https://doi.org/10.21061/jte.v3i1.a.2

Another Look at Technology and Science

Rodney E. Frey

"Science and technology" is a phrase that rolls off the tongue with easy familiarity. This linkage is so commonplace that science and technology are often assumed to share a common methodology, common symbol systems (language and mathematics), and a common community of practitioners. Despite these perceived commonalities, science is generally assumed to precede technology.

This misconception about the nature of science and technology and about the relationship between them can be misleading at best and fatal at worst for technology education. As educators advocate, promote, and implement technology education in the public schools, they may find that the new curriculum is equated with science or competes with science programs. In either case the distinctive character of technology is misunderstood. Over two decades ago DeVore (1968, 1970) argued the same point and urged industrial arts teachers to study technology. Now, even more, teachers of technology education need a clear understanding of similarities and differences between science and technology.

In ordinary conversation, the term science seems to be used in three distinct ways: "(1) science as a human and social enterprise, (2) science as the body of well-established laws and theories, and (3) science in its applications" (Borgmann, 1984, p. 17). The first view encompasses the community of science practitioners and the activity or particular approach used by the community. The second view is concerned with the cognitive content and structure of science. The third view often equates applied science with technology.

Technology can be viewed as a corollary to science in all three senses if some latitude in fit is allowed. First, technology is a problem-solving activity practiced by a community of professionals. Second, there is a well-defined body of technological knowledge. And, finally, the world is replete with technological devices, procedures, and systems.

There is a fourth sense in which the terms technology and science are used. Both can be regarded in the abstract as mental categories or constructs which incorporate the other three senses. Taken to the extreme, technology and science are then seen as disembodied forces which exist independent of the

---

Rodney E. Frey is Associate Professor and Head, Industrial Arts Education, Bethel College, North Newton, KS.

https://doi.org/10.21061/jte.v3i1.a.2

natural, material, or social world. Discussions about technology and science often fail to distinguish clearly how the terms are being used. In this paper, attention will focus on the first three uses of the terms: practitioners, knowledge, artifacts.

The fundamental position taken in this paper is that technology is a human activity involved with the making and using of material artifacts. As a human activity, technology is situated on the same level as art, politics, science, economics, and the like, and not subsumed under any other category.

The purpose of this paper is to draw attention to subtle distinctions between technology and science. Specifically, three topics will be addressed: distinctive approaches to the natural world, distinctive aims and purposes, and distinctive knowledge structures and content. (See Borgmann, 1984, chs. 5, 6, and 12 for distinctions between technology and science based on "explanation.")

Approaches to the Natural World

Both technology and natural science assume the existence of an objective, physical reality which is independent of one's perception of it. Bunge (1979) lists these assumptions as "(1) the world is composed of things; (2) things get together in systems; (3) all things, all facts, all processes, whether in nature or in society, fit into objective stable patterns (laws); [and that] (4) nothing comes out of nothing and nothing goes over into nothingness" (pg. 270). Technologists and scientists often act and talk as though this external world can be "known" and that the laws and principles described by symbols and equations do, in fact, correspond with objective physical reality. This view of nature is a variety of realism and although not all natural scientists hold this view, it likely predominates (Wartofsky, 1968; Casti, 1989).

In spite of agreement on fundamental presuppositions about the existence of the natural world, technologists and scientists act differently upon these assumptions. For the natural scientist, nature is the object of research. Scientists are interested in discovering all they can about natural phenomena, whether directly available to human experience or through active intervention (atom splitting) in natural processes. Through systematic investigation and experimentation the natural world can be discovered and universal laws stated which explain how the natural world functions. The natural world is a "thing in itself," worthy of study, research, and experimentation to uncover fundamental laws, patterns, and structures. Because the scientist is interested in nature for what it is, all nature is open for investigation and all nature is equally valued from the smallest particle of matter to the vast universe (Bunge, 1979; Rapp, 1974).

An example from Newtonian physics may be helpful. To the physicist friction is a force which is always opposed to the direction of motion. Kinetic frictional force, empirically determined for any two types of surfaces which are dry and not lubricated, is equivalent to the coefficient of friction times the normal force acting on the body in motion. The coefficient of friction is a

https://doi.org/10.21061/jte.v3i1.a.2

constant characteristic for the materials involved and determined experimentally. As an empirical law the mathematical equation adequately describes the relationship between frictional force and normal force. Although this law does not rest on any deeper theoretical understanding of the mechanisms which cause friction, it is satisfying because it describes a portion of the physical world.

The technologist, on the other hand, approaches nature in a fundamentally different way. Nature as a "thing for us" is not neutral because value is attached to it depending on the circumstances of use. This is true for physical laws and natural resources. In engine design frictional force is considered undesirable and efforts are made to reduce its effects. On the other hand braking systems are designed to utilize the effects of friction. In both cases the physical phenomenon, friction, is valued differently because of the circumstance.

"Because of his pragmatic attitudes," Bunge (1979) suggests, "the technologist will tend to disregard any sector of nature that is not or does not promise to become a resource" (p. 268). Thus, all nature is not equally valued. In fact, it is quite common for the technologist to ignore or overlook any material or phenomena not immediately useful. At a later date, because of changing societal values, political, economic, or social conditions, the ignored or discarded resource may become highly prized. Before the development of atomic energy, uranium ore was a nuisance. After technological breakthroughs in nuclear reactor design and construction made nuclear energy an economically feasible reality, uranium ore became valuable. The same can be said about solar energy. As political alliances in the Middle East shift, threatening oil supplies, interest in and commitment to the technologies of solar and wind energy also shift.

If scientists were limited to an objective reality accessible directly through the five senses, little scientific progress would be possible. At some point, scientists penetrate the surface reality to directly intervene in natural processes and natural structure. For instance, particle accelerators and supercolliders are built to break apart matter to investigate the fundamental building blocks of nature.

Technologists, too, directly intervene and alter nature. The intervention is not at the level of fundamental physical phenomena through controlled, systematic experimentation, driven by mathematical theory. More likely, nature will be altered at the macroscopic level. For instance, metals are refined from ores to produce pure elements not occurring naturally. These metallic elements are then combined in controlled quantities to yield other metals (alloys) with new properties. In this sense the physical world (space, raw materials, fossil energy) is altered and transformed with the intent of appropriating nature for human purposes (Rapp, 1981, pp. 152-153). In short, "whereas science elicits changes in order to know, technology knows in order to elicit changes" (Bunge, 1979, p. 264).

Aims of Technology and Science

https://doi.org/10.21061/jte.v3i1.a.2

Early in his book Borgmann (1984) introduces an engaging phrase: "taking up with the world" (p. 3). People take up with the socially constructed world through politics, economics, and social institutions. They also take up with the natural and material world through technology and science. In both cases the human activity is open, dynamic, patterned, and purposeful.

There is not a clear consensus about the ultimate aim or purpose of natural science. The situation becomes muddled when the notion of motivation of the scientist gets mixed in with aims and purposes of science as an activity. A commonly formulated statement of motivation suggests that scientists pursue scientific activity out of intellectual curiosity and inquisitiveness about the natural world. The more pristine formulation can be found in Campbell (1953) where he insists on science as a form of pure intellectual study which aims "to satisfy the needs of the mind and not those of the body [and] appeals to nothing but the disinterested curiosity of mankind" (p. 1). This view of science, and scientists, is unsullied by concerns of the daily world or by base motives such as recognition, power, money, and prestige. Thoughtful and reflective scientists would reject Campbell's view of motivation, especially when they consider the social/cultural context within which science is practiced. They might, however, retain curiosity as a stimulant to scientific activity.

Even though the motivation of the scientist is understood, the ultimate end, purpose, or aim of science remains obscure. What is the result of scientific activity? If the answer to this question is approached by recalling the discussion above of the scientists' view of nature, the subsequent discussion will carry more meaning.

The more common contemporary answer about the aim of science involves a complex interweaving of relationships involving laws, theory, explanation, and understanding. Suppose it is noted that certain phenomena are related in such a way as to form a stable, regular pattern. This pattern is called physical law. For example, as a piston moves within a closed-end cylinder, a relationship between volume and pressure is observed. This observation can be communicated by stating that as the volume decreases the pressure increases and as volume increases pressure decreases. A more concise formulation states that pressure (P) is inversely proportional to volume (V). In the interest of simplicity, this can be reduced to the mathematical equation $PV=k$ where k is a constant. This pressure-volume relationship, known as Boyle's Law, is an example of an empirical law because it is a descriptive summary of empirical observations (Casti, 1989, pp. 22-23). Empirical laws describe the regularities of natural phenomena, and may predict an outcome given appropriate conditions, but they do not explain why something happens. For this theory is needed which explains the uniformities expressed as empirical law (Hemple, 1966, p. 70).

In the example above, the empirical law of gases (Boyle's Law) does not provide explanation of the physical phenomena in the scientific sense. For explanation deeper theory based on Newtonian mechanics is needed, specifically $f = ma$, which does not use concepts of pressure and volume. Instead,

https://doi.org/10.21061/jte.v3i1.a.2

particle motion, mass, and velocity can be used to derive the formal mathematical relationship.

Scientists and philosophers of science have articulated various aims for science. Some emphasize explanation and understanding which is consistent with the view of science as a body of knowledge; of well-established laws and theories. For instance, Feibleman (1972) argues that "pure science has as its aim the understanding of nature; it seeks explanation" (p. 33). In a sense, this could be characterized as a *realistic* view because it assumes a correspondence with an objective reality "out there" (Casti, 1989, p. 24).

A different perspective holds that science aims at producing theories which have the ability to predict data accurately. Theories are not judged to be true or false, nor are they claimed to be an explanation of reality "out there." Instead, theories are instruments or heuristic devices for looking at phenomena, for testing the congruence between data and hypothesis, and are open to change as new data are available through experiment and observation (Suppe, 1974, pp, 29-30, 127-135; Casti, 1989, p. 25; Borgmann, 1984, pp. 18-19).

A third perspective of science emerges as an extension of the view of science as an organized, systematic body of knowledge. In this view the aim, or issue, of science is Truth because the knowledge we have about the natural world describes a reality presumed to be true whether anyone knows it or not. This scientific truth is objective, cumulative, independent of the lives of scientists, and timeless (Wartofsky, 1968, p. 23).

In contrast to the views above (explanatory, instrumental, truth) are the ideas of Thomas Kuhn. Kuhn (1970, p. 24) states that "no part of the aim of normal science is to call forth new sorts of phenomena; indeed those that do not fit the box are often not seen at all. Nor do scientists normally aim to invent new theories, and they are often intolerant of those invented by others."

In a Kuhnian framework there are two kinds of science; "normal" science and "revolutionary" science. It is normal science which occupies the daily work of most scientists. In Kuhn's view the aim of "normal" science is to solve the puzzles and problems inherent in already established phenomena and theories. The ebb and flow of normal and revolutionary science suggest that scientific knowledge is discontinuous, subject to the interpretation of the community, and time-bound: a view clearly at odds with those expressed above. Against this background the aims of technology can be considered.

Technology serves a practical end which the common bromide describes as "meeting human need." But the picture is not that clear, nor the conception that simple. Indeed, there appears in the literature numerous, often conflicting, accounts of the aim of technology. In broad outline the views can be grouped into two categories: the material technology of concrete objects and processes and the nonmaterial technology of efficient action. The narrower view of the former is probably closest to a common sense notion of technology. The latter view is broader, less common, and a more abstract formulation of the aim of

https://doi.org/10.21061/jte.v3i1.a.2

technology. Some instances from the literature are helpful in clarifying these views.

The restricted view sees technology as aiming toward realizing concrete material objects. The natural world provides material resources which serve as one input into a transforming process which ultimately issues in an artifact (Rapp, 1981, p. 44). Devices and processes are applied and utilized within technological systems which are, in turn, embedded within larger social and economic systems. The purpose of these devices, processes, and systems is to relieve humans from physical work, to increase the capacity of human sensory organs, and to provide increased efficiency (pp. 47-49).

This view lies close to the heart of technology education. "Meeting human need" is the way it is often put. But does "meeting human need" account for the diversity of technological artifacts? Basalla (1988) does not think so. He states that "if technology exists primarily to supply humanity with its most basic needs, then we must determine precisely what those needs are and how complex a technology is required to meet them. Any complexity that goes beyond the strict fulfillment of needs could be judged superfluous and must be explained on grounds other than necessity" (p. 6). He continues the argument by noting that "we cultivate technology to meet our perceived needs, not a set of universal ones legislated by nature" (p. 14). Diversity of technological artifacts can be explained more adequately through consideration of human aspiration and as the "product of human minds replete with fantasies, longings, wants, and desires" (p. 14).

A distinctly different view of the aim of technology shifts the focus of the activity toward a nonmaterial character of technology. Although two positions can be identified, (1) efficient action, and (2) social/organizational, they are not entirely discrete and independent views.

In the first position, artifacts, devices, and processes are acknowledged to be the result of technological activity. More important, however, is the internal dynamic which drives the quest for new and better objects of the same kind. For example, better, in this context, means increased durability, reliability, speed, and sensitivity, and produced at less expense and within a shorter period of time. This internal dynamic to produce better objects is best expressed as the pursuit of effectiveness. Effectiveness is analyzed through a theory of efficient action. The aim of technology is effectiveness (efficient action) (Skolimowski, 1966, pp. 372-377).

In the second approach the idea of efficiency is extended explicitly into the social/organizational/methodological arena. This view is congenial to other aims of technology which have to do with artifacts, procedures, systems, and efficient action. It simply holds that these do not go far enough. This is made clear by Bunge, (1979): "We take technology to be that field of research and action that aims at the control or transformation of reality whether natural or social" (pp. 263-264). Elaborating on this idea he tentatively outlines the branches of technology as follows: (a) material technology to include physical, chemical, biochemical, and biological; (2) social technology to include psy-

https://doi.org/10.21061/jte.v3i1.a.2

chological, psychosociological, sociological, economic, and warfare; (3) conceptual technology to include computer science; and (4) general technology, including automata theory, information theory, linear systems theory, control theory, and optimization theory (p. 264). Especially revealing is the caption under a flow diagram depicting the technological process. The caption reads: "The end product of a technological process need not be an industrial good or a service; it may be a rationally organized institution, a mass of docile consumers or material or ideological goods, a throng of grateful, if fleeced, patients or a war cemetery" (p. 265).

In spirit, but not detail, Richter (1982) agrees with Bunge. Technology is seen as a human phenomenon encompassing "tools and practices deliberately employed as natural (rather than supernatural) means for attaining clearly identifiable ends" (p. 8). Richter extends the idea of "means" to include *organizational* patterns to realize social ends or societal goals and *symbol* systems as technologies designed to realize communication, persuasion, and computation. This is obviously the broadest interpretation of the aims of technology so far. It may be so broad that it weakens as a useful concept to distinguish technology from other forms of human activity.

Knowledge Structure and Content

An obvious concern when considering the relationship between technology and science is the location of the claim for knowledge. Conventional thinking often situates technological knowledge within the same knowledge base as science or in a position subsidiary to scientific knowledge. This thinking can lead to the view that there is no distinct cognitive content for technology or that science generates new knowledge which technology then applies as is evident in the phrase "technology is applied science."

Recent scholarship in technology rejects this view and claims that technology is a cognitive system; that technology is knowledge (Layton, 1974). On a superficial level, the question about structure can be approached by answering the question: "Where can I find knowledge about X?" Our reason for wanting knowledge about X, say an air conditioner, may be to repair, or to design, or to use one. For each of these three cases the technological knowledge is different (some overlap will exist), structured and presented in patterns most usable for the purpose, and available in textbooks, manufacturer's literature, reference manuals, and technical documentation. Nevertheless, the technological knowledge is organized, coherent, intelligible, and different from scientific knowledge. This is knowledge organized around devices, processes, and systems.

At a more abstract level technological knowledge can be structured by the patterns of thinking inherent in the individual branches of technology (Skolimowski, 1966), or by the problems put to the technologist (Jarvie, 1966), or by the methodology used in problem solution (Vincenti, 1979). Skolimowski illustrates specific structures of thinking within branches of technology by

https://doi.org/10.21061/jte.v3i1.a.2

suggesting *accuracy of measurement* for surveying, *durability* for civil engineering, and *efficiency* for mechanical engineering (pp. 376-381).

The idea above is extended by Jarvie (1966) to include “the overriding aim that is to govern the solution” (p. 387). He suggests that speed, appearance, low unit cost, social cost, worker and customer satisfaction could be aims which structure the problem solution, the thinking patterns, and consequently the knowledge structure.

Parallel to this view is a conclusion drawn by Vincenti (1979) resulting from a case study of technological methodology. He concluded that the method [parametric variation] used to supply data for designing airplane propellers structured the thinking patterns and, consequently, the form of that technological knowledge (p. 743). It appears that the problem put to the technologist and the distinctive method of solution contribute to patterns of thinking and to unique technological knowledge.

A fourth approach places technological knowledge within a community of practitioners; a sociological approach. Fundamental to the structure of technological knowledge is the practice of a technological community because “technological knowledge comprises traditions of practice which are properties of communities of technological practitioners” (Constant, 1980, p. 8). In his study of change in technological knowledge, two broad communities within the aircraft industry were considered--those concerned with propeller-driven aircraft and the emergence of a community formed around turbojet aircraft. As justification for this approach, Constant (1984) states that “the issue is what practitioners do, which to me is a promising and fruitful path into what they know and how it changes” (p. 28). Constant provided evidence of the unique structure and content of specific technological knowledge within each community. This should not surprise industrial educators, who, for decades, have pursued a similar practice. Knowledge unique to crafts and trades was defined and structured by observing the practicing communities.

Four general comments about technological knowledge will help to understand the unique character of its content. First, technological knowledge is formulated in levels of discursive and symbolic complexity (Carpenter, 1974). At the lowest level is tacit knowledge which resists all attempts at verbalization. Such knowledge develops during deep and sustained experience. For example, the novice welder observing an expert welder might wonder how the expert knows when aluminum is about to collapse as he TIG welds. When asked, the expert might reply, “I just know.” Tacit knowledge is not unique to technology. It is part of every cognitive system. At the highest level, technological knowledge which is obtained analytically, is often expressed symbolically in mathematical form. Chvorinov's Rule is a simple example from metal casting. Expressed mathematically, $t = B\,(V/A)^n$, where $n = 1.5$ to 2.0. “The total solidification time [t] is the time from pouring to the completion of solidification; V is the volume of the casting; A is the surface area; and B is the mold constant...” (DeGarmo, 1988, p. 312).

https://doi.org/10.21061/jte.v3i1.a.2

The extremes in levels of technological knowledge have been chosen to make a point. At the worst, in the popular conception of technology, tacit knowledge is assumed to be the sum and substance of the cognitive content, and is often expressed as “technology is know-how.” At the best, in the popular conception, abstract, mathematical formulations of technological knowledge have the appearance of being “scientific.” This leads to the formulation of “technology is applied science.” Both views do an injustice to the richness, complexity, source, and distinctiveness of technical knowledge.

Claims made about the content of technological knowledge must be situated in relation to the content of scientific knowledge. Two case studies by Vincenti (1982, 1984) illustrate such an effort. On the one hand, Vincenti (1984) documents the development and refinement of technological knowledge which owes no debt to science. In this case study, the knowledge of flush riveting (details of rivet size, shape, head angle, tolerance, material, riveting tools and technique, skin thickness, countersink procedures) was developed using systematic, analytic, and rational procedures and “no enabling scientific discovery was necessary” (p. 569). On the other hand, Vincenti (1982) selected a problem from thermodynamics (control-volume) which provided wide regions of overlap between engineering and physics. He documented how the different communities of practitioners regarded and used the concept of control-volume--“engineers have developed control-volume analysis and use it, physicists have not and do not ... the difference arises out of a difference in purpose” (p. 172). Knowledge generated by engineers working with control-volume is different from science “in both style and substance” (p. 173).

Another approach can be taken by acknowledging the necessity of scientific knowledge but recognizing its insufficiency. In this view scientific knowledge must be made useful by transforming it, restructuring it, and appropriating it according to the specific demands of a design problem (Aitken, 1985; Staudenmaier, 1985).

To an important degree the content of technological knowledge is determined by praxis rather than theory. A simple example is provided by fluid flow. In classical fluid mechanics flow problems are described by mathematical equations and Newton's law of constant viscosity. However, printer's ink, paint, grease, and coal slurries do not have constant viscosities, i.e., they are non-Newtonian fluids thus falling outside the classical framework. Modifications to the classical mathematical equations were made based on extensive testing which revealed complex behaviors and additional variables. Knowledge of these additional conditions resulted directly from praxis. This was also evident in the previous examples of flush riveting and metal solidification.

It may seem necessary to establish priority, historical or conceptual, between praxis and theory as a way to distinguish between technology and science, but it is not. In the development of technological knowledge they reciprocate as though in dialogue with one another (Caws, 1979, pp. 229-231).

https://doi.org/10.21061/jte.v3i1.a.2

Concluding Comments

Differing perspectives on technology can be identified by examining the claims made for the aims, goals, or purposes of technology. One view holds that the goal of technology is to produce things, products, processes, systems, installations, i.e., some concrete manifestation of purposeful, structured praxis (Caws, 1979, p. 235) designed to deliberately alter the natural world. A second perspective affirms a broader conception of technology which encompasses managerial and social supporting systems. The aim, it seems is toward optimization, at the technical and the organizational level. Consequently, included in, or at least in principle not limited by, this concept of technology could be the theory and practice of bureaucratic coordination, advertising strategies, management, teaching and training, and economic decision making (Brooks, 1980; Sigaut, 1985).

The author accepts the first of these perspectives. When technology is understood in the second sense, "the concept staggers under the interpretive load it has to carry" (Laudan, 1984, p. 5). Too much is subsumed within the framework of technology. For the broader concept of technology to have meaning, the characteristic and distinctive features of technology would have to be articulated in relation to science, economics, politics, business, and the like. And this is no easy task because difficult questions must be addressed: questions about knowledge (epistemology), values (axiology), ethics, practice (praxis), and the nature of each activity (metaphysics). For our purposes, the problem is delimited by following Mitcham's (1978) suggestion that technology refers to "the human making and using of material artifacts in all forms and aspects" (p. 232).

When thought of in that frame of reference, the nearest neighbor to technology becomes natural science and claims for technology must be situated in relation to natural science. Although technology and science have been discussed as independent, parallel cognitive systems with "hard edges," the literature, especially in the history and sociology of technology, suggests otherwise. Instead, technology and science are viewed as systems with "soft edges" which allow interaction and interpenetration. This does not deny the influence of the broader social/cultural environment; it simply states that technology has features more in common with natural science than with other forms of human endeavor.

What implications does this have for technology education? First, the profession is moving closer to a theory of technology which will guide program rationale, curriculum development, textbook content, and laboratory activities. One aspect of this theory is the relationship between technology and science as expressed in distinctive approaches to the natural world, distinctive aims and purposes, and distinctive cognitive systems.

Second, a theory of technology will articulate presuppositions about the ultimate aim of technology. A technology education curriculum could be developed around the view that technology aims toward realizing technical solutions manifest in artifacts, processes, and systems. Or, rational effective action

https://doi.org/10.21061/jte.v3i1.a.2

and optimization could be the focus of the curriculum. These curriculums will differ radically from each other in content and activities.

Finally, technological knowledge has profound linkages with praxis in the generation of new knowledge as practical problems are solved, in the development of technological rules and laws, and in the formation of theoretical models which rationalize practical experience. This unique characteristic can be emphasized through laboratory activities which permit students to design, fabricate, and test technological artifacts and simple systems within specified criteria. These activities allow the teacher to show regions of overlap between scientific and technological knowledge and how the two interact and interpenetrate. They also permit the student to generate technological knowledge which can be organized, codified, and communicated.

References

Aitken, H. G. J. (1985). *The continuous wave: Technology and American radio, 1900-1932*. Princeton, NJ: Princeton University Press.

Basalla, G. (1988). *The evolution of technology*. New York: Cambridge University Press.

Borgmann, A. (1984). *Technology and the character of contemporary life*. Chicago, IL: The University of Chicago Press.

Brooks, H. (1980). Technology, evolution, and purpose. *Daedalus, 109*(1), 65-81.

Bunge, M. (1979). Philosophical inputs and outputs of technology. In G. Bugliarello & D. B. Doner (Eds.), *The history and philosophy of technology* (pp. 262-281). Urbana, IL: University of Illinois Press.

Campbell, N. (1953). *What is science?* New York: Dover Publications.

Carpenter, S. (1974). Modes of knowing and technological action. *Philosophy Today*, *18*(2), 162-168.

Casti, J. L. (1989). *Paradigms lost: Images of man in the mirror*. New York: William Morrow.

Caws, P. (1979). Praxis and techne. In G. Bugliarello & D. B. Doner (Eds.), *The history and philosophy of technology* (pp. 227-237). Urbana, IL: University of Illinois Press.

Constant, E. W. II. (1980). *The origins of the turbojet revolution*. Baltimore: Johns Hopkins University Press.

Constant, E. W. II. (1984) Communities and hierarchies: Structure in the practice of science and technology. In R. Laudan (Ed.), *The nature of technological knowledge. Are models of scientific change relevant?* (pp. 27-46). Boston: D. Reidel.

DeGarmo, E. P., Black, J. T., & Kohser, R. A. (1988). *Materials and processes in manufacturing*. New York: Macmillan.

DeVore, P. W. (1968). Toward unity and diversity in industrial arts teacher education. *Journal of Industrial Teacher Education*, *5*(4), 13-26.

DeVore, P. W. (1970). Discipline structures and processes: A research design for the identification of content and method. *Journal of Industrial Teacher Education*, *7*(2), 21-31.

Feibleman, J. K. (1972). Pure science, applied science and technology: An attempt at definitions. In C. Mitcham & R. Mackey (Eds.), *Philosophy and technology* (pp. 33-41). New York: Free Press.
Hempel, C. G. (1966). *Philosophy of natural science*. Englewood Cliffs, NJ: Prentice-Hall.
Jarvie, I. C. (1966). The social character of technological problems. *Technology and Culture*, *7*(3), 384-390.
Kuhn, T. S. (1970). *The structure of scientific revolutions* (2nd ed. enlarged). Chicago, IL: The University of Chicago Press.
Laudan, R. (1984). Cognitive change in technology. In R. Laudan (Ed.), *The nature of technological knowledge* (pp. 83-104). Boston: D. Reidel.
Layton, E. T. (1974). Technology as knowledge. *Technology and Culture*, *19*(1), 31-41.
Mitcham, C. (1978). Types of technology. In P. T. Durbin (Ed.), *Research in philosophy and technology*, *1*, (pp. 229-294). Greenwich, CT: JAI Press.
Rapp, F. (1974). Technology and natural science-A methodological investigation. In F. Rapp (Ed.), *Contributions to a philosophy of technology* (pp. 93-114). Boston: D. Reidel.
Rapp, F. (1981). *Analytic philosophy of technology* (S. Carpenter and T. Langenbruch, Trans.). Boston: D. Reidel. (N. D. for original work)
Richter, M. N., Jr. (1982). *Technology and social complexity*. Albany, NY: State University of New York Press.
Sigaut, F. (1985). More (and enough) on technology! *History and Technology* *2*, 115-132.
Skolimowski, H. (1966). The structure of thinking in technology. *Technology and Culture*, *7*(3), 371-383.
Staudenmaier, J. M. SJ. (1985). *Technology's storytellers*. Cambridge, MA: MIT Press.
Suppe, F. (1974). *The structure of scientific theories*. Urbana, IL: University of Illinois Press.
Vincenti, W. G. (1979). The air-propeller tests of W. F. Durand and E. P. Lesley: A case study in technological methodology. *Technology and Culture*, *20*(4), 712-751.
Vincenti, W. G. (1982). Control-volume analysis: A difference in thinking between engineering and physics. *Technology and Culture*, *23*(2), 145-174.
Vincenti, W. G. (1984). Technological knowledge without science: The innovation of flush riveting in American airplanes, ca. 1930- ca. 1950. *Technology and Culture*, *25*(3), 540-576.
Wartofsky, M. W. (1968). *Conceptual foundations of scientific thought*. New York: Macmillan.