Leonardo

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ON ART, INVENTION, AND TECHNOLOGY*

Cyril Stanley Smith**

Nearly everyone believes, falsely, that technology is applied science. It is becoming so, and rapidly, but through most of history science has arisen from problems posed for intellectual solution by the technician's more intimate experience of the behavior of matter and mechanisms. Technology is more closely related to art than to science—not only materially, because art must somehow involve the selection and manipulation of matter, but conceptually as well, because the technologist, like the artist, must work with many unanalyzable complexities. Another popular misunderstanding today is the belief that technology is inherently ugly and unpleasant, whereas a moment's reflection will show that technology underlies innumerable delightful experiences as well as the greatest art, whether expressed in object, word, sound or environment.

Even less widely known, but important for what it tells of man and novelty, is the fact that historically the first discovery of useful materials, machines, or processes has almost always been in the decorative arts, and was not done for a perceived practical purpose. Necessity is *not* the mother of invention—only of improvement. A man desperately in search of a weapon or food is in no mood for discovery; he can only exploit what is already known to exist. Discovery requires aesthetically-motivated curiosity, not logic, for new things can acquire validity only by interaction in an environment that has yet to be. Their origin is unpredictable. A new thing of any kind whatsoever begins as a local anomaly, a region of misfit within the preexisting structure. This first nucleus is indistinguishable from the few fluctuations whose time has not yet come and the innumerable fluctuations which the future will merely erase. Once growth from an effective nucleus is well under way, however, it is then driven by the very type of interlock that at first opposed it: it has become the new orthodoxy. In crystals undergoing transformation, a region having an interaction-pattern suggesting the new structure, once it is big enough, grows by demanding and rewarding conformity. With ideas or with technical or social inventions, people eventually come to accept the new as unthinkingly as they had at first opposed it, and they modify their lives, interactions, and investments accordingly. But growth too has its limits. Eventually the new structure will have grown to its proper size in relation to the things with which it interacts, and a new balance must be established. The end of growth, like its beginning, is within a structure that is unpredictable in advance.

The Shape of Universal History

The 'S' curve (Fig. 1) (adapted from a paper on the transformations of microstructure responsible for the hardening of steel) can be used to apply to the nucleation and growth of anything, *really* any 'thing' that has recognizable identity and properties depending on the coherence of its parts. It reflects the underlying structural conflicts and balance between local and larger order, and the movement of interfaces in response to new conditions of components, communication, cooperation, and conflict.

Applied to the growth of either individual technologies or to the development of whole civilizations based upon interactive technologies, the 'S' curve reflects origin in art, growth in social acceptance, and the eventual limitation of growth by interactions within a larger structure which is itself nucleated in the process. The conditions of beginning, development, and maturity are very different.

Though a computer program can duplicate such curves, it is only by looking at the whole hierarchical substructure and superstructure that intuitive understanding can be gained. All stages involve a balance between local structure and overarching regional restraints. All change involves a catastrophic change of connections at some level while topological continuity is maintained, though perhaps with strain, at levels both above and below. Human history follows the same general principles of structural rearrangement as a phase change in a chemical system, though most teachers of history ignore the nucleating role of technology and concentrate on the social changes that are engendered by it.

The transition from individual discovery and rare use of techniques to the point where they affect the environment of Everyman and the content and means of communication between people and peoples underlies virtually every great social or political change and every fundamental change in man's view of the world. Few general histories reflect this. An understanding of the proper place of technology within the whole human experience is desperately needed in order that society can wisely decide what to develop and what to discourage. Technology needs to be seen in the perspective that humanists have traditionally applied to man's other activities. Personally, I believe that the life of a craftsman, indeed of any man making

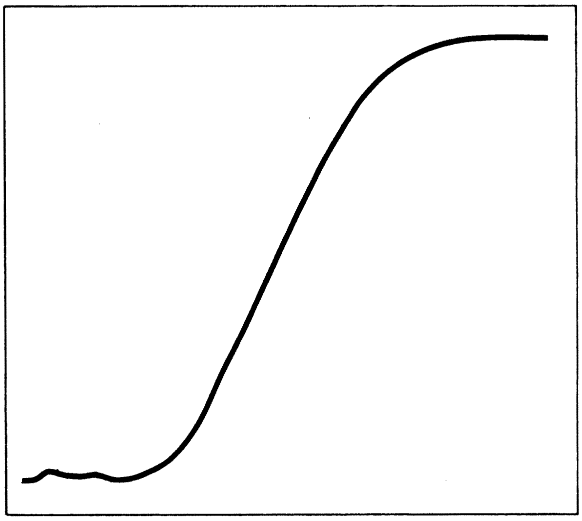

Fig. 1. Curve depicting the beginning, growth, and maturity of anything whatever. Adapted from a paper on the hardening of steel, it is here used to show the beginnings of most branches of technology in the decorate arts, their industrial growth in response to a social demand, and their maturity in conflict and balance with other things. Both the beginning and the end depend on highly localized conditions and are unpredictable in detail.

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something to be enjoyed or used, is a fine example of what it is to be human: mind, eye, muscle, and hand interacting with the properties of matter to produce shapes reflecting the purposes and cultural values of his society, and sometimes extending them.

The verbal records conventionally used by the historian reflect this very poorly indeed. Conversely, works of art, when seen at every level from the atom to the whole, provide excellent records of almost everything about man. Usually they are enjoyed for their outer form and symbolism alone, and appreciated as a statement of the artist's ideas on some aspect of the world, an expression of the forms and feelings that he selectively absorbed from the culture of which he was part. However, his work is also an object and as such a product of technology. Thus, the famous bronze statue of Poseidon shown in Fig. 2 involves technology both submerged in the emotional and cultural meanings carried by its glorious form, and also more tangibly in the actual operations of smelting, alloying, casting, and welding that produced it. The techniques had themselves developed through earlier (non-Greek) history and they were to have an influence on the subsequent development of the Western world comparable, in my view, with that of Greek ideas in aesthetics and philosophy.

Historians of science, while properly emphasizing the development of unifying concepts, commonly overlook the fact that the thoughtful intimate awareness of the properties of matter first occurred in the minds of people seeking effects to be used decoratively. Both Democritus' atoms and Aristotle's elemental qualities are expressions of what the philosophers could have observed on a stroll down Hephaestos Street, noting the changes in strength, plasticity, texture and color produced by the treatment of materials as the artisans shaped things for their customers. Similarly the multi-valent game tokens found in very early excavated sites in the Middle East as well as the space-filling interlock of features in decorative pattern must have some place in the earliest history of mathematics.

Archaeologists and art historians, of course, long ago learned to interpret human experience from the evidence of artifacts. But even they have concentrated upon iconographics and styles, on ideas external to the object, and only occasionally have they sought to understand the technical experience in its production. Yet in making a work of art, a man must select material having a 'nature' that will conform to the larger shapes that he wishes to impose upon it. There is a continuous hierarchy of interactions: the objects stands at the very point where the structures and properties of matter resulting from forces between atoms are in visible interaction with man's ideas and purposes. An artist's work preserves a record of both—one in the outer form and decoration, the other in the texture and color and fine contours that result from the interplay of atomic, molecular, and crystalline forces. The texture continues downward into a rich microstructure: hierarchical patterns of atomic order and disorder that change in recognizable ways as matter is subjected to thermal and mechanical treatment in its compounding and shaping.

Everything complicated must have had a history, and its internal structure features arise from its history and provide a specific record of it. One might call these structural details of memory 'funeous', after the unfortunate character in Borges' story 'Funes the Memorious' who remembered everything. The aim of respectable science through most of history has been to study afuneous details; it has been analytic, seeking the parts or ideally simplified wholes. Analysis is, of course, absolutely essential for understanding, but no synthesis based upon it can reproduce the funeous structures that provoked interest in the first place unless the essentials of their individual histories are repeated. History selects and biases statistics. The particular structures that do exist, however improbable they may be, must be given priority in man's studies. The messier sciences such as old-fashioned biology or my own metallurgy have always been concerned with complex structures, and they have emphasized the relation between real structure and properties, while the pure sciences have perforce avoided that which was structure-sensitive, and hence funeous. At least until very recently: now, however, the material sciences have merged with solid state physics and are showing how to study real structure with a wholly new emphasis upon imperfections in atomic order. Dissymmetry rather than symmetry is seen to be the key to many marvellous new materials—though dissymmetry is invisible except in a matrix of symmetrical order. New methods capable of

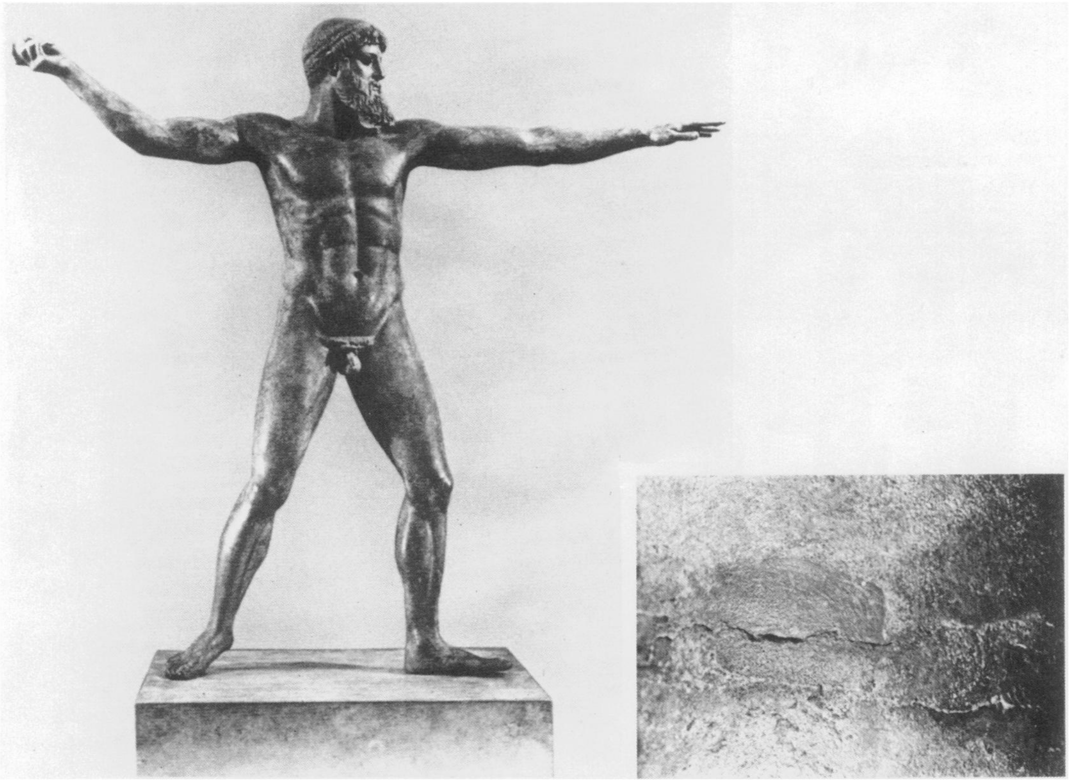

Fig. 2. Greek statue of Poseidon, Bronze, 475 B.C. The statue was cast in several parts by the lost-wax process, and the parts were joined together by running in superheated molten metal of the same composition, as shown in the accompanying photograph taken by Arthur Steinberg. For many centuries welding was used only in sculpture, though it is now an essential step in the construction of most machines and large structures. Courtesy National Museum, Athens.

revealing the whole structures at all levels have been developed—thereby incidently opening a new level of funeous record for study by historians.

The Origins of Techniques

Figs. 3 and 4 each show an antique bronze object and its structure as seen under the microscope. The microstructures differ more from each other than do the external forms—and they instantly reveal to a knowing eye the technical history of making the object. Such records are in a universal language, and they are free from the distortion that inevitably accompanies passage through a human mind. Through such records, I have communicated with dozens of craftsmen, including a Luristan smith of 800 B.C., a bronze founder of Shang China, an ancient Greek goldsmith, and a 13th-century Japanese swordsmith; and I have understood them better than I understand some of my English-speaking colleagues today! This newly-found Rosetta Stone is making accessible records of a new world, or more correctly, an unnoticed aspect of culture in the old. As a metallurgist trying to understand the history of his profession, I had exhausted the literary sources without finding evidence of the beginnings of most of the techniques that interested me: only when I moved from libraries to art museums did I find the real origins of metallurgical (and other) techniques, and in doing so my whole view of man, matter, and discovery changed.

Practical metallurgy is seen to have begun with the making of necklace beads and ornaments in hammered native copper long before 'useful' knives and weapons were made. The improvement of metals by alloying and heat treatment and most methods of shaping them started in jewelry and sculpture. Casting in complicated moulds began in making statuettes. Welding was first used to join parts of bronze sculpture together: none but the smallest bronze statues of Greece or the ceremonial vessels of Shang China would exist without it, and neither would most of todays' structures or machines. Ceramics began with the fire-hardening of fertility figurines moulded of clay; glass came from attempts to prettily glaze beads of quartz and steatite. Most minerals and many organic and inorganic compounds were discovered for use as pigments; indeed, the first record that man knew of iron and manganese ores is in cave paintings where they make the glorious reds, browns, and blacks, while the medieval painter controllably used pH-sensitive color changes long before the chemist saw their significance. In other fields, archaeologists have shown that the transplanting and cultivation of flowers for enjoyment long preceded useful agriculture, while playing with pets probably gave the knowledge that was needed for purposeful animal husbandry. To go back even earlier, it is hardly possible that human beings could have decided logically that they needed to develop language in order to communicate with each other before they had experienced pleasurable interactive communal activities like singing and dancing. Aesthetic curiosity has been central to both genetic and cultural evolution.

Fig. 3. Cast bronze ceremonial vessel, type Ting. Chinese, Shang or early Chou dynasty. 20.3 centimeters in diameter. This was cast in a clay mould made in several divisions. The different decorative details originate in different technical methods of treating the mold surface. (Fogg Art Museum, Harvard University, Bequest Grenville L. Winthrop). (Above) Microstructure of Chou dynasty bronze similar to that used in vessel shown. The metal has been sectioned, polished, and chemically etched in order to reveal the complex pattern of the metallurgical microconstituents. Magnified 250 times.

Mechanical devices were less developed in the ancient world than were materials of comparable complexity. Perhaps this was because the aesthetic rewards of play with simple, and hence invariant, mechanisms are small. However, note that wheels first appeared on toys, and that the automata based on hydraulic and mechanical tricks that were used in Greek temples and theatres were the prelude to the waterwheel and the clock. The lathe reached an apex of ingenuity in turning guilloché snuff boxes more than a century before heavy industry used it. The painting of pictures preceded purposeful type, and the use of rockets for fun came before their military use or space travel. The techniques of casting bells, like the material of which they were made, were ready to be directed toward a different kind of sound and purpose when princes wanted cannon.

Enjoyment of color has inspired the development of many alloys—for example the famous Mycenean inlaid dagger in the National Museum in Athens, and the exquisite colored metal inlay of Japanese sword furniture. It is also related to the refining and purification of metals in early times because of the use of corrodants to change the color of native electrum. The color changes in metals, oxides, and sulphides discovered by far earlier artisans permeate medieval alchemy—a dead end of delightful but unproductive theory. The marvellous golds and blues of medieval illuminated manuscripts came from pigments made by processes that foreshadow modern powder metallurgy and the flotation process of ore separation. The desire for pigments, dyes, and cosmetics inspired much mineralogical and botanical exploration, while precious stones, dyes, spices, and jewelry formed the first base of commerce, for long range trade did not

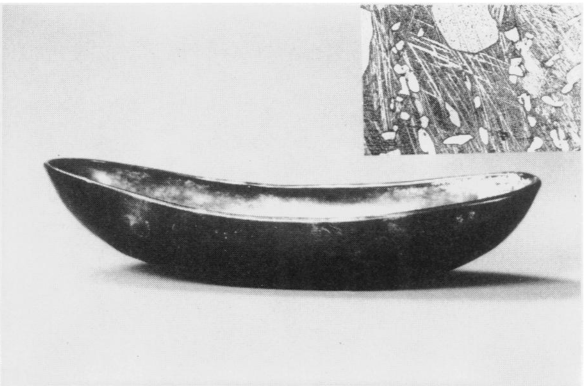

Fig. 4. Oval bowl of high-tin bronze. Iran, 7-8 century A.D. Made by hot forging, followed by quenching in water. Unlike steel, this alloy (22 per cent tin) is brittle if slowly cooled. (Metropolitan Museum of Art, Dr. Peter Meyers, Rogers Fund 1949). (Above) Microstructure of an Iranian bowl similar to that shown. The needle-like features are sections of plates resulting from a crystallographic change that occurred during rapid cooling. Etched. Magnified 500 times.

start with necessities. Even bankers were once goldsmiths. The chemical industry later grew from the need for quantities of mordants, bleaches and alkalies for use in the finer textiles and glass. Geology, chemical analysis, and high temperature research all took a leap forward in eighteenth-century Europe under the impact of the potter's efforts to duplicate the marvellous wares coming from the Orient, which had started the craze for chinoiserie. The great French scientist Réaumur made a cheap, crystalline 'porcelain' by devitrifying glass, and he also developed malleable cast iron in his search for a cheaper substitute for the handsome chiselled wrought iron work on the gates of the chateaux of the aristocracy.

More Like Love than Purpose

In all of these cases, and many more that could be cited, it was aesthetic curiosity that led to initial discovery of some useful property of matter or some manner of shaping it for use. Although the maker of weapons was quick to follow, it was nearly always the desire for beauty or the urge to make art available to the masses (or, if you will, the desire to exploit mass desire for pretty things in order to make profit) that led to advances in production techniques. The desire to beautify the utilitarian has always stretched the ingenuity of the mechanic, who made draw-benches, stamps, and screwpresses to shape trinkets before automobile parts or weapons. It is the same in building construction: temples and churches, greenhouses and Crystal Palaces, not necessary shelter, led to imaginative new structural methods. Even railroad rails and the steel girders for today's skyscrapers needed a precursor in the form of the little mill that rolled lead canes to be used in medieval stained-glass windows, and it was a French gardener who invented reinforced concrete because he wanted a larger flower pot for more magnificant display.

In the 19th century the milieu of discovery began to expand. Science created a new environment in which imaginative curiosity could operate. Though the discovery of voltaic electricity could have come from metal-replacement reactions used in the arts or from the delightful philosopher's toy, the *Arbor Dianae* (an electrolytic tree of crystalline silver), it actually came from an unaesthetic experiment on a frog's leg. It remained unused until 1837, when the electric telegraph and electrotyping were both seen to be useful. The utility of the latter, however, at first lay only in the arts: it was used as a process for electrolytically duplicating coins, plaques, statuary, and engraved or etched plates for the graphic artist. All the great illustrated newspapers stem from this—the *Illustrated London News*, the *Scientific American*, *L'Illustration*, and *Harper's Weekly*. Soon electrolytic baths were giving rise to monumental sculpture, some weighing over 7,500 pounds. Many of the 'bronzes' in the Paris opera house are of electrodeposited copper, while a nice English example is the ten and a half foot high statue of Prince Albert (Fig. 5) behind Albert Hall in London. It was made by the firm of Elkington in 1862.

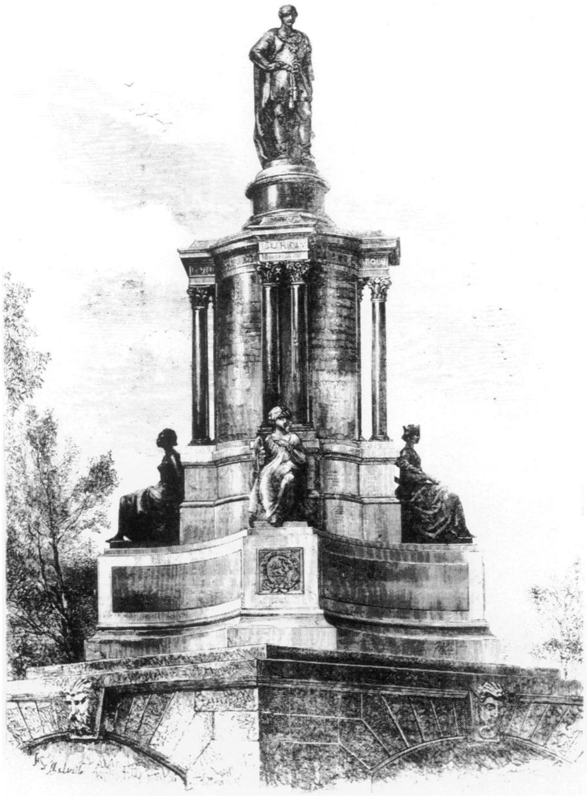

Fig. 5. Statue of Prince Albert with four flanking figures of the continents. Made in electrolytic baths by Elkington and Company in 1862. The statue, a memorial of the Great Exhibition of London, 1851 is still to be seen in London, immediately to the southeast of Albert Hall. The illustration is taken from the 'Illustrated London News', June 27, 1863.

Almost immediately an even larger use for 'galvanism' developed—the production for middle-class tables of metalware having all the glitter of the rich man's silver and gold. Within a decade, Sheffield plate was supplanted by electrodeposited silver plate, with a not always felicitous relaxation of restraint on design.

At first the electric current for these applications came from banks of small batteries (Daniell cells) in which nearly three pounds of zinc and acid were consumed for every pound of copper deposited. The larger uses of electricity could develop only after a steam-driven generator had grown out of an 1832 lecture-demonstration device made to intrigue physics students with the realities of Oersted's electromagnetic interaction. The first commercial electrical generator, constructed in 1844 to the 1842 design of J. F. Woolrich (whose patent includes also a plating bath), was used in the shops of the Elkington Company for several decades before it was donated to the Birmingham City Museum, where it now stands. The giant electric power industry of today thus did not begin with a preconceived desire for its utility—the first suggestion came from the arts. Once power generation had been demonstrated, however, it was ripe for development and use by men of a different cast of mind; soon came lighting (beginning with arc lights for light-houses), and then motive power. All big things grow from little things, but new little things will be destroyed by their environment unless they are cherished for reasons more like love than purpose.

Banquo expressed a deep human wish when he asked the witches 'If you can look into the seeds of time, and say which grain will grow and which will not, speak then to me.' But how do the seeds of human achievement form in the first place? Not just by taking logical thought, but rather by giving curiosity full rein and using all of a human being's capability—his holistic powers of understanding and aesthetic imagination as well as his analytical skills. I do not mean to imply that all technologists are sensitive aesthetes, but I do claim that the *beginning* of much useful technology (as indeed of most human achievements in the past) has arisen in aesthetic experience. The subsequent and more obvious stages of profitable development can occur only as a sequel to a quite different dynamic.

The simple picture of origins outlined above, which applies so well to the early stages of many early technologies, seems hardly applicable to the twentieth century. The experience of discovery in the laboratory is still an essentially aesthetic one (a fact rather thoroughly disguised by the accepted style of reporting the results) but the motivation is rarely a desire to create beauty. Why is this? Is it just that the patronage for creation has changed, or is it that most of what we notice today is not creation but merely a natural or unnatural refinement of the old, while the really new is around unnoticed, awaiting an environment that does not yet exist? In any case, neither art nor history can be understood without paying attention to the role of technology; and technology cannot be understood without history and art.

Author's Note

This paper incorporates, with permission, some of the text of a short copyrighted article in *The New York Times*, Section 2 of the issue of 25 August 1975.

It is a particular pleasure to dedicate this fuller version to Philip and Phylis Morrison, for conversations with them have helped me to form the views expressed herein.