Technology as Knowledge: Implications for Instruction

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Technology is organized knowledge for practical purposes
(Mesthene, The role of technology in society, 1969).

There is a strong belief among technology educators that technology constitutes a type of formal knowledge that can be reduced to curricular elements. It is suggested that since technology has its own knowledge and structure, its study is similar to how one would organize the study of any other discipline in the school, such as algebra or physics (DeVore, 1968; 1992; Erekson, 1992; Savage and Sterry, 1990). Lewis and Gagle (1992), for example, contend that technology educators "have two clear responsibilities; first to articulate the disciplinary structure of technology and, second, to provide for its authentic expression in the curriculum" (p. 136). Dugger (1988) argues that technology should be considered a formal, academic discipline. Similarly, Waetjen (1993) emphatically states that technology education "must take concrete steps to establish itself as an academic discipline" (p. 9).

This article suggests that technological knowledge is not a type of formal knowledge similar to that associated with the recognized academic disciplines. It has distinct epistemological characteristics that set it off from formal knowledge. A deeper understanding of technological knowledge opens the curriculum to possibilities that are obscured by a more restricted view. Greater direction is also given to the task of curriculum development. As Taba (1962) observes, confusion surrounding curriculum development often stems from insufficient "analysis of what knowledge in any subject or discipline consists of. This lack of analysis in turn causes misunderstandings about the role of knowledge in learning and curriculum" (p. 172).

To be sure, technology embodies knowledge. Parayil (1991), for one, observes that "Technology constitutes knowledge, and that all technologies are embodiments of some form of human knowledge" (p. 292). But what kind of knowledge, and how is it situated within the scope of human knowledge? And how can technological knowledge be reduced to elements for inclusion in the curriculum? It is the purpose of this article to examine these questions. It makes little sense to talk about curricular strategies until the epistemological dimensions of technological knowledge are first determined.

Technology includes important normative, social, political, and ethical aspects, among others. This article is limited to a discussion of the knowledge dimension of technology, and makes no attempt to probe these other aspects. Throughout, the discussion is informed by the work of individuals in the fields of the history of technology and the philosophy of science and technology.

What is Technological Knowledge?

The etymology of the term "technology" is instructive. It comes from the Greek technologia, which refers to the systematic treatment of an art (or craft). The root techne "combines the meanings of an art and a technique, involving both a knowledge of the relevant principles and an ability to achieve the appropriate results" (Wheelwright, 1966, p. 328). In other words, "technique" involves the practical skills of knowing and doing. The root logos has wider meaning, including argument, explanation, and principle, but its most relevant use is probably "to reason." Technology, thus, encompasses reasoned application. Technology, however, has always meant more than abstract study because of the emphasis on application, or doing, although the French use of the term "implies a high degree of intellectual sophistication applied to the arts and crafts" (Hall, 1978, p. 91). The French, in fact, are more precise in their definition and use two terms. "Technologie" is used to refer to the study of technical processes and objects, and the term "technique" refers to the individual technical means themselves, the actual application processes (Willoughby, 1990). The two concepts are mixed in the English use of "technology," and this leads to a failure to distinguish between its study and its application.

In the English language, the term "technology" acquired limited usage in the late 19th century as a way to refer to the application of science (knowledge) to the making and use of artifacts. In our century, formal knowledge is inextricably linked with the development of science and technology. More recent scholars generally emphasize the importance of knowledge in defining technology (Layton, 1974; MacDonald, 1983; McGinn,1978;1991; Vincenti, 1984). The recognition of the centrality of knowledge leads to conceiving technology as more than artifact, and as more than technique and process.

The defining characteristic of technological knowledge, however, is its relationship to activity. Although technological knowledge is considered to have its own abstract concepts, theories, and rules, as well as its own structure and dynamics of change, these are essentially applications to real situations. Technological knowledge arises from, and is embedded in, human activity, in contrast to scientific knowledge, for example, which is an expression of the physical world and its phenomena. As Landies (1980) observes, while the intellectual is at the heart of the technological process, the process itself consists of "the acquisition and application of a corpus of knowledge concerning technique, that is, ways of doing things" (p. 111). It is through activity that technological knowledge is defined; it is activity which establishes and orders the framework within which technological knowledge is generated and used.

Because of the link with specific activity, technological knowledge cannot be easily categorized and codified as in the case of scientific knowledge. Technology best finds expression through the specific application of knowledge and technique to particular technological activities. For this reason it is not considered a discipline in the sense that math or physics is. Skolimowski (1972), for example, suggests that there is no uniform pattern of "technological thinking," or, in other words, universals characterizing a "discipline of technology." The application of technology requires the integration of "a variety of heterogeneous factors" which are both "multichanneled and multileveled," and that specific branches of technology "condition specific modes of thinking" (p. 46). Technology, in other words, makes use of formal knowledge, but its application is interdisciplinary and specific to particular activities. There is a technology of surveying, civil engineering, architecture, biochemistry, hog farming and countless others, but technology is not a coherent discipline in the general sense.

Technology and Science

The term "technology" is strongly associated with the application of science to the solution of technical problems. Narin and Olivastro (1992) suggest that there is a continuum stretching from vary basic scientific research, through applied research and technology (p. 237). In some fields, on the other hand, such as communications, computing, medicine, and chemicals, the distinction between science and technology is blurred. The most active areas of high tech growth are often those that are very science intensive. Mackenzie and Wacjman (1985), however, suggests that technology is more than the product of scientific activity. In the case where "technology does draw on science the nature of that relation is not one of technologies obediently working out the `implications' of scientific advance. . . . Technologists use science" (p. 9).

Feibleman (1972) distinguishes between pure science, which uses the experimental method in order to formulate theoretical constructs, explicate natural laws, and expand knowledge; applied science which focuses on applications to purposeful activity; and technology which puts applied scientific knowledge to work. Hindle (1966), however, cautions that there are fundamental, historical tensions between science and technology, and that technology is more than applied science:

Science and technology have different objectives. Science seeks basic understanding--ideas and concepts usually expressed in linguistic or mathematical terms. Technology seeks means for making and doing things. It is a question of process, always expressible in terms of three dimensional "things"(pp. 4-5).

One major way to distinguish between scientific and technological knowledge is intention, or purpose (Layton, 1974; Mitcham, 1978). The purpose of scientific knowledge is to understand phenomena and the laws of nature. Science is about knowing. The purpose of technological knowledge, however, is praxiological, that is, to efficiently control or to manipulate the physical world, to do things (Skolimowski, 1972). Efficiency is the end purpose of technology. Science is based on observation and predicts in order to confirm theory; technology predicts in order to influence and control activity. Science values the abstract and general; technology stresses instrumentation and application. These distinctions set technology apart from science. "While science seeks to expand knowledge through the investigation and comprehension of reality," suggests Layton (1974), "technology seeks to use knowledge to create a physical and organizational reality according to human design"(p. 40).

Forms of Technological Knowledge

Vincenti (1984) identifies three categories of technological knowledge: a) descriptive, b) prescriptive, and c) tacit. Both descriptive and prescriptive are categories of explicit technological knowledge, but descriptive knowledge describes things as they are, while prescriptive knowledge prescribes what has to be done in order to achieve the desired results. Tacit knowledge is implicit in activity.

Descriptive knowledge

Descriptive knowledge represents statements of fact which provide the framework within which the informed person works, such as material properties, technical information, and tool characteristics. These facts are often applications of scientific knowledge. Carpenter (1974), however, observes that while mathematical formulae or scientific constructs are used, descriptive knowledge is not scientific in the sense that the explanatory theoretical framework is not fully developed, and Frey (1989) observes that while there may be correlates between the two, in the case of technological knowledge there are "certain properties not apparent in, or derived from, scientific theory" (p. 26). Nevertheless, descriptive knowledge approaches an approximation of the formal knowledge of a "discipline" since it describes things as they are, it can be in the form of rules, abstract concepts and general principles, and it often has a consistent and generalizable structure. Like all technological knowledge, however, descriptive knowledge finds its meaning in human activity.

Prescriptive knowledge
Prescriptive knowledge results from the successive efforts to achieve greater effectiveness, such as improved procedures or operations, and is altered and added to as greater experience is gained. McGinn (1978), however, cautions that prescriptive knowledge is more than simple "nonintellectual know how;" it may be "comparable with the achievement of new intellectual knowledge;" and it is "often undergirded by such knowledge" (p. 186). Mitcham (1978) identifies technical maxims or rules of thumb as "pre-scientific work" and "first attempts to articulate generalizations about the successful making or using skills" (p. 256). Prescriptive knowledge generated through experimentation, trial-and-error, and testing is used in specific ways to make predictions "at what might be termed a pre-theoretical level" (McGinn, 1978, p. 187). Because

prescriptive knowledge is less wedded to scientific principles and law, however, and because it is an outgrowth of specific application, it is not easily codified in a general form, and therefore it is less amenable to the formulation of instructional generalizations that go beyond a particular activity. "The easier a knowledge is codified, the easier it [can] be transmitted," observes Perrin (1990, p. 6).

Tacit knowledge
Tacit knowledge is implicit, and is largely the outcome of individual judgement, skill and practice (Polanyi, 1967). Tacit knowledge cannot be easily expressed formally. Descriptions, diagrams, and pictures help to explain tacit knowledge, but it largely results from individual practice and experience. Tacit knowledge often constitutes the "tricks of the trade" experienced workers learn, and it is often protected or restricted knowledge (Vincenti, 1984). "Many of the crucial, incremental improvements in process technology, for instance, occur on the shop-floor," Scarbrough and Corbett (1992, p. 8) note. Specialists, however, simply do not reveal all that they know. Tacit and prescriptive knowledge is closely related in practice since in both cases it has to do with procedures. Both types of knowledge are procedural (Vincenti, 1984).

A large part of tacit knowledge cannot be transmitted through written or oral form. It is personal knowledge, it is subjective knowledge, and it is immediate and specific knowledge. Tacit knowledge is primarily learned by working side by side with the experienced technician or craftsman. Tacit knowledge is mainly transmitted from one individual to another. Perrin (1990) suggests that operational knowledge primarily "remains tacit because it cannot be articulated fast enough, and because it is impossible to articulate all that is necessary to a successful performance and also because exhaustive attention to details produces an incoherent message" (p. 7).

Tacit knowledge is embedded in technological activity to a greater extent than is normally recognized. In addition, tacit knowledge has not disappeared with the use of more sophisticated ways of manufacturing based on the application of science and descriptive technical knowledge. "On the contrary, new forms of know-how have appeared and all these non-codified techniques play an important role in industrial production and in technical and technological innovation" (Perrin, 1990, p. 6). Rosenberg (1982) and Vincenti (1984) highlight the fact that even the so-called high-tech industries, such as aircraft production, electronics and telecommunications, rely heavily on tacit knowledge learned through experience. Considerable industrial innovation is acquired through non-codified techniques. Polyani (1967) has demonstrated that all human action involves some form of tacit knowledge.

Levels of technological knowledge

While incorporating the categories of knowledge identified by Vincenti (1984), Frey (1989) calls attention to different levels of technological knowledge, and observes that "the amount of discursive knowledge increases as the complexity of technological knowledge increases" (p. 29). Artisan, or craft skills constitute the lowest level, and are largely tacit, although prescriptive, and to a lesser degree descriptive knowledge is involved. Because of the high level of tacit knowledge, artisan skills are best taught through observation, imitation, and trial and error, rather than through discourse. Frey (1989) observes, for example, that "a highly skilled welder `knows' how to weld but very likely cannot articulate exactly how welding is accomplished" (p. 29).

Technical maxims comprise the next level of technological knowledge, and consists of generalizations about the skills applied in making or using technology. Technical maxims, however, are usually incomplete without the less recognized tacit knowledge accompanying the actual doing (Carpenter, 1974). For this reason, technical maxims, rules, recipes, and procedures are usually learned best in conjunction with on-going activity, often on the job.

Descriptive laws, the next level, are "scientific like" explicit, generalized formulations derived directly from experience. Because they are derived from experience they are referred to as empirical laws, and are mainly formulated on the basis of try-out and observation (Mitcham, 1978). Descriptive laws are not yet scientific because they lack sufficient explanatory theory, although they may be highly sophisticated and use formula and mathematical equations in addition to verbal description. Descriptive laws lend themselves to formalized instruction.

At the highest level are technological theories which systematically relate a number of laws or provide a coherent explanatory framework. Technological theories are applications of scientific knowledge to real situations. One characteristic of modern technology is that greater use is made of theoretical knowledge, and in this sense technology approximates a "discipline." However, to say that theory is becoming an increasing part of technological knowledge does not lessen the importance of prescriptive and tacit knowledge generated through practical experience (Willoughby, 1990), or change the fact that the contextual meaning of technological theories derives from application (Perrin, 1990).

There is an inexact, then, but nevertheless real correlation between the complexity of technological knowledge, eventual work levels and formalized instruction. Craft and artisan activities make considerable use of tacit know-how associated with manual or process skills that can be best learned on the job. At a highest level are descriptive laws and technological theories embedded in job activity. Engineers and technicians work at this level and receive most of their training through formal instruction. In between are technical jobs which make heavy use of descriptive and prescriptive knowledge learned both on and off the job. But all jobs use tacit knowledge.

Instructional Implications

Technological knowledge may have the appearance of a formal discipline, but it is a qualified form of knowledge. There is not a clearly generalizable, representative structure characterizing all of technology, as one finds in physics, biology or economics. Technological knowledge acquires form and purpose in specific human activity; the character of technological knowledge is defined by its use; and efficiency, rather than understanding is its objective (Layton, 1974; McGinn, 1978; 1989; Parayil, 1991; Perrin, 1990; Skolimowski, 1972). Those who conceive of technology as a discipline confuse technique in the French sense of the term, with the knowledge of a formal discipline. Although technique embodies knowledge, it is a particular form of knowledge applied to a discrete technological activity in contrast to the general abstractions which characterize formal knowledge.

Technology draws from formal knowledge, such as that found in the sciences and math, but it does so selectively and in response to specific applications. It is interdisciplinary in its use of formal knowledge. Technology also includes its own abstract concepts, theories, rules, and maxims but again, these are grounded in application, or praxis. A considerable proportion of technological knowledge is prescriptive and tacit, and difficult to codify and generalize. The form as well as the complexity of technological knowledge is related to the kind and level of technological activity. Isolated from activity and removed from the implementing context, much of technological knowledge loses its meaning and identity.

Knowledge as discipline

The prevailing tendency among some technology educators to conceive of technology as a discipline is understandable. There are enormous public pressures for the school to become more academic and more rigorous. School reform has been promoted by social conservatives as an essential step in making the country more productive and competitive (Giroux, 1988). "Soft" subjects, such as art, music, technology education and health have been de-emphasized in favor of renewed emphasis on language, science and math. Proponents of "back to basics" have called for the teaching of explicit academic skills, student assessment and national measures of performance as a way to strengthen instruction (Newman, 1994). By couching technology in terms of a discipline, the expectation is that technology education will have greater appeal to the educational public, and that the subject can distance itself from its historical applicative roots. In other words, technology education too can emphasize the acquisition of knowledge and the development of intellectual skills.

Historically and currently, disciplines are treated in the curriculum as separate subjects and emphasis is on the ideational. To conceive of technology primarily as a discipline, however, is not only erroneous but limiting for curriculum development purposes. Important epistemological distinctions are ignored which are at the heart of understanding technological knowledge and its instructional use. Technology education can make a distinctive educational contribution even though it is not conceived of as a discipline.

Technology as instruction
The primary distinguishing characteristic of technological knowledge is that it derives from, and finds meaning, in activity. Accordingly, there is a number of implications for curriculum development. First, technological knowledge is most clearly specified when it is linked to specific activity, such as testing the strength of material, calculating environmental damage, programming a computer, tuning a violin, or plucking poultry. The technological activity conditions the use of knowledge. It is through activity that both the structure and substance of technological knowledge can be identified, and hence, generalized to instruction. Moreover, since much of technological knowledge is difficult to codify, an abstract treatment is incomplete without the accompanying activity.

Technology makes extensive use of formal, abstract knowledge, mainly from the sciences and mathematics, but this knowledge does not constitute a discipline because it is primarily a manifestation of the selective use of disciplines. Formal knowledge used in the technological sense lacks a coherent, independent and generalizable conceptual framework, since it is the technological activity itself that is integrative and provides the intellectual structure. For this reason, formal knowledge should not be conceived as a body of content to be mastered, but as a correlative to activity. Technological activity conveys to the learner the distinct ways that formal knowledge is used.

Technological knowledge, then, is more than a compendium of information to be transferred to the student; it is more than various facts, laws, theories, concepts and general information proffered to students. Technical knowledge is dynamic, and meaning is constructed and reconstructed as individuals grapple with the use of knowledge, whether it be conceptual, analytical or manipulative. Generalizations, theories, principles, technical maxims and procedures take on meaning as they are applied to practical applications. Activity helps make explicit to the learner how knowledge is generated, communicated and used to analyze and solve technological problems. Then again, knowledge becomes intelligible through activity as it is categorized, classified and given form; through technological activity students are helped to perceive, understand, and assign meaning. Effective instruction, in other words, includes the distinct ways through which technological knowledge is generated, used, assigned meaning, and reconstructed.

The intellectual processes which are employed are themselves a meaningful focus of instruction (California Department of Education, 1990). Processes are the integrative concepts that unite activity and knowledge. Technological knowledge is created, used, and communicated through such processes as observing, formulating, comparing, ordering, categorizing, relating, inferring, applying, correcting, and diagnosing. Technology, then, is not only content to be learned but the vehicle though which the intellectual processes embedded in technological activity can themselves be learned.

All three kinds of technological knowledge are important for instructional purposes. There is probably a general tendency to underestimate the extent and importance of the tacit dimensions of technological knowledge. But beyond the more easily codified descriptive and prescriptive forms of knowledge that inform technological activity, there is a wide array of subjective and tacit forms which are not as readily communicable, but which, nevertheless, substantially influence how technological activity is carried out.

For curriculum development purposes, it is difficult to generalize from technological knowledge because of its contiguous link with a specific kind and level of activity. If technological knowledge is broadly defined, it loses much of its usefulness. When generic terms like "technological literacy" or "technological method," for example, are not associated directly with specific activity they become operationally meaningless for developing curricula. They mean very little outside of the context in which they are applied, and there are few conceptual guidelines for selecting content (Taba, 1962).

Finally, technology education has not capitalized on what is probably its most important potential educational value, namely, its interdisciplinary character. Technology draws content from across different fields of inquiry. It provides a way to integrate learning, not only with other fields, but with purposeful activity. And knowledge is applied at the prescriptive, descriptive as well as tacit levels. Learning is truly integrative. Few other subject fields have the capability to integrate as fully interrelated fields of knowledge, based on the ordered activities of these fields as they are applied to the acquisition, use and reconstruction of technological knowledge and technique.

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