collective, misconduct is, in its way, characteristic of LaFollette's book, which is more concerned with listing, enumerating, and cataloging than with producing new analysis or insight. Nevertheless, there is no doubt the book is valuable, for its bibliography among other reasons. The bottom line on it is this: I intend to use it next spring in the research ethics course we have recently begun teaching at Caltech. I'm sure it will be used in other such courses that are blossoming around the country.

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Technological Intuition

Engineering and the Mind's Eye. EUGENE S. FERGUSON. MIT Press, Cambridge, MA, 1992. xvi, 241 pp., illus. $24.95.

I recently sat in on an undergraduate engineering design course. Twenty students, mostly seniors majoring in engineering, were to design and build a walking robot. Most of them found the project very difficult. They could use mathematical techniques and computer programs to determine the details of motion and structure, but they had a hard time coming up with the design, imagining how the machine should work. They knew how to analyze, but not how to synthesize.

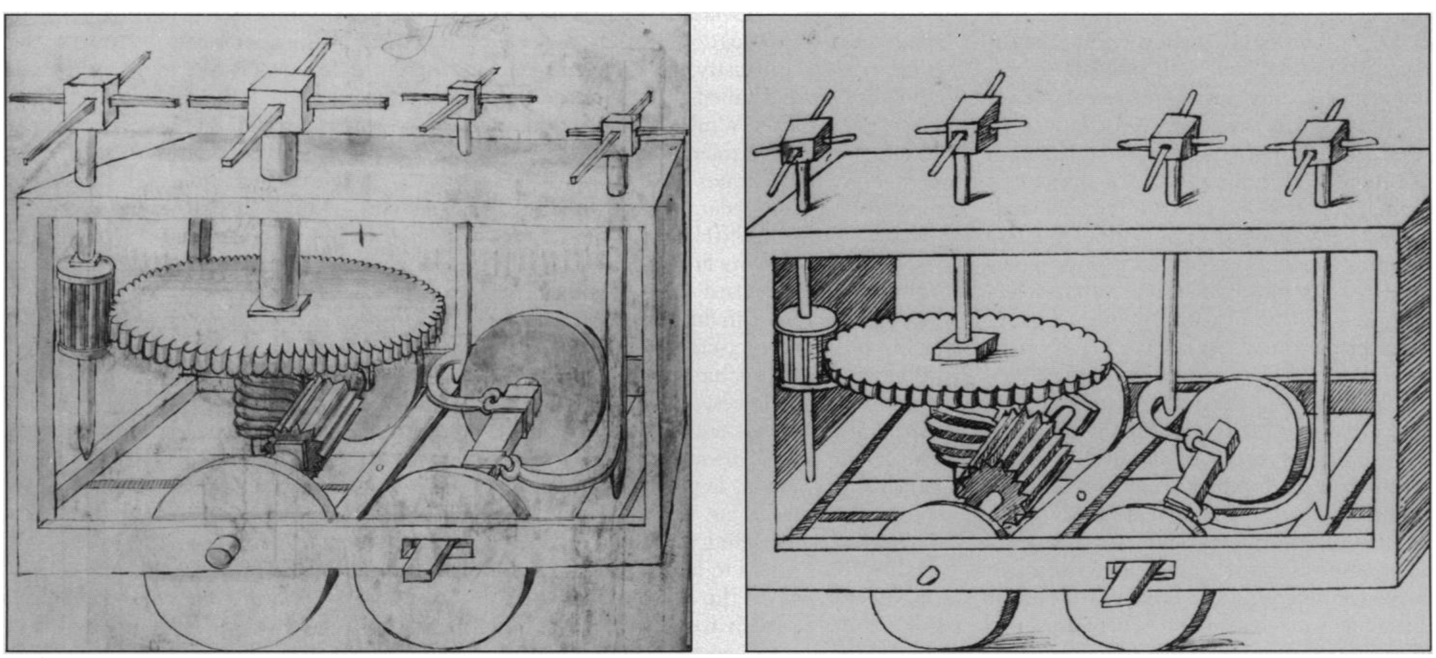
Eugene Ferguson, emeritus professor of the history of technology at the University of Delaware, explains why this is. Engineering education, he argues, has lost sight of the true nature of technological work. Engineering is not a scientific discipline. It is closer to art than science. It is non-verbal, creative, physical, and intuitive, based on experience of the real world, not on equations borrowed from the scientist.

A good engineer must have an "intimate, firsthand, internalized knowledge"—an "intuitive sense"—of technology. The only way to get this, says Ferguson, is to gain a "tactile and muscular knowledge" of moving machinery, materials, and fabrication processes. Students should visit factories and construction sites and get their hands dirty. But today, "engineering schools teach contempt, not admiration" for the people who actually build things. The 1952 Grinter Report on Engineering Education, for example, recommended that courses that taught skills or engineering practice be eliminated and replaced by courses in "engineering science." The move away from the real world was reinforced, Ferguson suggests, by the increased use of computers in engineering.

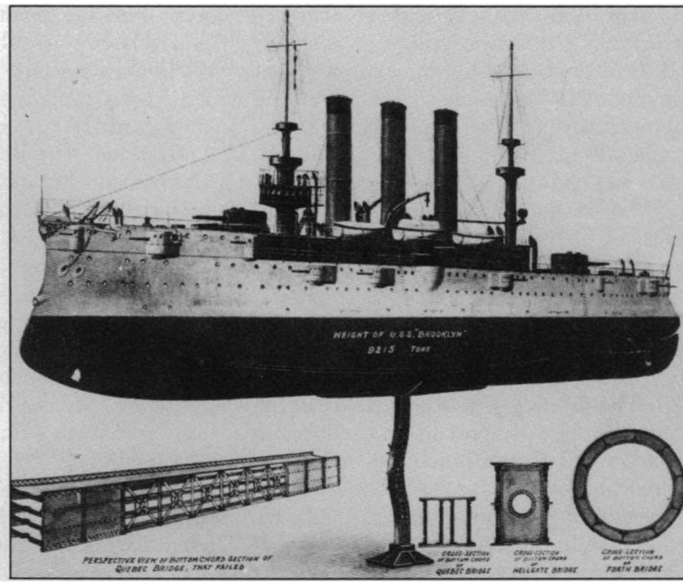
"By the 1980s," Ferguson writes, "engineering curricula had shifted to analytical approaches, so visual and other sensual knowledge of the world seemed much less relevant." He claims that the ensuing loss of "sound judgment and an intuitive sense of fitness and adequacy" and its replacement by engineering science has been responsible for many recent engineering failures, from the collapse of the Hartford Coliseum in 1978 to the myopia of the Hubble space telescope. "The successful design of real things in a contingent world," he writes, "will always be based more on art than on science."

This might seem the nostalgic screed of an curmudgeonly old-time engineer, upset with the rising prestige of science and the declining reputation of engineering. Be that as it may, the arguments throughout are based on some excellent history, a lifetime of thinking about technology, and a sophisticated, thoughtful, and provocative analysis of the nature of engineering.

The strength of the book is its analysis of engineering thought. The first step in design is visual, tactile thinking. Ferguson describes the extraordinary powers of visual imagination of great engineers. Elmer Sperry, for example, could visualize his gyroscopes as though they were hanging in the air in front of him. This visual facility depends on hands-on knowledge. "My fingers," wrote Walter Chrysler, "were an intake valve through which my mental reservoir was being filled."



A demonstration of the hazards of copying technical drawings. At left is an original drawing of a design for a carriage by Francesco di Giorgio, around 1470. At right is a copy made in the 1540s by a Sienese artist who was trained in the copying of such drawings. "Francesco's carriage was to be steered by moving the axle whose rectangular ends slide in slots on the near side of the carriage (and presumably on the far side also). The near half of Francesco's movable axle is attached to the J-shaped end of a capstan's vertical turning shaft. Note carefully the attachment at the end of the J, a loop fitting loosely in a loop attached firmly to the axle. The attachment on the far half of the axle is also a pair of loosely fitting loops. On the other hand, the copy shows two solid attachments instead of loosely fitting loops. Francesco's arrangement was clumsy, but it would work; the copyist's version would not." [From *Engineering and the Mind's Eye*]



Aftermaths of the failure of the Quebec City railroad bridge, which collapsed during construction in 1907. *Left*, the remains of the bridge, which "fell straight down onto itself, leaving an amazingly compact line of wreckage." An early report published in *Engineering News* and that of a year-long Canadian government inquiry agreed that the reason for the collapse was that "one of the members in the bottom chord of the landward ('anchor') arm of the cantilever truss buckled." *Right*, a "lesson" on buckling published in *Scientific American* after the collapse. "The weight of the cruiser *Brooklyn* was about the same as the calculated axial load on the chord girder that failed at Quebec City. The perspective drawing of the girder reveals inadequate bracing." [From *Engineering and the Mind's Eye*]

The next step is to convert mental images into drawings and specifications. Ferguson describes how this happens, from the "thinking sketch," to the "talking sketch," used in the collaborative process of design, to the "prescriptive sketch," used to direct the drafting of a finished drawing. Ferguson suggests that drawings "changed radically the balance of power between managers and workers," shifting the locus of decision-making from the shop floor to the drafting room.

Engineering drawings may look precise, scientific, and "true," but, like the design itself, they conceal "many informal choices, inarticulate judgments, acts of intuition, and assumptions about the way the world works." Ferguson does not claim that technology is "socially constructed," a creature of economic, political, and social forces, as more radical historians and sociologists of technology insist. Indeed, there's not enough analysis in the book of the ways larger cultural and social forces influence engineers' work. For Ferguson, engineering design is a social process, but he sees this mostly as a function of engineers looking over each other's drawing boards or talking over projects at lunch.

The increasing ability to capture visual images on paper and to make copies for others to see was a turning point in the rise of modern technology. The invention of pictorial perspective and printing in the 15th century changed engineering. For the first time, the exact visual information essential to technological knowledge could be communicated widely. Ferguson discusses the two traditions of technological picture books. "Theaters of machines," Renaissance compilations of illustrations of mechanical ideas such as Agostino Ramelli's *Le Diverse et Artificiose Machine* (1588) described technological possibilities, suggestions that an engineer might use where he saw fit. These, Ferguson suggests, were "simultaneously disruptive and progressive." They suggested the possibility of new ways of doing things. Detailed descriptions of existing technical processes, such as Agricola's 1556 *De Re Metallica*, on the other hand, had a more conservative effect; they diffused established techniques.

Ferguson's most interesting case study is his discussion of the art and science of fortification. In response to improvements in cannon in the late 15th century, military engineers developed a new kind of fortress design, a regular polygon with gun platforms at each corner to protect the walls with gunfire. For hundreds of years military engineers were fascinated with the "ideal form" of a fortress. In their attempts to make the perfect fortress—to make it in reality as it was on paper—they decreed that the area of the fortress must first be turned into a flat plain. The environs of a fortress (and by extension, of any engineering design), according to this scheme, must be predictable and controllable, uncluttered with people or nature. This "fortress mentality," Ferguson suggests, is the mindset on which modern engineering is based.

Engineering and the Mind's Eye is full of interesting suggestions like this, historical vignettes that are mined for their bigger implications about the nature of engineering. Ferguson fears that engineering has changed for the worse. To revive it, he recommends that engineers be taught more about the real world, and less mathematics; that common sense play a greater role in engineering; that there be more hands-on management of engineering; and that the engineering profession be more accepting of outside criticism. This is good advice. Thoughtful engineers will find Ferguson's historical essays fascinating and his ideas about engineering education worthy of consideration.

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Biotic Prognostications

Global Warming and Biological Diversity. ROBERT L. PETERS and THOMAS E. LOVEJOY, Eds. Yale University Press, New Haven, CT, 1992. xxii, 386 pp., illus. $45. From a conference, Washington, DC, Oct. 1988.

Since 1920 the average temperature of the earth has increased about 0.5°C relative to the 1861–1900 average. This trend is correlated with a parallel increase in the concentrations of carbon dioxide, methane, and chlorofluorocarbons in the atmosphere. These "greenhouse gases" come from a variety of sources related to the relentless demands placed on the planet by a human population in log-phase growth, and they