the two: In his view, technology was applied science. "Nature to be commanded must be obeyed" (Book I, Aphorism III, Commins & Linscott, 1954, p. 80), he wrote; technological knowledge grew out of knowledge of the properties and processes of nature. Useful inventions such as the magnetic compass and gunpowder were examples of how knowledge of nature could increase human control over nature. As McGee (1989) points out, this is still a commonly held view of the science/technology relationship. Science provides the knowledge of nature that technology then uses: Science leads, technology follows. This equation of technology with applied science underpinned the establishment of organizations such as the Royal Institution and the British Association for the Advancement of Science, which sought to apply scientific knowledge to the world of practical affairs. Numerous historical examples can certainly be found which seem to lend weight to the idea of technological innovations arising out of scientific knowledge (e.g., the wireless telegraph and atomic energy).

The idea that pure science is the source of technological innovation has had some distinguished advocates. Vannevar Bush, a United States presidential advisor on science policy in the 1940s, argued that

> basic research leads to new knowledge .... It creates the fund from which the practical applications of knowledge must be drawn. New products and new processes do not appear full-grown. They are founded on new principles and new conceptions, which in turn are painstakingly developed by research in the purest realms of science. (Bush, 1945, pp. 13-14)

This is, of course, the classic utilitarian argument for supporting basic research, and one much favored by the science research lobby. The same epistemological position underlies the views of Professor Eric Rogers, quoted earlier. It is hardly surprising, therefore, to find the technology-as-applied-science view strongly entrenched in school curricula. Gardner (1990) points out that technological artefacts are commonly presented in school science texts as illustrations of scientific principles: The blast furnace exemplifies reduction/oxidation reactions; the telescope, the laws of refraction; the electric bell, the laws of electromagnetism. The implication, usually unstated, is that these artefacts are physical outcomes of the scientific principles that explain their operations. Such approaches can of course be defended: Teaching students a relevant scientific principle can help them to understand how the technology works.

There are, however, several objections that can be raised to presenting technology as applied science. The first is that, for most of recorded history, it is simply untrue that technology has resulted from the application of scientific principles. Humans were making iron thousands of years before the chemistry of redox reactions was understood; telescopes were made before the laws of refraction had been formulated. Edwin Layton (1977) notes that Benjamin Franklin's invention of the lightning rod in the 18th century was a rare instance at the time of a technological innovation based upon science; most inventions were based "almost wholly on the empirical insights of craftsmen, with no discernible scientific input" (p. 208). It was not until the growth of science-based technologies such as electricity and chemistry in the 19th century that science began to make major contributions to technological development. (Science, in this context, refers to systematic, public knowledge, based on theorizing, observation, and experiment.)

As McGee (1989) points out, "The applied science model fails to account for technical innovations made in classical or medieval times when the communities of science and technology were distinct, and the opportunity for communication between them did not exist" (p. 28). Even in more recent times, when scientific and technological communities could and did communicate with each other, major technological advances were made without much scientific input. McGee notes that the applied science model also fails to account for "many major innovations — the automobile, the airplane, and so on — which were originally developed with little recourse to science." Project Hindsight, an evaluative study by the United States Department of Defense on expenditures and outcomes of the department's weapons development program, illustrates this point. The study (Isenson, 1969) identified 700 significant "events" (i.e., key contributions to the program) over a twenty year period. Of these, 91% were technological improvements to previous technology, 8.7% were from applied science research, and only 0.3% — two events — involved basic science research. Price (1969) argues that the "naive picture of technology as applied science simply will not fit all the facts. Inventions do not hang like fruits on a scientific tree" (p. 97). Most technological innovations are developments of older techniques, rather than applications of knowledge gained from natural science.

The second objection is that having students learn the scientific principles which explain how a piece of technology works is not the same as developing their understanding of how the technology was designed to meet a human need. We could, for example, disassemble a photocopier in order to teach students about the physics of the photo-receptor surface, the optics of the lenses and mirrors, the mechanics of the paper-feed mechanism and the chemistry of the ink, but this would tell us absolutely nothing of the 22 years of intensive human effort by its inventor (Chester Carlson) to overcome numerous design problems and thus turn a creative idea into a workable prototype (Owen, 1986). The original scientific study on photo-conductivity (the property of some electrically charged non-conductors to lose charge when exposed to light) was done on sulphur, but this is not a durable material. It was only when selenium was found to have similar photo-conductive properties that this design problem could be overcome. The accurate feeding of the paper was another source of difficulty. Some of the design problems were tackled by trial-and-error: Various materials were used to wipe excess powdered ink off the photo-receptor surface, until it was discovered that the belly-fur of the Australian rabbit was suitable!

Trial-and-error techniques have a distinguished history in technological innovation. They were used by James Watt in his attempt to find strong, durable, tight-fitting, and low-friction materials for the piston and cylinder of his steam engine (Scherer, 1965), and by Thomas Edison in his search for suitable materials for his electric light bulb (McCormack, 1985). Using trial-and-error, however, is almost the antithesis of applying a scientific principle: It is the method technologists (and scientists!) use when they *lack* appropriate scientific knowledge. One curriculum effect of presenting technology as applied science, then, is to emphasize the science and neglect other important procedures for making technological progress.

A third objection is that the technology-as-applied-science view often fails to recognize the contribution of technology to the gaining of scientific knowledge (e.g., Galileo's use of the telescope to investigate Jupiter and the moon; the contribution of the steam engine to our understanding of thermodynamics; and Marconi's transmission of trans-Atlantic radio signals, which led to the discovery of the Heaviside layer of the ionosphere). Sometimes, too, major scientific discoveries are made as unintended by-products of research conducted with technological motives. Morison (1974) describes how research conducted in the General Electric laboratories in an attempt to improve the design of the electric light bulb led Irving Langmuir to study the mechanism of chemical reactions at surfaces, work which won him the 1932 Nobel Prize. This particular objection cannot be raised against the SAT11 course; one of the goals does state that students should understand that "technology is both a cause and an effect of scientific activity" (Ministry of Education, 1986a, p. 4).

The fourth objection is that emphasizing the application of science results in insufficient attention being given to other determinants of technological innovation. Technology is much more than applied science, it is an expression of culture, the ways in which humans understand their world and their place in it, the ways in which they transform that world. Mumford (1961) argues that it is "impossible to isolate the invention from the inventor, or the inventor from the place and the labor force and the culture that presented him with his opportunities and his incentives — or placed obstacles in his way and rejected his results" (p. 236). Mumford cites the immense authority vested in the Pharaoh as a result of the new solar religion and not any new mechanical inventions, which made possible the construction of the Pyramids through the use of a "thousand-legged human machine;" the Benedictine monks' desire for a well-ordered life which permitted time for religious devotion that led to the invention of mechanical clocks and labor-saving devices; slide- and movie-projectors and helicopters, which had their origins in 19th century mechanical toys for children, a genre of artefacts that began to be developed in the late Middle Ages as a result of increased attention to child care. An emphasis on technology as applied science may lead to a neglect in the curriculum of a consideration of these cultural forces. Again, however, this criticism is not entirely applicable to the SAT11 course: One of the intended learning outcomes of the initial (compulsory) module is that students should be able to give an example of how "society influences the development of technology" (Ministry of Education (1986a, p. 7).

Mumford's point about obstacles and rejection is also significant. Chester Carlson's development of the photo-copier was almost scuttled by a serious shortage of finance; even when the first working model had been built, IBM accepted advice from consultants that the market for such machines was likely to be small, and declined to become involved (Owen, 1986). Financial difficulties were among the many obstacles that James Watt had to overcome to turn his model steam engine into a commercially successful venture (Scherer, 1965).

The fifth objection is that even in cases where a technological innovation clearly does follow from a scientific discovery, the technology-as-applied-science view treats the issue of *application* superficially, as if there were an obvious connection between the scientific principle and its embodiment in an innovative artefact. Actually, the connection between a principle and its utilization is rarely obvious; application requires the reshaping of scientific knowledge and its creative synthesis with technical skill. The development of the direct-current dynamo during the 19th century and the jet engine in this century illustrate this point. Henry Rowland, originally trained as an engineer, pursued pure research in physics and published some important work on magnetic permeability and mathematical descriptions of electromagnetic circuits. Rowland failed to make practical use of his findings, although they were relevant to improving the design of the d.c. dynamo; he seemed to be more interested in discovering laws of nature than industrial design principles. Meanwhile, an English engineer, John Hopkinson, working in cooperation with Thomas Edison, had devised a graphical method of describing dynamo behavior in a form that allowed major improvements to be made, by changing the dimensions of some of its parts (Mayr, 1971; Layton, 1971). (There is some delightful irony here, incidentally, since Rowland held to a very Aristotelian view of the importance of pure science and made disparaging remarks about the vulgarity of inventors who "stole" the ideas of pure scientists!)

The technological principle of the jet engine was known to Hero of Alexandria in the first century, when he used a jet of steam in his toy "aelopile." Rockets were first employed for military and other purposes in the 13th century. The basic physics — Newton's action-reaction law — was elucidated in the 17th century, and the idea of a gas-driven turbine was put forward late in the 18th century. However, when, in 1929, a 22-year old RAF cadet named Frank Whittle conceived of applying the gas turbine to jet propulsion in aircraft,

> he still had a dozen years of frustrating effort ahead of him before he had an engine operating in actual flight. His difficulties were not matters of fundamental principle, but technical points like the proper setting of turbine blades or the control of air turbulence in the compressor. (Rae, 1961, p. 397)

Layton (1990), citing Staudenmaier (1985), argues that technological knowledge is not

> the same in form, and sometimes in substance, as the knowledge generated by the basic sciences. It is structured by the tension between the demands of functional design, on the one hand (that is, it must enable the achievement of some design purpose), and the specific constraints of the ambience, on the other (that is, the contextual constraints such as cost-limits, deadlines, ergonomic and durability requirements, individual and social preferences). Because of these differences those engaged on technological tasks have often to rework scientific knowledge in order to be able to use it. (p. 13)

*Technology and Science as Interrelated Communities.* Instead of equating technology with applied science, a more complex story can be told, based on the following three propositions:

- For most of recorded history, technology and science have been separate areas of endeavor; prior to the Industrial Revolution, there are only rare instances of technological innovations being derived from scientific knowledge.

- This picture began to change during the Industrial Revolution as technology changed from craft to profession, but mainly through technologists adopting the quantitative and experimental methods of science to investigate their own problems, rather than by applying knowledge gained by scientists.

- In modern times, technologists and scientists have become closely interacting communities, with a two-way relationship between technology and science.

The first proposition has been discussed earlier and requires no further elaboration. Discussion of the second requires a distinction to be made between the use made by technologists of ideas derived from pure science and their use of scientific modes of inquiry to investigate the behavior of machinery in ways that permitted technological advancement. Cardwell (1965) observes that "classical mechanics, although admirably adapted to solving such problems of accelerated motion as the behavior of planets and satellites, did not lend itself readily to the study of the power obtainable from unaccelerated machines" (p. 192). He notes that in 1704, Antoine Parent proposed a relationship between the speed of water and the power of a waterwheel. It turned out to be incorrect, but it represented the beginnings of a new phase of technological progress: The scientific study of machine behavior, using mathematical methods and experimental trials. During the 18th century, technologists would use such methods to discover that overshot waterwheels were more efficient than undershot waterwheels, and that curved wheel blades were more efficient than straight ones. Treating the machine as an object of scientific study was central to the development of engineering during the 19th and 20th centuries. Kline (1987), for example, notes how the successful development of the alternating-current induction motor required engineers to go beyond Maxwell's electromagnetic theory and develop an engineering theory *of the motor* in order to make progress.

The adoption of scientific methods to solve technological problems did not take place in a social vacuum, and this leads to the third proposition. In the 19th century, technologists and scientists began to form interacting communities. Technologists began to adopt the institutions of science: laboratories, journals, and professional societies. Edison's Menlo Park laboratory epitomized the new approach; it was the precursor of the modern industrial research and development facility. (Edison's laboratory was anticipated a century earlier by the Boulton-Watt workshop in England, where a team of technicians worked under James Watt's direction to develop the commercial version of the separate-condenser steam-engine.)

Knowledge began to flow in both directions. For example, James Francis, a 19th century technologist, not only improved the efficiency of water wheels by adopting experimental procedures and mathematical analysis, but also contributed to scientific theory in the process (Layton, 1981). In an earlier paper, Layton (1971) argued that the science technology relationship became symmetrical:

> That is, information can be transferred in either direction. The flow of technology into science in the form of instrumentation has long been recognized; but the traditional model does not provide for the possibility that technological theory might influence science. (p. 578)

Layton cites several examples of engineering ideas influencing scientific theory: The theory of elasticity of materials was drawn upon in an attempt to explain the transmission of light through the "ether"; Carnot's studies of the efficiency of heat engines were translated into the physics of thermodynamics.

The achievements of James Francis offer a rare example of technological and scientific advancement being made by the one person. In modern times, it is more commonly a team effort. Layton (1977) comments that, although the growth of science-based industries in the 19th century led to the idea that technology was applied science,

> rather paradoxically, when attempts have been made to apply this model of science-technology relations to historical case studies, they have frequently failed. Historians of technology have virtually abandoned this model, since it is seldom helpful in understanding technological development. Thus, the invention of the transistor, though it involved science in rather fundamental ways, cannot be explained simply as an application of preceding advances in science. ... The work on it was done by an interdisciplinary team which included both physicists and engineers. Attempting to divide the credit for this innovation between two neat compartments is just not possible if one knows enough of the actual circumstances. The source of the confusion is quite simple. The divisions between science and technology are not between the abstract functions of knowing and doing. Rather, they are social; they are between communities that value knowing and doing, respectively. (pp. 208-209)

An earlier paper (Layton, 1971) had argued that in modern times, science and technology have become "mirror image twins": "Science ranks theoretical knowledge high and application low, whereas technology ranks theoretical knowledge as merely necessary and the making of things the highest good of all." It would appear that the ghosts of Aristotle and Francis Bacon are still contending.

*Educational Implications and Some Suggestions*

What are the implications of all this for the teaching of SAT11 (and other, similar courses on science, technology and society)? If school curricula which deal with STS issues are to provide faithful representations of the relationship between technology and science, then the inadequate picture of technology as applied science will have to be replaced by a more complex view of technology and science as largely initially independent communities which have become interdependent during the past two centuries.

Academic educators are often accused of being long on critical analysis and short on practical advice. (One teacher, attending an academic conference on education, is said to have remarked that he came to the Pentagon and found the generals playing chess.) I want to conclude, therefore, by offering some suggestions for improving the quality of the SAT11 course. Clearly, this will require a combination of approaches. The curriculum content and its associated documents might be revised, to give more emphasis to technological capability and studies of the technological process. The academic status problem will have to be addressed, in the long term, by educating a body of teachers with recognized university studies in the STS field. In the short term, there is an obvious need for inservice courses and teacher networks so that good ideas can be introduced and shared. These efforts could be supported by having education authorities and universities prepare case study materials which introduce students to the history and philosophy of science and technology, in ways that reflect current scholarship in the field.

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Note: This paper is an abridged and amended version of a paper, "From Aristotle to British Columbia: Some Reflections on a Grade 11 Science and Technology Course," presented at the joint National Science Teachers' Association/British Columbia Science Teachers' Association area convention, Vancouver, November 1991. It was written while the author was on study leave as a visiting professor in the Department of Mathematics and Science Education at the University of British Columbia. The helpful comments of Dr. John Willinsky, Director of the Centre for Curriculum and Instruction at UBC, on the earlier version of the paper are gratefully acknowledged.

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