Technology as a scientific capacity to produce

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What is technology? What does technology mean? Where does technology reside? One notion of technology, which originated in the Greek *téchnē*, points to the rational ability to create and produce. Modern technology grew out of ancient *téchnē* by developing its own reasoning and knowledge into science. In this sense, technology is inalienable from human activities. It resides not only in high-tech products but also in scientific knowledge, human understanding, and organization of social institutions.

Embryonic notion of technology in Greek philosophy

The ancient Greeks often discussed *epistēmē* and *téchnē* together, just as we now mention science and technology in one breath.[1] Plato sometimes used the two terms interchangeably. Aristotle distinguished them more carefully.

Epistēmē had several meanings in ancient Greek. Broadly, it meant knowledge in general. Narrowly, it referred to a specific kind of knowledge, which is usually translated as science. Aristotle explored three types of knowledge, which took on different topics and underlay different rational activities:

Knowledge (*epistēmē*)	Topic	Activity
Science (*epistēmē*)	unchanging being	contemplation (*theōria*)
Art (*téchnē*)	bringing into being	production (*poiēsis*)
Prudence (*phronēsis*)	ethics	action (*praxis*)

"*Téchnē* is a state of capacity to produce with a true *logos*," Aristotle defined.[2] *Logos* was a central notion in Greek philosophy, broadly meaning reason and discourse. Because art had its own reasoning and discourse, it was knowledge, as distinct from opinion (*doxa*) and mere experience. Many arts existed, among others Aristotle cited architecture, medicine, and mathematics.

Aristotle remarked that art originated from experiences but went well beyond mere empiricism. He explored the characteristics of *téchnē* in detail. Among other things, his explication addressed what we now call education, research, and the contents of technological knowledge [3].

● *Education*: Aristotle said: "It is a sign of the man who knows, that he can teach, and therefore we think art more truly knowledge than experience is; for artists can teach, and men of mere experience cannot." In the old days, apprentices learned the skills of trade by working in

workshops, where masters not so much taught via concepts as showed by their own practices. With the rise of scientific engineering, tacit know-how has been increasingly articulated, criticized, systematized, and developed, so that they can be promulgated in books and taught to student away from the workshops. Since the eighteenth century, when technological universities first appeared in France, apprenticeship has given way to education.

● *Research*: Aristotle said: "Art arises, when from many notions gained by experience one universal judgment about similar objects is produced." The ability to generalize and uncover principles behind diverse phenomena is also the hallmark of science. This ability is honed and practiced mostly in research. Graduate schools and industrial research laboratories first appeared, almost hand in hand, in Germany in the late nineteenth century. From the beginning, many, although far from all, research projects are applied oriented. Today, engineers stand shoulder to shoulder with natural scientists at the cutting edge of research.

● *Contents of knowledge*: Aristotle said: "Men of experience know that the thing is so, but do not know why, while artists know the 'why' and the cause of thing that is done." Not to accept what meets the eye unquestioningly but to seek explanations is another hallmark of science. Explanations are facilitated by universal judgments and general concepts, which give tongue to what are inarticulate in mere experiences.

Aristotle also investigated what kinds of explanations – causes of things – were acceptable. He analyzed four kinds of cause: material cause, formal (structural) cause, efficient (dynamic) cause, and final (purposive) cause. Some historians of science asserted that of the four Aristotelian causes, only the efficient cause, which concerned forces, remained "scientific" after the Scientific Revolution. These historians were too much obsessed by the glamorous part of Newtonian mechanics to notice the many applied oriented researches that were going on. The other three causes continue to be studied and are very much alive in today's science and technology. Galileo started his scientific career investigating the material and structural causes of building construction. These topics had been developed by natural philosophers as well as civil engineers all through the eighteenth and nineteenth century, with conspicuous fruits such as the railroad bridges that symbolized the landscape of the industrial revolution, or the skyscrapers that dominate the skylines of modern cities. Stripped of its metaphysical trapping of finality, questions about functions of technological products are very important in today's engineering.

The Aristotelian definition of practical art is significant because it insists that *téchnē* contains its own *logos*. When the intrinsic *logos* of *téchnē* is systematically articulated and developed, it naturally grows into technology.

Internal and external notions of "technology"

Concatenations of *téchnē* and *logos* appeared in Latin writings with ambiguous meanings. According to the *Oxford English Dictionary*, the etymology of "technology" is systematic treatment. As such it can be viewed internally or externally.

In the external view, technology means the systematic discourse *about* practical art. Technology is the science about practical art just as entomology is the science about insects and geology

about planet Earth. Here *logos* belongs to scholars who takes practical art and artists as their topics of investigation but is foreign to and not a part of the art or artists. It neglects the cognitive ability of the artists and concentrates on their products and social status. Appeared in the sixteenth century -- French rhetorician Peter Ramus used *technologia* for systematic arrangement of all arts -- this sense is mostly outdated. Today scholarly discourses about practical art or engineering are called not technology but technology *studies*, which include history, philosophy, and sociology of technology. Nevertheless, technology studies have a tendency to emphasize the external stance of seeing technology mainly as mindless physical or social systems. In many studies, technology is drained of science, engineering, and intellectual contents. Scientists and engineers are treated on the same status as catalysts and scallops in the "actor-network model," one of the most influential sociological models in science and technology studies.[4]

The internal view inherits the Greek notion of *téchnē* containing its own *logos*, so that technology means the systematic reasoning *of* practical art itself. In this view, art and reasoning are not separate entities that later enter into a marriage. They are intertwined cognitive potentials inherent in every human being, because living in, coping with, and modifying the real world is primordial to all human life. Technology is the explicit rendition of reasoning inherent in practical art; the systematic abstraction of essentials; the articulation, generalization, refinement, and development of knowledge involved in productive and creative activities. Thus practical art -- engineering and technology -- became scientific not by imitation but by self development. This view was expressed by Galileo in *Two New Sciences*, one of his two major books: "in this department [the Venetian arsenal] all types of instruments and machines are constantly being constructed by many artisans, among whom there must be some who, partly by inherited experience and partly by their own observations, have become highly expert and clever in explanation."[5]

Some seventeenth-century puritan theologians argued that what was nature to us was God's creation. Therefore they rejected the Aristotelian distinction between natural science and productive art and proposed *technologia* that encompassed both. Among the puritans was William Ames, whose ideas were influential in Massachusetts.[6] In 1829, Boston botanist Jacob Bigelow observed that the word "technology," found in some old dictionaries, was revived among practical men. He delivered a series of lectures entitled *Elements of Technology*, in which gave a definition with Aristotelian ring: Technology is "the principle, processes, and nomenclatures of the more conspicuous arts, particularly those which involve application of science."[7] He later sat on the board of trustees of Massachusetts Institute of Technology, the foundation of which in 1861 publicized the concept of technology.

Technology and modern technology

The internal view of technology spread in the nineteenth century. It has two connotations. In the broad sense, favored by anthropologists and historians, technology embraces all practical arts primitive and sophisticated. In a narrower sense, favored by engineers and scientists, technology includes only those practical arts that incorporate a significant body of explicitly articulated knowledge and explanation that is scientific in the modern sense.

Both internalist senses were used by Karl Marx, the first great economist to expound the deep relation between modes of production and human welfare. He wrote: "Technology reveals the active relation of man to nature, the direct process of the production of his life, and thereby it also lays bare the process of the production of the social relations of his life, and of the mental conceptions that flow from those relations." Containing man's relations both to nature and society and incorporating all skills and knowledge about material creation and production, technology in this sense has a very broad scope. However, Marx also observed that "right down to the eighteenth century, the different trades were called 'mysteries.'" Then, he continued, the veil of mystery was torn apart by "the modern science of technology."[8] In this narrowed-down sense, technology is the science in which practical artists articulate and explain their own work.

Both the broad and narrow meanings of technology are currently used. For instance, the five-volume *A History of Technology* covers practical arts since antiquity, but its editors observe that "not until the nineteenth century did the term [technology] acquire a scientific content and come ultimately to be regarded as almost synonymous with 'applied science.'"[9] This intrinsic relationship between technology and science is revealed in the organization of many universities with School of Engineering and Applied Science.

Technology as intellectual, human, physical, and social capital

In the internal view, technology is a scientific capacity to produce and create. A society's technological capacity is one of its major assets. It resides in four areas:

- *Intellectual capital*: factual knowledge, theories, patents, algorithms, science.
- *Human capital*: understanding, skills, and practices of scientists, engineers, and other workers.
- *Physical capital*: machines and their operating principles, plant layouts, infrastructures.
- *Social capital*: organization of educational, research, industrial, and other social institutions.

These capitals are products of technological activities: education, research, development, industry, and other productive works. Some products of these activities, notably high-tech goods and services, are consumed by people and most familiar to them as the essence of "technology." Not all products are consumed, however. Many are plowed back as social investments that expand technological capacities.[10]

Of the four kinds of technological capacity, science is explicitly articulated and can be promulgated rather easily. Other kinds of knowledge are more difficult to spread because they are tacit and embodied in living people, physical infrastructures, and social organizations. Transmission of tacit knowledge in "technology transfer" depends heavily on the travel or migration of engineers and managers, the establishment of firms or educational institutions, or the moving or building of physical plants. Tacit and embodied knowledge is the most valuable asset of technologically advanced nations, their greatest comparative advantage over catcher-ups, because it can only be patiently accrued in concrete beings as a major form of capital accumulation.

Notes

1. Edel, A. 1982. *Aristotle and His Philosophy*, Chapel Hill: The University of North Carolina Press.
2. Aristotle, *Ethics*, 1140.
3. Aristotle, *Metaphysics* 981.
4. See, for example, Bijker, W. E., Hughes, T. P., and Pinch, T. J. eds. 1987. *The Social Construction of Technology Systems*. Cambridge: MIT Press.
5. Galilei, G. 1638. *Dialogues Concerning Two New Sciences*. New York: Dover; p.1.
6. Edel, *op cit*, p. 338.
7. Bigelow, J. 1829. *Elements of Technology*. Boston: Boston Press, pp.iii-iv.
8. Marx, K. 1867. *Capital, I*. New York: Vintage Books, pp. 493; 616).
9. Singer, C., Holy, E. J., and Holmyard, E. J., and Hall, A. R., eds. 1954. *A History of Technology*. Oxford: Oxford University Press, p. vii).
10. Auyang, S. Y. 2004. *Engineering – An Endless Frontier*. Cambridge: Harvard University Press, Section 2.1.