Strategic Technology Institute

The Structure of Paradigm Change in Science and Technology

By Blake L. White

The Essence of Science and Technology

Our management consulting practice deals extensively with technology as it relates to business problems and opportunities. But just what do we mean by technology, or for that matter, science? Numerous definitions and descriptions of these words have been written, none of which have been able to succinctly encompass all of the characteristics of these terms. The "man in the street," according to J.B. Conant, considers science to be the activity of people who work in laboratories and whose discoveries have made possible modern industry and medicine. [28] This statement, although it may appear to be true to many laypersons, is quite shallow as a meaningful description of what science is. For example, many people who clearly qualify as scientists do not have any association with laboratories and their discoveries do not have any direct applicability in either modern industry or medicine. As important as contributions to these areas have been, this concept illustrates the need to develop working definitions with significant key words so we may clarify just what concepts science and technology employ.

Science is the body of knowledge obtained by methods of observation. It is derived from the Latin word scientia, which simply means knowledge, and the German word wisenschaft, which means systematic, organized knowledge. Thus, science, to the extent that it is equivalent to wisenschaft, consists not of isolated bits of knowledge, but only of that knowledge which has been systematically assembled and put together in some sort of organized manner. [29] In particular, the science with which we are concerned is a body of knowledge that derives its facts from observations, connects these facts with theories and then tests or modifies these theories as they succeed or fail in predicting or explaining new observations. In this sense, science has a relatively recent history --perhaps four centuries. [30]

Although, science as an activity has existed as long as humans have existed, the modern Western notion of science began with the European awakening during the High Middle Ages, the Renaissance, and the Industrial Revolution. Therefore we should clearly recognize that science, as America understands it, is a European concept that describes the process used to gather data about nature, use that data to draw general conclusions, and test the conclusions under critical observation. Make no mistake as to the thrust here --the process is important in the European concept of science. This should not block our interest in broadening that concept to include definitions from other cultures, personal definitions, or that of the ancients. However, we must recognize that the critical difference between the modern view of science and the ancient view rests on the methods employed and the ultimate aims for using scientific

*Excerpt from **The Technology Assessment Process: A Strategic Framework for Managing Technical Innovation**, Quorum Books, a Division of Greenwood Press, 1987. Also excerpted from an earlier works by Blake White © 1983, Library of Congress Registration TXU 139-650 and TXU 131-062.*

knowledge. More will be said about the alternative views of science shortly; for now, let us develop an understanding of the term technology.

Much of the relevance of science to mankind and to society arises by way of technology. There are intimate relationships between science and technology; yet science is not technology and technology is not science. The origin of the word technology gives valuable insight into its meaning. It is derived from the Greek words, techne and logos. The former meaning art or craft and the latter signifying discourse or organized words. The practice of technology frequently is that of an art or craft, as distinguished from science, which is precise and is based upon established theoretical considerations. Even though we do not normally think of technology as consisting of written or spoken words, as implied by logos, it does involve the systematic organization of processes, techniques and goals. Technology is applied, but not necessarily based upon science. In fact, as California State University's Robert Fischer notes, "to define technology as applied science is to miss much of the significance of the relationship that exists between science and technology."[31] He defines technology as the totality of the means employed by peoples to provide material objects for human sustenance and comfort.

One connotation of the working definition of technology is that it is a human activity. It is people who use the products of technology. Furthermore, it is people whose livelihood and comfort is the goal of technology, whether this goal is actually accomplished by technology or not.

According to Fischer, technology is directed in specific instances toward specific material objects, that is, toward the production of physical objects. This is not to exclude the importance of non-material concepts to human sustenance and comfort, but it is meant to drive home the central theme that technology is driven by physical needs. By definition, technology is not neutral because it is directed toward satisfying a physical need, as determined by a human value system. Technology is power and one who controls technology controls the power inherent in its application. Technology is defined, to some degree, by our relationship with the environment. It involves our attempt to control and shape the world and to make use of whatever resources are available in that environment. [32] The basic Western motive for "bringing about technology" is the desire to obtain more or better material things. There are of course more immediate and less profound motivations for individuals in either science or technology (such as the desire to get a paycheck and retain one's job), as Fischer notes. Other points of comparison involve grander motives such as the ancient beliefs of using technology to devote monuments to gods, heroes or esthetics. The concept of technology as "more and better material things" is a Western concept born out of the flowering of knowledge and materialism that was the European Renaissance.

Technology has a much longer history than science --a history as long as humanity. We have evolved together with our tools and techniques over millions of years. The major changes in human population are due to the technology we have developed to domesticate grain, irrigate land, store and preserve food. We exist by the generosity of the earth, but how many of us live and how many of us starve depends on how well we use and distribute the earth's resources. During the pre-European period of the Inca, Aztec and Mayan civilizations, perhaps 15 million people lived in the Americas. Most lived in the major civilizations with cities in Mexico, Central and South America where agriculture was relatively advanced. Most human labor was used to obtain food. We now have well over half a billion people in the

Americas with less than five percent of our labor force needed to produce food. [33] Without technical developments in agriculture we could not sustain such a population growth, and in no way would we have the time or the physical energy to develop a more advanced civilization. All of our time and effort would be devoted to the maintenance of life.

Technology has developed separately from science throughout most of recorded history. Technological change has generally derived empirically, simply by trial and error. The method used in proceeding to the development of new technological advances is determined primarily on the basis of two factors: (1) the existing technology and (2) the existing scientific knowledge. This scientific knowledge used in technology is not a replacement for the trial-and-error method of technology; rather, it provides a means of selecting what trial to undertake next and thus contributes to the efficiency and effectiveness of the trial-and-error process. Technology can use scientific knowledge and, in this sense, can be sometimes viewed as applied science. Yet much technology continues to be developed with little or no basic scientific knowledge. For example, Fischer cites how photography was developed to a high degree of sophistication even without many of its early practitioners having even the most moderate understanding of the underlying chemical phenomena. [34]

Suffice it to say for our use that technology is science plus purpose. While science is the study of the nature around us and subsequent development of scientific "laws," technology is the practical application of those laws, in sometimes non-rigorous ways, toward the achievement of some purpose --usually material. [35]

Historical Perspective of the Scientific Process

As previously mentioned, our conception of science and technology has a relatively modern European flair. However, make no mistake about it, both science and technology existed with different underlying assumptions before the Renaissance, before the Roman Empire, before the Greeks conquered the "known world," and even before the great flowering of Egypt. Both concepts and their applications may be directly traced back to the "cradle of civilization." As noted by historian Chancellor Williams, ancient cultures that occupied the fertile crescent of the Nile Valley prior to Egypt's greatness was the exclusive province of Kushites, Nubians, Shebans, Mesopotamians, and Thebans, which we now refer to collectively as Ethiopians. [36] These ancient people were accomplished agriculturalists and were very religious. Indeed, religion to the Ethiopians was far more than ritual reflecting beliefs, but a reality reflected in their way of life. Religion from the earliest times became the dynamic force in the development of all the major aspects of their civilization.

Their belief in immortality was a simple matter of course and beyond the realm of debate. This belief was the great inspiration for ancient technology. The Ethiopians built, on a grand scale, structures that were meant to stand forever. Actually, it was necessity that gave birth to mathematics and astronomy. Building the Ethiopian pyramids and the most elaborate system of temples the world had known required the development of engineering. [37]

Therefore, we see that Ethiopian scientific and technical development was driven by religious beliefs. This contrasts to the modern Western view of technology, which is embedded with drivers for a more-and-better world. Both schools of thought stress the products of technology but the motivations are quite different.

Many of the ancient temples were dedicated to reflective thinking and discovery --what we might call colleges. These temple-centered colleges fostered free discourse and viewed science as purely a process of thought. Scholars from foreign lands came to study, and from here religious ideas and their architectural designs spread abroad. Since the Ethiopian Empire at that time included what we now call ancient Egypt, it was natural that these facets of the Upper Nile culture should spread to the lower Nile and the northernmost part of the continent. The early Greeks were heavily influenced by these same architectural structures, scientific methods and religious concepts, according to Williams. The Greeks eagerly copied, reshaped and made them into parts of a new Western culture. [38)

The Ionian Greeks exemplified by personages such as Thales of Miletus, Anaximander, Pythagoras, Socrates, and Plato developed many of their ideas using ancient Ethiopian and Egyptian works as their base. The Ionian Greeks had an earthy tradition that stressed the enjoyment of life, commercial property, esthetic refinement, and acceptance of newcomers --all of which allowed free thought and inquiry to flourish. From its earliest manifestations, the Greek mind had turned to natural philosophy (at least the minds of the upper classes) .The beginnings of Greek philosophical thought were identical with the beginnings of Greek science. Led by Thales of Miletus, the Greeks saw the formation of the earth by natural processes, no longer through an act of the gods. Greek science by the sheer process of speculation, argument, intuition, plus an occasional dash of empirical reasoning had moved, within the space of two generations, from the early mythical notions to a point that is surprisingly close to modern concepts. [39)

"The Ionians conceived of nature as a completely self motivating entity," as historian of science Thomas Goldstein explains. The workings of the universe occurred as mere extensions of the primordial chaos, automatic functions of its basic elements. Matter possessed its own evolutionary quality. "Order" and "law" were mere concepts superimposed by the human mind on the autonomous processes of nature. Nature knew of no laws. It was Pythagoras who is credited with the introduction of the vision of an intrinsic natural order and Plato adopted this vision. [40)

Aristotle, Plato's pupil, took his master's basic philosophy, added more structure and advocated verification of intuitive natural laws with objective observation. Like Plato, Aristotle thought it necessary to, first of all, understand and explain the workings of the human mind and to show what kinds of reasoning were valid and could be relied on to provide knowledge with surety. In his *Organon* or Logic, Aristotle made clear the processes of logical, reasoned thinking and for proving the correctness of its conclusions. He made plain the steps by which a science or body of knowledge may be firmly built up from its starting point in certain fundamental axioms or obvious statements, perceived intuitively to be true. Every science, as Aristotle pointed out, must begin with a few general truths. They cannot be logically proved, but our minds by simple intuition accept them as obviously true. Without such assumptions as foundations, we could never start to build anything. [41]

Louise Loomis, editor of a modern translation of Aristotle's scientific philosophies, notes that he reasoned like Plato, from ideal abstract principles, whenever the subject of the reasoning lay outside the field of observation possible to him. However, he was also willing to reject or change his theories when a closer examination of nature proved them wrong. Both a great thinker and a great scientist, he set the tone for future scientists by his method of inquiry and an avowed determination to yield to observation as the final arbiter. As a result, an atmosphere of sober empiricism distinguished the Hellenic Greeks from the Ionians, with Aristotle being credited as being a great dividing line in Greek history. Having channeled the power of Greek philosophical thought into a logical system of scientific classification, Aristotle's system came to exercise an enormous influence over European science for the next two thousand years. [42]

The classic Roman civilization built upon Greek science to develop their mighty empire with its renowned technical prowess. The Romans, being driven by conquest, glory, commerce, and an increasing need to find new resources never really flowered as scientists. Free thought was not the hallmark of Rome. The Roman way of doing things was impressed upon its citizens and conquered states as a matter of standard procedure. The Romans did, however, undertake massive engineering feats such as extended roads, aqueducts and highly structured cities. [43] Here technology flourished but no new ideas of "earth-shattering" philosophical importance stand out. Great translators of other works, the Romans were exploiters of resources and fantastic implementers of technology.

As Rome crumbled under the weight of countless invasions, the cosmic vision of the Greeks and the technological achievements of the Romans shriveled. With Europe over-run by the Germanic tribes, scientific inquiry was stunted for a millennium. Europe slept in a stupor of ignorance for one thousand years. "To those who lived through the catastrophe, it seemed that the utter breakdown of civilization had come, the ruin of everything humanity had ever tried to create over thousands of years, a verdict from a wrathful heaven," according to Goldstein. [44] Europe reacted with a radical readjustment of mind, turning their backs on the world of the senses, which now seemed unworthy of intellectual scrutiny. The end of Roman civilization meant a steadfast attachment by Europeans to the dogma of Christianity. To Europeans it offered the only hope left.

Medieval Christianity stunted the growth of science but not that of technology. Since it asked, indeed demanded, renunciation of the world of the senses, Christianity left no room for scientific observation. However, in an ironic way it fostered the development of ever-powerful weaponry to carry out its "Holy War" against the Moslems. The development of armor, hardened weapons, better cavalry equipment, battering rams, catapults, fortresses, and cannons al~ contributed to the steady growth of European technology. Over time, an influx of resources, increased improvements in agriculture under the feudal system, a burgeoning economic prosperity, and exposure to very diverse cultures as a result of the Crusades, made it difficult to reconcile reality with the world-denying traditions of the medieval mind.

When the hope given by the Church was no longer needed, new morals and money provided the impetus for Europeans to cast the Church aside in favor of a new age --the Renaissance. Suddenly, being earthy and gauche was in. Once again Europe entered an age of free inquiry, but this time a novel twist accompanied the new age.

The new twist was represented by a view of life advocated by a new breed of wealthy philosopher/scientist. The European Scientific Revolution of the 16th and 17th centuries began with Nicolaus Copernicas who overthrew the geocentric view of Ptolemy and The Bible that had been accepted for over a thousand years. After Copernicus, the earth was no longer the center of the universe but merely one of the many planets that circled a minor star in an insignificant galaxy. Radical in its impact, this view of the world robbed humans of their proud position in the center of God's creation. (Actually, a Greco-Egyptian named Aristarcus developed the same theory 2000 years prior to Copernicus. [45]) Without dogmatic theological constraints, other scientists such as Johannes Kepler who is credited with the laws of planetary motion, Galileo Galilei the re-discoverer of many of the principles of gravitation and the invention of the telescope, and sir Isaac Newton who combined much of his previous work into the laws of motion each contributed to the Renaissance's spirit of inquiry.

Two aspects of these scientists' work stand as foundations of modern science: (1) the empirical approach based upon objective, rational observation and (2) their use of mathematics to describe nature. These principles laid the groundwork for modern scientific methods of inquiry and were forcefully argued by Rene' Descartes, the philosopher and Francis Bacon, the theologian. [46] Therefore, Europe awakened to an approach to knowledge that goes all the way back through the works of Bacon, Newton, Copernicus, and Aristotle that included the process of observation, generalization, explanation, and prediction fully rooted in an earthy materialism, indicative of the age. This view of knowledge became pervasive, changing assumptions not only in science but also in the entire social fabric of Europe.

Europe came to understand that:

(1) Nature (the physical realm) is real.

(2) Nature is orderly.

(3) Nature is, in part, understandable.

To what extent can we actually know nature? Carl Sagan eloquently expresses our potential and limitations as he compares our physical realm to the world of a grain of salt. He discusses, in Broca's Brain, that the one thousand trillion sodium and chlorine atoms in a grain of salt would overwhelm our ability to understand salt if we were forced to know about every atom. This is because the human brain has a limit of approximately ten trillion neurons and dendrites (connections between neurons). Since there are more atoms in salt than connections in our brains, we can never expect to know everything with certainty in the microscopic world of a grain of salt. Just as unknowable are phenomena on the cosmic scale of the universe. [47]

However, if we use the empirical approach and seek out regularities and principles, we can understand both the grain of salt and the universe through extrapolation. We may never understand everything, but we can get some pretty good indications that allow rational conclusions to be drawn. Sagan's main point is that our scientific method of inquiry is based upon our senses. Since we inhabit physical space and time, phenomena outside this realm, things of the microscopic world of the interior of atoms or the macroscopic world of the universe --are beyond our physical senses. Although, we may use electron microscopes to probe the atom or radio telescopes to study the universe, we cannot escape the fact that these are merely devices that transform signals into the forms that our senses can recognize. Therefore, if we understand our limitations, we will be forced to understand the limitations of science.

This is an important lesson for a culture that depends heavily on science and technology. We have become quite adept at conquering tangibles with technology. From medical science to space travel, from instantaneous communications to automated warfare, Western science and technology have consistently proven their utility. When we turn to the world of the intangibles, technology and science face definite limitations. Social problems transcend mathematical descriptions and involve emotions that cannot be touched, measured or successfully manipulated. Theological questions transcend our three physical dimensions of space and our one dimension of time. What exists beyond those dimensions can only be entertained as speculation or believed through blind faith. Science is a search for truth and truth is limited to the facts of nature that are there for observation via our senses. As a result, technology cannot emulate human feelings and science cannot define God.

Implications for the Modern Corporate R&D Strategy

As we have seen, science has many facets. In essence it is pure neutral knowledge extracted painfully from nature through systematic means for dissemination to all humanity. Technology is not science. Technology is how we do things, not how we think of them. However, technology relies very heavily upon basic scientific knowledge in addition to existing technologies.

There is also a strong influence in the reverse direction. Modern science relies to a large extent upon current technology as well as prior scientific knowledge. Science and technology reinforce each other by complex interactions. Each one, science or technology, can build upon itself or upon a linkage from one to the other. Technology is dependent on science for knowledge of the properties of materials and energy and for predicting the behavior of natural forces. "Science is equally dependent upon technology for its tools and instruments, for preparation of materials, for the storage and dissemination of information, and for the stimulation of further research," according to Fischer. [48]

Indeed, science is not technology and technology is not science but they are firmly interrelated. One could not exist in modern society without the other. Although science and technology are closely related, a competitive organization needs to clearly delineate the components of its Research and Development (R&D) strategy. If we loosely correlate science with the research part of R&D and technology with the development part of R&D, then a firm needs to know whether there is too much of a tilt toward science or technology whether excessive emphasis is placed on "blue-sky" theory without practical results or, conversely, whether the firm is ignoring important new developments in basic research in favor of a purely pragmatic, short-term, tangible-return development focus. Overweighing either end of the R&D continuum can be a prescription for long-term stagnation. We have found that research centers, "think-tanks," laboratories, high-tech manufacturers, and other organizations whose products are, in essence, "technologies" need strong scientific research programs as input to their technology product development strategies. However, companies producing goods and services, i.e., those whose products are other than technologies, need to consider concentrating on technology strategies as input to their product value chains, as a means to improve processes, and as a way to focus limited R&D funds. Finding just the right balance between science and technology in the R&D strategy is the first step toward ensuring a successful technology assessment effort.

The Process of Scientific and Technological Change

Scientific Paradigm Shifts

Every individual lives and acts in accordance with his or her own worldview. A wide variety of views have been formulated and adhered to by people. Some are limited in scope; others are more comprehensive. Some have been well thought out and developed with precision; others are vague and ill defined. Some are based upon reason, others upon emotion, and most upon some combination of both. [49]

Cultural development has been facilitated by evolving, sometimes revolutionary, paradigms. The world-views held by individuals or by groups are very influential in determining behavior, as well as in determining motivations, attitudes and actions.

Scientists and engineers, being fully human, also experience the effects of paradigms. They and their findings are influenced by the mainstream of social thought framed by current technology and prevalent belief systems.

By using knowledge of the universe, creativity and a scientific approach to problem solving, scientists develop new paradigms. What actually causes them to change views as new evidence suggests a revision of a school of thought was thoroughly examined by MIT professor Thomas Kuhn, a science historian and philosopher, in his landmark 1962 book, The Structure of scientific Revolutions. [50]

Kuhn described a paradigm as a way of seeing the world and practicing science in it. The characteristics of a new paradigm include new scientific achievements sufficiently unprecedented to attract an enduring group of adherents away from competing modes of scientific activity and, at the same time, sufficiently open-ended to leave all sorts of problems for the new group of practitioners to solve. Kuhn notes that paradigm development goes through several predictable structural stages from "normal science" to new paradigm acceptance.

<u>Normal science</u> as defined by Kuhn means the body of research firmly based upon one or more past scientific achievements that some particular scientific community acknowledges for a time as supplying the foundation for its further practice. [52] Today such achievements are the basic recounts, though seldom in their original form, by elementary and advanced textbooks. The findings of such achievements are the bases for all underlying scientific assumptions and free the scientific community from constantly re-examining its first principles. This freedom allows members of that community to concentrate exclusively upon the subtlest and most esoteric of the phenomena that concern it. Inevitably this increases the effectiveness and efficiency with which the group as a whole solves new problems. There are always competing schools of thought, each of which constantly questions the very foundations of the others. It is these competing schools that provide science with a self-correcting mechanism that ensures that the- foundations of normal science will not go unchallenged. [53]

Scientific revolutions are inaugurated by a growing sense, often restricted to a narrow subdivision of creative minorities within the scientific community, that an existing paradigm has ceased to function adequately in the explanation of an aspect of nature for which that paradigm itself had previously led the way. This sense of crisis drives a reevaluation of the existing view and need not be generated by the work of the community that experiences the crisis. For instance, new instruments such as the electron microscope or new laws like Maxwell's wave theories may develop in one specialty and their assimilation may create a crisis in another.

So as the crisis, that common awareness that something has gone wrong, shakes the very foundations of established thought, it generates a scientific revolution. Just as in politics, scientific revolutions seem revolutionary only to those whose paradigms are affected by them. To outsiders they may seem normal parts of the developmental process, almost invisible. Astronomers, for example, could accept X-rays as a mere addition to knowledge since their paradigms were unaffected by the existence of the new radiation. But for the Kelvins, Crookes and Roentgens, whose research dealt with radiation theory and cathode ray tubes, the emergence of X-rays necessarily violated one paradigm as it created another. From their perspective, these rays could only have been discovered by something going wrong with normal science.

Those scientists whose paradigms are threatened typically react with resistance. Only when the number of instances that refute the old paradigm grows beyond supportable structures of the establishment, does a new paradigm arise. The decision to reject a paradigm is always simultaneously a decision to accept another with the judgment leading to that decision involving the comparison of both paradigms with nature and with each other.

Kuhn explains that revolutions close with a total victory for one of two opposing camps, with the winner rewriting scientific knowledge. Will the victorious group ever say that the result of its victory has been something less than progress? That would be admitting that they are wrong and the old paradigm holders are right. To the victors the outcome of a revolution must be defined as progress and they are uniquely positioned to make certain that future members of their community see past history in the same way because the new paradigm holders are the ones that get their work published. [54]

When it repudiates a past paradigm, a scientific community simultaneously renounces as a fit subject of inquiry, the past paradigm's experiments and subsequent textbooks. Scientific education makes use of no equivalent of the art museum or the library of classics, according to Kuhn. The result is sometimes a drastic distortion in the scientists' perception of their discipline's past. More than the practitioners of other creative fields, the scientist comes to see his or her discipline as evolving in a straight line to the present paradigm. In essence, the new paradigm is seen as progress and thus no alternative is available to the scientist while remaining in the field. The new paradigm is free to mature until the endless circle of challenge and debate inevitably signals its death.

Kuhn continues by challenging those who claim that when paradigms change, the world itself changes. Rather, led by a new paradigm, scientists actually adopt new instruments and look in new places. Even more importantly, scientists see new and different things when looking with familiar instruments in places they have looked before. It is almost as if the professional community had been suddenly transported to another planet where familiar objects are seen in a different light and are joined by unfamiliar ones as well. Of course, there is no geographical transplantation. Outside the laboratory, life continues as before. But, paradigm shifts cause scientists to see the world differently and they, in effect, are responding to a different world. It then becomes only a matter of time before their paradigms become popularized in a community of technologists and the social fabric begins to be re-woven as a result.

Technological Drivers

Technological change occurs as a result of economic and or social necessity. It may occasionally be the result of rational debate between competing schools, but it is more likely to be driven by a combination of external forces and, as we noted earlier, technology frequently is the product of creative attempts to solve a problem. Such creativity may involve trial-and-error and a flash of intuition, i.e., insight.

Insight --the "ah ha" of problem solving --influences science but drives technology. When combined with a goal, insight allows us to apply scientific findings in new ways to attack old problems of physical survival, comfort and convenience. Technologists, in the form of inventors and engineers, also experience revolutions of thought but in a very different environment than scientists. Technologists hardly, if ever, invent without help from colleagues and predecessors. Unlike science, technology seldom throws out old paradigms; it builds upon them. Vertical progress comes from constantly improving old technologies and spin-offs result from horizontal exchange of ideas across disciplinary boundaries.

Progress of course is relative to the goals of technology, the inventor and those people who are affected by the new development. For example, during the introduction of robots into the American auto industry, few line workers considered them progress, however, engineers and managers viewed them as a triumph toward "bottom-line" corporate goals. Technology, being goal-directed, relies on relative definitions to define progress. Despite this relativism of perspectives, technological progress can and does occur in vertical and horizontal directions by integrating sciences, innovative techniques and old technologies. In reality, technical progress follows the parameters described by futurist John Naisbitt, "...change occurs when there is a confluence of both changing values and economic necessity, not before."[55]

Economics and human goals are the drivers of technological innovation. BBC reporter and author of Connections, James Burke, presented a good summary of the ways in which technologists experience the effects of economics and human values. Burke designates six major initiators of technical innovation. They are: deliberate invention, accidents, spin-offs, war, religion, and the environment. [56]

First, as one might expect, technical innovation occurs as a result of deliberate attempts to develop it. When inventors like Lewis Howard Latimer and later Thomas Edison began work on the incandescent bulb, it was done in response to the inadequacy of the arc light. All the means were available: a vacuum pump to evacuate the bulb, electric current, the filament which the arc light used, and carbon for the filament. With these components the remainder of the required work was the synthesis of technologies toward a definite goal --the light bulb's creation.

A second factor that frequently occurs is that an attempt to find one thing leads to the discovery of another. For example, William Perkin, searching for an artificial form of quinine, used some of the molecular combinations available in coal tar and accidentally found that the black sludge produced by one of his experiments turned out to be the first artificial aniline dye.

Unrelated developments have decisive effects on the primary event. An example of such spin-off developments can be seen by the development of paper. The medieval textile revolution, which was based upon the use of the spinning wheel and the horizontal loom, lowered the price of linen to the point where enough of it became available in rag form to revolutionize the paper industry. Burke discusses other examples of how unforeseen circumstances play a leading role in technical innovation. This includes the stimulation of mining activities for metals to make cannons when Chinese gunpowder was exported to Europe and the development of a barometer as a result of frequent flooding of mines and the failure of pumps.

The fourth and fifth factors are all too familiar: war and religion. The need to find more effective means of defense (or offense) has driven technology from the most ancient of times. The use of the cannon led to defensive architectural developments that made use of astronomical instruments. As previously discussed, ancient Ethiopian, Egyptian and pre-European indigenous American religious beliefs led to great strides in engineering and architecture and the Islamic world developed advanced astronomy because of the need to pray, feast and fast at specific times.

Finally, physical and climatic conditions play important roles. For example, the extreme changes in Europe's winters in the 12th and 13th centuries provided urgent need for more efficient heating. The chimney filled the need and had a profound effect on the cultural life of that continent.

For whatever reasons we seek to apply, technology borrowing from scientific revolutions forces changes in thought as does science, but it goes beyond science by modifying behavior. Because of the social effects sometimes wreaked upon the organization by technological change, paradigm holders who are unable to see the need for change frequently resist such advances. However, one fact remains certain --American industry cannot turn its backs on technical change as the English Luddites tried when they destroyed their textile looms. Technology will not go away that easily and the company that ignores innovation tends to meet it again under more unfriendly circumstances, e.g., as an ally of the competition.

A wiser approach is to assist, rather than fight the technical change process. This is especially important in light of an examination of the history of successful new companies. As a later discussion of technology trends and maturity curves will show, phenomenal growth of creative new firms frequently results from exploiting technical change instead of shying away from it. In today's competitive environment, organizations really have no choice in the long run. They must embrace technical change! Francis Bacon best summarized it in his essay Of Innovations:

> *"Retention of custom is as turbulent a thing as an innovation; and they that reverence too much old times are but a scorn to the new. Surely, every medicine is an innovation and he that will not apply new remedies must expect new evils."* [57]

Works Cited

28. J.B. Conant, **Science and Common Sense** (New Haven: Yale University Press, 1951}.

29. Robert Fischer, **Science, Man & Society** (Philadelphia: W.B. Sanders Company, 1975}, pp. 5-7.

30. Joseph B. Platt, *The Value of Science and Technology to Human Welfare*, **Bulletin of the Atomic Scientists** (Oct. 1973}.

31. Fischer, **Science, Man & Society**, p. 76. 32. Ibid.

33. Platt, *The Value of Science and Technology to Human Welfare*.

34. Fischer, **Science, Man & Society**, p. 77.

35. Richard C. Dorf, **Technology, Society, and Man** (San Francisco: Boyd & Fraser Publishing Company, 1974}, pp. 1.

36. Chancellor Williams, **The Destruction of Black Civilization** (Dubuque, Iowa: Kendall/Hunt Publishing Company, 1971} , pp. 34-35.

37. Williams, **The Destruction of Black Civilization**, p. 38. Ibid.

39. Thomas Goldstein, **The Dawn of Modern Science** (Boston: Houghton-Mifflin Company, 1980), pp. 48-64. 40. Ibid, p. 52.

41. Louise R. Loomis, ed., **Aristotle, On Man and the Universe** (Roslyn, N.Y.: Walter J. Black, Inc., 1971), pp xi-xxxviii.

42. Ibid.

43. L. Sprague DeCamp, **The Ancient Engineers** (New York: Balentine Books, 1976), pp. 172-280.

44. Goldstein, **The Dawn of Modern Science**, p. 55.

45. Carl Sagan, **Cosmos** (New York: Random House, 1980), p 14-21.

46. Fritjof Capra, **The Turning Point** (New York: Simon and Schuster, 1982), pp. 15-120.

47. Carl Sagan, **Broca's Brain** (New York: Random House, 1974), pp. 15-16.

48. Fischer, **Science, Man & Society**, p. 78.

49. Fischer, **Science, Man & Society**, pp. 3-173.

50. Thomas S. Kuhn, **The Structure of Scientific Revolutions** (Chicago: University of Chicago Press, 1970), pp. 1-181. 51. Ibid.

52. Ibid, p. 10.

53. Ibid, p. 163. 54. Ibid, p. 166.

55. John Naisbitt and Patricia Aburdene, **Re-inventing the Corporation** (New York: Warner Books, 1985), p. 42.

56. James Burke, **Connections** (Boston: Little, Brown and Company, 1978) , pp. 289-295.

57. Francis Bacon, **The Essays or Councils, Civil and Moral; of Francis Ld. Verulam** (Mount Vernon, N.Y.: Peter Pauper Press), pp. 96-97.