The technology-science relationship: some curriculum implications

P.L. Gardner[1]
School of Education
Monash University, Melbourne

Abstract

Technology encompasses the goods and services which people make and provide to meet human needs, and the processes and systems used for their development and delivery. Although technology and science are related, a distinction can be made between their purposes and outcomes. This paper considers four possible approaches to teaching students about the relationship between technology and science. A technology-as-illustration approach treats technology as if it were applied science; artefacts are presented to illustrate scientific principles. A cognitive-motivational approach also treats technology as applied science, but presents technology early in the instructional sequence in order to promote student interest and understanding. In an artefact approach, learners study artefacts as systems in order to understand the scientific principles which explain their workings. Finally, a technology-as-process approach emphasises the role of technological capability; in this approach, scientific concepts do not have privileged status as a basis for selecting curriculum content.

1. Introduction

Technology education

Technology education has been defined as "the comprehensive curriculum area ...concerned with technology, its evolution, utilization and significance;... its organization, personnel, systems, techniques, resources, and products; and their combined social and cultural impacts" (ITEA, 1985, p.25). During the past few years, Australian education systems have been introducing technology education into the curriculum. One pressure for this is economic, arising from a recognition that Australian industry must become more innovative. Other pressures come from liberal concerns: technology touches upon virtually all aspects of modern life, and all citizens ought to develop some technological understanding. In the 1990s, given adequate resource support, technology education could develop into a major curriculum innovation.

Many writers emphasise the importance of education *in* technology, arguing (rightly, in this writer's view) that the technology curriculum should be principally concerned with developing learners' capabilities. However, there is also value in learning *about* technology; this includes encouraging learners to explore the links between technology and other areas of knowledge.

Technology is being introduced into schools by teachers with experience in fields such as industrial arts, art and craft, home economics and computer studies. Science teachers can also make an important contribution, although many, lacking industrial experience and design and manufacturing skills, may feel hesitant about doing so. This paper is concerned with the relationship between technology and science; it has been written with science educators in mind. Its purpose is not to offer a detailed analysis of the nature and philosophy of technology or a broad set of principles of technology curriculum design. The aim is much narrower, namely to compare various instructional approaches which have been used in teaching about technology and science.

The nature of technology

Technology encompasses the goods and services which people make and provide to meet human needs, and the knowledge, organisational systems and processes used to develop and deliver those goods and services. Technology meets human needs through a marriage of thought and action, a combination called *technological capability*. Technology has been described (Black & Harrison, 1985, p.5) 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.

Technological capability requires problem-solving ability. It involves a synthesis of the many skills needed for technological development: the ability to conceive of a product or service, and then to design, make, use, disseminate and improve it. Technological development has been described as a process of invention, refinement, innovation, diffusion and transfer (Mensch, 1979; Baklien[2]; Staudenmaier, 1985; Gardner, Penna & Brass[3]). Some writers have discussed technological development in terms of the personal characteristics of creative problem-solvers (e.g. Crosby, 1968); some have written about it in systems-analysis terms (Robertshaw, Mecca &

Rerick, 1978); others have emphasised the importance of societal influences (Bereano, 1976; Boyle, Elliott & Roy, 1977).

Technology and science

What is the relationship between technology and science? The terms are often mentioned in the same breath (especially by non-technologists), implying a close link between the two. The *Oxford English Dictionary* (Vol. XI, p.137) gives one definition of technology as "the scientific study of the practical or industrial arts", which clearly assumes such a link. A British curriculum guide for science teachers (Holman, 1986, p.23) defines technology as "the enabling process by which science is applied to satisfy our needs". The *Penguin Dictionary of Economics* (Bannock, Baxter & Rees, 1978, p.433) also recognises that technology is linked to science, but that other forms of knowledge are also important: technology is "the sum of knowledge of the means of producing goods and services. Technology is not merely applied science...things are often done without precise knowledge of how or why they are done except that they are effective."

These descriptions by non-technologists all omit mentioning that science is often the product of technology, that doing frequently precedes understanding. However, as McCann e.a. (1984, p.101) point out,

> Historically, technology has often been the parent of science, rather than the reverse. The principles of geometry, for example, succeeded the practices of surveying. It is important to appreciate that technology may often include effective techniques for which satisfactory understanding at any deep theoretical level is lacking.

Practical techniques which serve useful ends do not always require scientific understanding. For example, the use of heat treatment in canning food preceded Pasteur's research on micro-organisms. (Of course, as McCann e.a. note, modern 'high' technology does depend upon theoretical understanding.)

For Scriven (1985, 1987), technology and science have differing histories, goals, products and methods. For example, the Iron Age began in the Near East and south-eastern Europe around 1200 BC (*New Encyclopaedia Brittanica*, Vol.6, p.388). During the next two centuries, there was a rapid spread of practical knowledge of the metallurgy and uses of iron. The subsequent history of iron extraction (ibid., Vol.21, p.360-388) is mostly a story of thoughtful trial and error. Scientific understanding of the chemistry of the process has developed only during the past two centuries, exemplifying what Scriven calls "the historical seniority of technology". The development of iron extraction undoubtedly involved problem solving, directed trial and error, and evaluation of results, but, Scriven argues, this was not *science* because "neither its main aim nor its principal product was an understanding of natural and social phenomena". Science aims primarily at generating ideas, explanations and understanding; Scriven considers that "the great scientific breakthrough is the idea, but in the case of technology the ideas are just the beginning of creating a new or improved technology". Hacker and Barden (1987, p.3), in a school textbook on technology, make a simple but effective distinction: "Science is the study of why natural things happen the way they do. Technology is the use of knowledge to turn resources into the goods and services that society needs." Fensham[4] drew upon the work of the National Curriculum Committee (1988) in England to argue that science is analytic, concerned with discovery, understanding and generalised knowledge; technology is synthetic, concerned with invention and manufacture, with whatever specific knowledge is useful to solve a problem.

This epistemological analysis portrays science and technology as different but equal, a perception not universally shared: science tends to be accorded higher status. Observe how we say, 'science and technology' rather than 'technology and science', thus unconsciously emphasising science, and possibly implying that technology is an offshoot of science. Storer's (1966, p.2) whimsical comment that achievements in space are regarded as scientific triumphs, while unsuccessful launches are due to engineering failures, can be interpreted as an attempt by scientists to pretend to higher status.

2. Instructional approaches

Analyses by the author of science textbooks and research papers reveal four approaches to the question of how to present instructional content on the relationship between technology and science to learners:

- technological applications are presented after an instructional sequence based on scientific concepts and principles; this can be called a technology-as-illustration approach;
- technological applications are introduced early in an instructional sequence in order to stimulate student interest and enhance meaningful learning of scientific concepts (a cognitive- motivational approach);
- technological artefacts (real or simulated) are disassembled in order to develop understanding of the various parts of the artefact, how they interact, and the principles involved, (an artefact approach); and
- technology is regarded as a process of problem-solving (inventing, designing, making ...); scientific ideas are relevant if they contribute to this (a process approach).

Other approaches are possible. For example, STS (Science, Technology and Society) approaches tend to place less emphasis on both scientific content and technological capability and more emphasis upon the problematic nature of scientific knowledge, and upon the interdisciplinary nature of knowledge, in an attempt to show how science and technology are shaped by social forces and how they affect society. Solomon (1988) comprehensively reviews these approaches.

3. Technology as illustration

A common approach to teaching about technology in science courses is to introduce a phenomenon (e.g. the reflection of light or the behaviour of an electromagnet), present relevant experiences (laboratory work, photographs, etc) and scientific principles which are then illustrated by referring to technological applications. This approach, which treats technology as applied science, is often found in school texts. Chapter 2 of *PSSC Physics* (Haber-Schaim e.a., 1976) introduces the laws of reflection, presents photographs of reflected beams and develops the concepts of ray geometry and virtual images. Plane mirrors are dealt with first, and then parabolic mirrors. The text then displays a photograph of the parabolic telescope at Mt Palomar, and describes the mechanical mounting needed to track the apparent motion of stars.

An Australian science text to which the writer contributed some years ago (Baldock e.a., 1970) contains similar sequences; e.g. students are introduced to the magnetic effects of electric currents through labwork; they make a solenoid, study its properties and the effect on a compass needle of reversing the current. Students compile a list of devices utilising electromagnets, and then examine an electric bell and propose explanations of how it works.

A recent American Association for the Advancement of Science report on technology education (Johnson, 1989) clearly regards artefacts as illustrations of scientific ideas:

> The principles of energy and its use should be taught in science courses, but their application must be thoroughly experienced or demonstrated in technology activities in elementary and secondary school. Concepts of work, kinetic and potential energy, storage of energy, and thermodynamics and entropy, among others, should be accompanied by purposeful experiences...(e.g.) water wheels, windmills, and simple solar heaters (p.15).

When technology is treated as applied science, the science content of the curriculum is usually taken for granted; choices about the technology content are made subsequently, by selecting artefacts whose workings can be understood in terms of this science content. The laws of reflection and refraction, for example, are standard components of a physics course; a physics teacher seeking a modern illustration of an artefact in which reflection and refraction are important might offer the photocopier as an example, by discussing how an image of a document is formed on a cylindrical photo-receptor drum. A teacher discussing the properties of sulphur and selenium, both Group VI non-metals, might mention that they are photo-conductive: they can be electrically charged, but will hold that charge only in the dark. Shine a light on part of a photo-conductive surface, and that part becomes discharged. It is this property of photo-conductivity which is central to the photo-copying process; modern photocopiers contain a selenium-coated drum.

Rennie (1987) has reported that science teachers (but not technical teachers) frequently regard technology as an embodiment of scientific ideas. Perhaps such teachers hold to an implicit learning theory which advocates the teaching of general principles before specific illustrations. This is not irrational: *scientific* understanding of a reflecting telescope, electric bell or photo- copier does require understanding of the relevant scientific principles. Some science educators, however, have come to recognise the limitations of this approach. Holman (1986, p.23) cites an English comprehensive school which "decided that the traditional methods of presenting the science first and then throwing in a quick word on applications was too pure and unsuitable as a motivator of 14-16 year olds".

4. A cognitive-motivational approach

A second approach also treats technology as applied science, but adopts a different rationale and sequence of presentation, in an attempt to stimulate interest and understanding. The technological application is intended to serve a motivational and cognitive function and is introduced early.

This early introduction could be done superficially, with the teacher using an interesting artefact merely to capture students' attention. The artefact may then be put aside, with subsequent instruction concentrating upon the real agenda: the science content. Most writers who adopt a cognitive-motivational approach, however, argue for a more central role for the artefact, by making it the focus throughout the instructional sequence. Violino (1987), an Italian writer, advocates introducing technology into the primary school to provide "concrete experience which leads children to an understanding of an important scientific concept". He suggests using an espresso coffee-pot and a plywood overshot water wheel to model a steam turbine. Children can then be encouraged to build other machines -- which, he claims, they do enthusiastically -- and as a result of these activities, their ideas about energy can be developed.

Jones and Kirk (1989) adopt the same justification for introducing technology into secondary school physics. They point out that physics "is often remote from the students' real world ... one method of bridging this gap is to introduce technological applications". They argue that the approach can enhance learning: "a technological focus which is perceived by students as being relevant should enable the students both to attend to the learning situation (engagement) and to generate more adequately links between the new and existing ideas" (p.165). They advocate a five-stage teaching/learning sequence of focussing, exploring, reporting, formalising and applying, in which a technological application (or some other real world phenomenon) serves as the focus, and offer examples of this sequence in practice. The predominant goal (understandable in a physics course) is to develop students' understanding of the *physics*. This resembles the technology-as-illustration approach, but the place of technology in the script changes from epilogue to prologue and theme.

One of their units starts with a flash-gun, which the students disassemble. The goal is primarily to help students understand the concept of capacitance, and not to provide them with details of all the physics involved in a flash-gun/camera system. Their paper presents data (teachers' and students' reactions) indicating strong evaluative support to the approach. They also report a difficulty: physics teachers were frequently so concerned about syllabus demands that they believed that there was "not enough time available for the introduction of technological applications ... Thus teaching packages had to develop concepts required by the syllabus while not increasing the amount of time spent on the topic." If the aim is to teach *science*, as it was in this case, this may be sensible, pragmatic solution to a real instructional problem. But if the aim is to teach *technology*, the approach is open to epistemological challenge.

5. Technology as artefact

A third approach involves studying artefacts to learn how they work, a kind of technological equivalent of anatomy and physiology. Artefacts are taken apart (either literally or intellectually) to study the parts, their functions and how they inter-relate. This approach is common in children's encyclopedias when they explain, in terms of scientific laws and principles, how some familiar object such as a car engine, or electric power generator, works. In Germany, Dahncke and colleagues[5] have developed instructional approaches in which children disassemble household artefacts in order to understand their workings. This approach treats artefacts as *systems*; the aim is to help learners understand how a system works *in toto*. While the capacitors in a flash-gun are obviously vital to its successful operation, scientific understanding of how a *flash-gun* works also requires understanding of the electronics of the flash-tube, the optics of the reflector and the shutter system of the camera. Similarly, while the photo-receptor drum of the photocopier is undoubtedly the most creative invention in the system, the whole system would not operate without an optical sub-system, a paper-feed sub-system, an ink-feed sub-system, an ink-paper fusion sub-system....

This approach shifts the emphasis away from specified topics in a science curriculum to the artefact itself, viewed as a system. But the science is still there: scientific principles are drawn upon by the teacher to explain how the artefact works, or are formulated by learners seeking further explanations. Newman, Cosgrove and Forret (1988) have adopted this approach, utilising constructivist teaching strategies, in a unit on refrigeration.

6. Technology as process

None of these approaches, however, provides a faithful representation of the nature of technology: learning the science which explains how something works is not synonymous with learning how technologists design solutions to practical problems. Pressing technology into the service of science education may help students to learn science, but it may do little to develop their technological capabilities. The Royal Society for the Encouragement of the Arts, Manufactures and Commerce (RSA), which sponsored the *Education for Capability* movement in the UK in the early 1980s, was critical of curricula in which learners "acquire knowledge of particular subjects but are not equipped to use knowledge in ways that are relevant to the world outside the education system" (RSA, 1986). The society called for an emphasis on the culture of doing, on creativity, competence at making things, decision-making ability, and the capacity to work co-operatively with others, all of which are central to the technological development process.

Approaches which treat technology as applied science, which present artefacts to learners as objects of scientific study, do little to illuminate the process of technological development. The three approaches may lead to misrepresentation of the historical and epistemological relationships between technology and science; all of them fail to present an accurate portrait of the nature of technological capability as a process involving problem-solving, invention, design, making....

A study of the principles which scientists would use to describe the workings of an artefact tells us little of the nature of the problems that the technologist had to overcome in inventing, designing and manufacturing that artefact. *Yet it is the identification and surmounting of those problems which are at the heart of the technological development process.* Any curriculum which fails to present this aspect of technology to learners is not teaching technology at all, but something else: applied science, perhaps, or technical skills.

Learners can be helped to understand the process of technological development, through direct involvement, or vicariously (e.g. through case studies of technological innovations). Whichever approach is used (they may of course be used together), the emphasis is upon confronting problems, upon using whatever resources are available to attain an adequate solution. Scientific knowledge may be important, but it does not have privileged status: any knowledge, skill or resource is relevant if it contributes to a solution of the problem at hand.

Secondary school students can be directly involved in technological problem-solving. Black e.a. (1988, p.14) offer illustrations of tasks that might be tackled by students:

- Develop an aid for drivers reversing a large vehicle
- What can be done to provide villages in Peru with a continuous water supply?
- Decide on best energy source for a purpose chosen by each student
- Toy manufacturer needs a small-scale paint drying device
- Design and make a hypothermia-avoidance kit for old people

Such direct attempts at problem-solving can be complemented by vicarious experiences e.g. through case studies of the technological development process. The history of the photocopier provides the basis for a fascinating case study. Owen (1986) offers an account of the technological development process in action. He describes the 22 years of struggle by Chester Carlson, following his discovery in 1938 of the principle of xerography ("dry writing"), to develop the first Haloid XeroX 914 office copier. Science played an important role in this story: knowledge of the photo-conductive properties of sulphur and selenium was crucial to the development of the technology. (The first experiments were with sulphur-coated surfaces but selenium was later found to be more durable.) Other problems -- human, technical and economic -- had to be surmounted as well. One problem was that of finding an efficient method of wiping excess toner (powdered ink) off the photo-receptor drum after each copy had been made. What branch of *science* could possibly predict that the belly fur of Australian rabbits had just the right consistency? (Beaver and raccoon pelts were tried, but could not be easily cut to the right tolerances.) Carlson's difficulties in obtaining funds illustrate how social factors foster (or hinder) technological development. He was near the bottom of his bank account when he received a $3000 grant from a private research foundation, after IBM, RCA and General Electric had all turned him down. Even after the prototype had been made, IBM accepted consultants' advice that the market for such machines would be small, and declined to become involved.

Selected case studies of this type in the curriculum, in conjunction with direct involvement by learners in tackling more tractable problems, might help to illuminate the complexity of the technological development process.

Such studies may serve to indicate that the creative technologist must be able to synthesise many sources of knowledge and skill, not just scientific, in order to develop technological capability. Some ideas for suitable topics might be obtained from contributions to the Fourth International Symposium on World Trends in Science and Technology Education (Riquarts, 1987). If the potential value of this curriculum approach is accepted, the next steps would be for curriculum developers to investigate the history of the particular area of technology chosen for study, develop instructional materials for students and support materials for teachers, and try them out in classroom settings.

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Notes

1. Dit artikel is de weergave van een colloquium dat Dr.Gardner tijdens een studieverblijf in januari 1992 heeft verzorgd voor het Centrum voor Didactiek der Wiskunde en Natuurwetenschappen te Utrecht.
2. A. Baklien *Technology assessment and project evaluation*. Unpublished paper, Monash University, 1988.
3. P.L. Gardner, C. Penna & K. Brass, *Technology education in Australia: meanings, developments, issues and challenges*. Paper presented at the annual conference of the Australian Association for Research in Education, University of Adelaide, 28 Nov - 2 Dec, 1989.
4. P.J. Fensham, presentation at the 1989 CONASTA (Australian Science Teachers' Association annual conference).
5. Professor Dahncke is the leader of a national group based at the Pedagogical Institute in Kiel. He described the group's work at a seminar at Monash University in 1989.

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