The 21st Century Engineer

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What does a 21st century engineer need to know? To attempt an answer, let's briefly examine some of the new capabilities that are shaping the future of engineering—terascale, nanoscale, complexity, cognition, and holism. Because science and technology are transforming forces, it will be these emerging fields, the unpredicted territories, that will change and expand our capabilities as engineers and innovators. Reasonable people can argue about whether or not these are the right ones, but they seem an appropriate starting point.

Terascale. This new capability takes us three orders of magnitude beyond present general-purpose and generally accessible computing capabilities. In the past, our system architectures could handle hundreds of processors. Now we are working with systems of 10 000 processors. In a very short time, we'll be connecting millions of systems and billions of "information appliances" to the Internet. Crossing that boundary of one trillion operations per second will launch us toward new frontiers.

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For example, the protein-folding problem, the Holy Grail of computational biology, has withstood countless attacks, undertaken by many bright minds and augmented by years of scientific supercomputer time. On current systems, the simulation of a millisecond of protein folding (the longest undertaken to date) requires two months. In the real world, typical protein folding times are 20 ms. That means some 40 months of processor time are needed to run a full-scale simulation on current systems. With new terascale systems, we may be able to reduce this time one thousand-fold. That means one day instead of three years.

Nanoscale. This advance will take us three orders of magnitude below the size of most of today's human-made devices. Nanostructures are at the confluence of the smallest of human-made devices and the large molecules of living systems, letting us imagine connecting machines to living cells. Nanotechnology lets us manipulate matter one atom or molecule at a time. It could lead to amazing breakthroughs—for example, to molecular computers that could store the equivalent of the U.S. Library of Congress in a device we could wear.

Complexity. Mitch Waldrop writes in his book, *Complexity*, about a point "where the components of a system never quite lock into place, and yet never quite dissolve into turbulence, either...." It's often called the edge of chaos, "where new ideas and innovative genotypes are forever nibbling away at the edges of the status quo...." If we look at science and engineering, we discern this zone of transformation at many scales, in many disciplines, and in the most unexpected places.

For example, researchers are trying to wed polymers to silicon—a marriage of opposites, because plastics are chaotic chains while silicon consists of orderly crystals. The resulting electronic devices would have marvelous flexibility, be less expensive to make, and, therefore, empower more people. Again, it comes down to managing order and disorder, all at once. Perhaps there ought to be a term for it—how about "chaotic engineering"?

Cognition. The dictionary defines cognition as "the mental process or facility by which knowledge is acquired." Because of new knowledge, methods, and tools, I believe we are on the verge of a cognitive revolution that may dwarf the information revolution. We are poised for many exciting new discoveries in this area. These breakthroughs will lay the foundation for progress in many areas of national importance, from teaching children how to read to understanding learning processes; from building human-like computers and robots to designing networks and systems capable of cognition.

Holism. According to the dictionary, again, holism is "the concept that an entity is greater than merely the sum of its parts." It refers to new capabilities to put things together—how to integrate seemingly disparate things into a greater whole. This includes social as well as physical and virtual engineering systems. I believe the hallmark of the modern engineer is the ability to see connections among seemingly disparate components, and to integrate them in ways that exceed the sum of their respective capacities.

All told, progress in these areas—tera, nano, complexity, cognition, and holism—will lay out the capacity for an integrated design field far beyond what is imaginable with today's technology.

Taken together, this means that 21st century engineers will need to be astute makers, trusted innovators, agents of change, master integrators, enterprise enablers, technology stewards, and knowledge handlers. They will need more than first-rate technical and scientific skills. They will need to embrace complex systems and the issues they present, and reach the right decisions about how huge amounts of time, money, people, knowledge, and technology are tasked to a common end.