Stressing *the* Science *of* Engineering

Design, theory, and practice are inherent in our species.

By Adrian Bejan

William John Macquorn Rankine (1820-1872) founded thermodynamics along with Rudolf Clausius and William Thomson, Lord Kelvin.

Few things bother me more than when I hear my peers speak of "engineers and scientists." Are we really two kinds of animals, like cats and dogs? The worst was an engineering administrator who would explain to the parents of incoming freshmen that engineers are those who make things based on the discoveries given to them by scientists.

I had no idea that engineers were that inferior, but unfortunately, this is the common impression, and we are guilty of propagating it. It hurts our profession and self esteem. I want to change that.

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Words have meaning. The dictionary defines engineering as the science of useful processes, phenomena, and devices. If we delete "useful" from this definition we are left with the definition of physics, the darling of the Nobel committee. This does not mean that physics is unconcerned with useful things. Physics is concerned, and when it addresses usefulness, it calls itself "applied physics."

The B.S.M.E. degree is a reminder that engineering is science. The framers of ASME knew this, because in the ASME Constitution they wrote that "The purposes of this Society are to: Promote the art, science, and practice of mechanical and multidisciplinary engineering. ..."

Sometimes engineering is also called an art. Many of us are raised with the notion that "science" is about pure ideas that are fun, and that "art" is about purposeful things. This is wrong because science is useful, and art is not always about usefulness.

The science that promises to come from the Super Collider may be interesting and fun, but the public funding for it comes from a very loud selling argument promising great payoffs for the energy survivability of humanity. This is an example of how science and engineering are one. All science is useful.

Art, on the other hand, is the human activity to make things, i.e. the creativity of man. This, the creativity, applies equally to those who imagine new designs and those who formulate new laws of physics. Niels Bohr noted that "It is wrong to think that the task of physics is to find out how nature is. Physics concerns what we say about nature."

Creativity—the gift to have original ideas occurring in the mind—is what unites us as scientists. The engineer is not to be confused with the technician, whose role requires the application of knowledge, but not necessarily in an imaginative way. In his 1951 *Memoirs*, President Herbert Hoover wrote, "Engineering without imagination sinks to a trade."

Science is a story, and the better story is the better science. Science with engineering is a much better story than science without engineering.

How the Future Is Being Designed

Think of how science "happens," what science is, and why science is good for all of us—so good that we keep telling its story! Think of science as a good joke—in fact, the best joke because it is repeated the most.

Science lives up to its literal meaning, which is "knowledge" (scientia in Latin). As we come to know more, we become more reliant on our knowledge to predict accurately what will happen if we make decision A, as opposed to making decision B. We compare the known consequences of A and B, and we choose. With science, we design the future, we predict it, we build it, and we walk into it.

Nicolas Léonard Sadi Carnot (1796-1832) graduated from the École Polytechnique, and in 1824 published the book Reflexions on the Motive Power of Fire.

We are being selfish, because we design the future to be good for us, with ourselves inserted in it. This virtual future walks and drives with us, in front of us, like the carrot in front of the horse. We have it much better than the horse: we eat the carrot, lots of carrots, and we cover enormous areas. We develop new carrots, and keep on going. In this future we make our best choices, all the time. We go with the flow, and the flow goes with us.

Without knowledge, we would be crawling back into the caves, fearful of everything that moves. Read the news: this still happens today.

I remember very clearly one morning in October 1967, when I was walking to class. The subject was one of the pillars of engineering: strength of materials, which is a misnomer for the resistance (stiffness) of loaded structures. I was reviewing in my mind the previous lecture, which had been about how to select the thickness of a steel bar such that it will not break when a specified weight was attached to its end. It is an easy piece of analysis, but when I was crossing the street I was struck by a mental image so powerful that it felt dangerous. I saw that by knowing the principles I knew what will happen to that bar. I knew the future of the bar and of those sitting on it.

Valuable is the economics and strategic benefit derived from such knowledge: one does not have to construct several bars, test them all, and keep the ones that do not break. This is a big deal, and it is easy to see.

The value of science is a lot more subtle, and it is monumental. Crossing the street I saw that my teachers were giving me the power to predict the future. Not one future but several, one for each bar that I was contemplating. Even better, I was being given the knowledge to select the future that serves us best—the future with a bar that is strongest, lightest, and easiest to build. This meant that I was being empowered to design the future. I, a veritable nobody from nowhere behind the Iron Curtain, was acquiring powers that before science were attributed to the work of God.

Ludwig Prandtl (1875-1953) is widely recognized as the father of modern fluid dynamics.

Good Ideas Travel Far, and Persist

Look at the oldest technical book (perhaps the only one from antiquity) that continues to be used unchanged: Euclid's *Elements* (ca. 300 B.C.), which is the basis of science (plane and solid geometry, arithmetic) and the method of proving and disproving on a clean table, naked, in front of everybody (no tricks allowed).

Geometry is the science of figures. Its ancient counterpart, mechanics, is the science of contrivances made with those figures. Geometry and mechanics are the seeds from which our engineering and civilization grow to this day. Many besides Euclid have contributed to this grand design.

Each engineer respects his own pantheon of grand figures. For me it is Carnot, Rankine, Gibbs, and Prandtl. These were engineers, mechanical engineers in the current terminology. Carnot and Rankine started the science of thermodynamics. Gibbs gave it analytical geometry, and with boundary layer theory, Prandtl put fluid dynamics at the fingertips of all of us.

Their impact on science is so great that most academics today think that these men were physicists, not engineers. Why is this? Rankine explained in 1859:

"...The improvers of the mechanical arts were neglected by biographers and historians, from a mistaken prejudice against practice, as being inferior in dignity to contemplation; and even in the case of men such as Archytas [an ancient Greek philosopher] and Archimedes, who combined practical skill with scientific knowledge, the records of their labours that have reached our time give but vague and imperfect accounts of their mechanical inventions, which are treated as matters of trifling importance in comparison with their philosophical speculations. The same prejudice, prevailing with increased strength during the middle ages, and aided by the prevalence of the belief in sorcery, rendered the records of the progress of practical mechanics, until the end of the fifteenth century, almost a blank. Those remarks apply, with peculiar force, to the history of those machines called PRIME MOVERS." (The capitals are Rankine's.)

Why We Want Science

Why is it human to want power (prime movers)? Why is it human to have mental images, to want to know, and if possible, to know in advance, to predict? Why is it human to want science?

The answer turns out to be so "one size fits all" that it is anticlimactic. All our urges—to have life, food, shelter, knowledge, and continuity—are design features that facilitate the movement of all animal mass over the Earth. Without such designs our mass would not be moving as easily and as far. Without other flow designs (exergy streams called food and fuel), our mass would not be moving at all. In the physical world, all systems natural and man-made follow a design principle: they evolve their designs in time in the direction of easier movement.

The net result of civilization's advances in knowledge and technology is that we move more mass over greater distances. This time direction is the constructal law, the physics law of design and evolution, and this mental viewing came from engineering.

Engineering science consists of these few principles on which nature is founded: the laws of mechanics, thermodynamics, and design. The principles lead us straight, not on a blind and crooked path of trial and error.

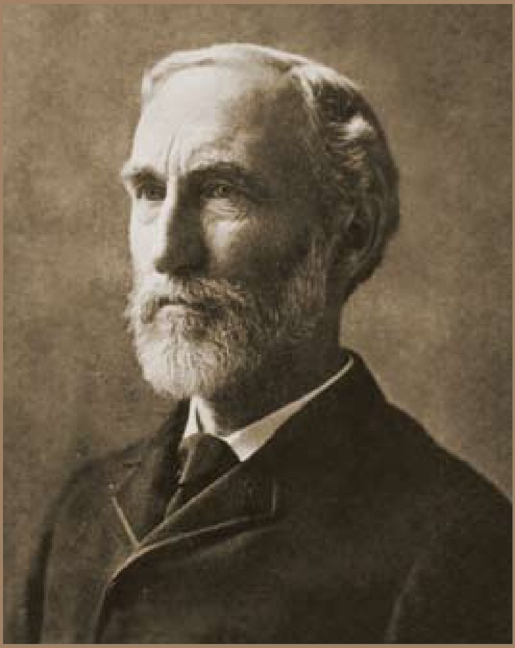
These few principles unite the animate systems (the biosphere, animals, vegetation, organs, cells, humans, societies) with the inanimate systems, which are much older on Earth (river basins, lightning, lava, winds, ocean currents, plate tectonics, magma). They unite the "natural" with the "artificial."

The natural are all the animate and the inanimate systems. Artifacts are objects made by human work. Any such object (including ideas, learning, science) is an extension, an add-on to the individual.

The "human" is not the naked body sketched in the anatomy book. Because of artifacts (writing, transportation, communication, commerce, security, etc.), each of us is faster, more efficient, longer lasting, and farther reaching than his or her ancestors. We evolve. We change in time along with our artifacts. Each of us reaches around the globe.

The human is the body plus all its artifacts, and as such it constitutes the *human and machine species*. This is who we are, and why we evolve in front of our own eyes, as a civilization rooted in engineering science.

The artificial is natural, and to want engineering science is natural. ■



Josiah Willard Gibbs (1839-1903) received the first American Ph.D in engineering for his thesis On the Form of the Teeth of Wheels in Spur Gearing *(1863, Yale University).*

To Learn More

This article is based on three of Adrian Bejan's recent books: *Advanced Engineering Thermodynamics*, 3rd ed. (Wiley 2006); *Convection Heat Transfer*, 3rd ed. (Wiley 2004); and *Design with Constructal Theory* (with S. Lorente, Wiley 2008).

His new book *Design in Nature* (with J. P. Zane) will be published by Doubleday in January 2012.