Samuel Neaman Institute

FOR ADVANCED STUDIES IN SCIENCE AND TECHNOLOGY

Redefining Engineering Disciplines for the 21st Century

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8 University, Education and Human Resources

Technion - Israel Institute of Technology

ABOUT THE INSTITUTE

The Samuel Neaman Institute for Advanced Studies in Science and Technology is an independent public-policy research institute, established in 1978 to assist in the search for solutions to national problems in science and technology, education, economy and industry, and social development. As an interdisciplinary think-tank, the Institute draws on the faculty and staff of the Technion, on scientists from other institutions in Israel, and on specialists abroad. The Institute serves as a bridge between academia and decision makers in government, public institutions and industry, through research, workshops and publications.

The main emphasis in the professional activity of the Samuel Neaman Institute is in the interface between science, technology, economy and society. Therefore the natural location for the Institute is at the Technion, which is the leading technological university in Israel, covering all the areas of science and engineering. This multi-disciplinary research activity is more important today than ever before, since science and technology are the driving forces for growth and economic prosperity, and they have a significant influence on the quality of life and a variety of social aspects.

The Institute pursues a policy of inquiry and analysis designed to identify significant public policy problems, to determine possible courses of action to deal with the problems, and to evaluate the consequences of the identified courses of action.

As an independent not-for-profit research organization, the Institute does not advocate any specific policy or embrace any particular social philosophy. As befits a democratic society, the choices among policy alternatives are the prerogative and responsibility of the elected representatives of the citizenry. The Samuel Neaman Institute endeavors to contribute to a climate of informed choice.

The Institute undertakes sponsored research, organizes workshops and implements continuing education activities on topics of significance for the development of the State of Israel, and maintains a publications program for the dissemination of research and workshop findings. Specific topics for research may be initiated by the Institute, researchers, government agencies, foundations, industry or other concerned institutions. Each research program undertaken by the Institute is designed to be a significant scholarly study worthy of publication and public attention.

Origins

The initiative for establishing this Institute in Israel was undertaken by Mr. Samuel Neaman. He nurtured the concept to fruition with an agreement signed in 1975 between himself, the Noon Foundation, the American Society for Technion, and Technion. It was ratified in 1978 by the Senate of the Technion. Mr. Neaman, a prominent U.S. businessman noted for his insightful managerial concepts and innovative thinking, as well as for his success in bringing struggling enterprises to positions of fiscal and marketing strength, devoted his time to the activities of the Institute, until he passed away in 2002.

Organization

The Director of the Samuel Neaman Institute, appointed jointly by the President of the Technion and by the Chairman of the Institute Board, is responsible for formulating and coordinating policies, recommending projects and appointing staff. The current Director is Professor Nadav Liron. The Institute Board of directors is chaired by Prof. Zehev Tadmor. The Board is responsible for general supervision of the Institute, including overall policy, approval of research programs and overseeing financial affairs. An Advisory Council made up of members of the Technion Senate and distinguished public representatives, reviews research proposals and consults on program development.

Redefining Engineering Disciplines for the Twenty-First Century.

Zehev Tadmor

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All engineering disciplines derive from military engineering[1] (Figure 1), which was formalized in eighteenth-century France through the creation of technical institutes. Inspired by the French Revolution and the "century of light," the first institute, the École Polytechnique, was established in Paris in 1794 (Bugliarello, 1991; Tadmor, 2003). The concurrent industrial revolution[2] and the so-called second industrial revolution associated with the rise of the steel, chemical, and electrical industries (Nybom, 2003), were driving forces behind the proliferation of the technical institute/university model that led to the establishment of a host of polytechniques in Europe, the Technische Hochshule in Germany, and institutes of technology in the United States (Rensselaer Polytechnic Institute, 1824; Massachusetts Institute of Technology [MIT], 1861; Stevens Institute of Technology, 1870; Georgia Institute of Technology, 1885; California Institute of Technology, 1891; Carnegie Mellon University, 1900) and elsewhere. These early institutes, which focused on the industrial arts, began by teaching civil engineering and then gradually other engineering disciplines.[3]

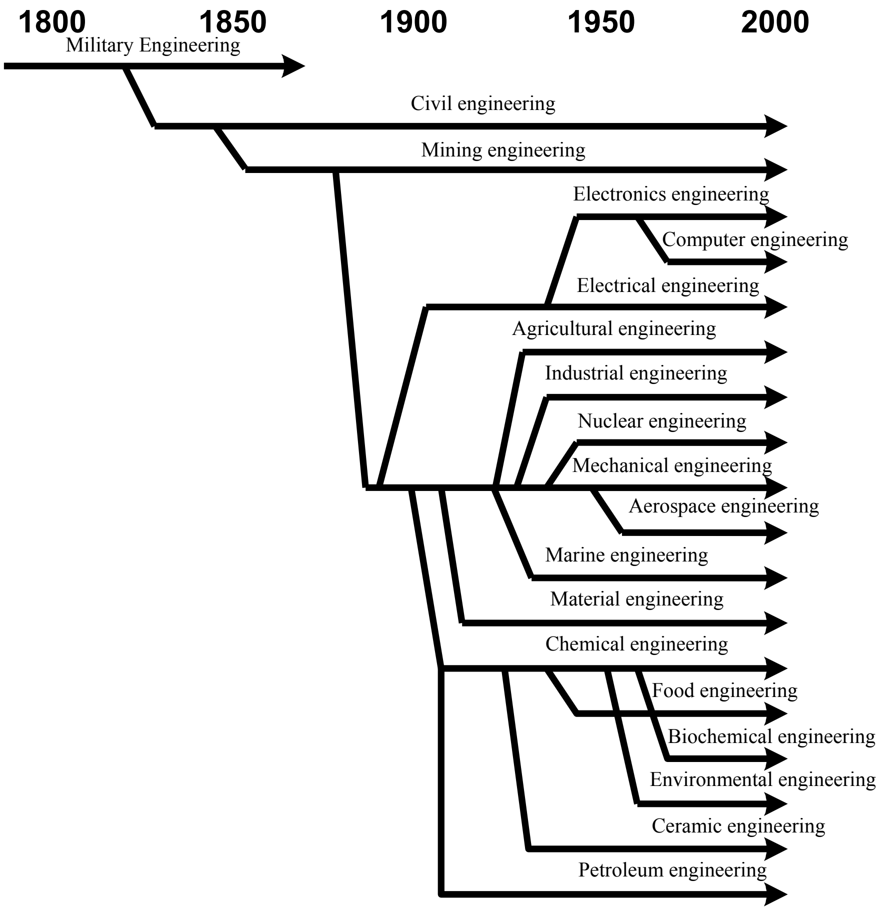

FIGURE1 A schematic approximation of the historical evolution of engineering disciplines.

Creation of Modern Engineering Disciplines

During the first quarter of the twentieth century, a new educational philosophy emerged that transformed engineering education from high-level, vocational, trade-school-like training in current industrial practices into a discipline firmly rooted in the sciences. One of the leaders who championed this transformation was Karl Taylor Compton, president of MIT, who made it the theme of his inaugural address in 1930 (Compton, 1930):

> I hope, therefore, that increasing attention in the Institute may be given to the fundamental sciences; that they may achieve as never before the spirit and results of research; that all courses of instruction may be examined carefully to see where training in details has been unduly emphasized at the expense of the more powerful training in all-embracing fundamental principles. Without any change of purpose or any radical change in operation, I feel that significant progress can thus be made.

As Compton foresaw, the movement toward fundamental principles became the dominant trend in engineering education throughout the century. Triggered by phenomenal successes in the natural sciences, which have expanded mankind's understanding and horizons beyond all expectations, the scientific method was applied to engineering. The movement gained momentum after World War II, when engineering curricula were gradually purged of vocationalism and were augmented by fundamental science studies. The impact of this change was so profound that it can be considered a revolution in engineering education. Indeed, the "science revolution" is the hallmark of engineering education in the twentieth century.

This profound restructuring of engineering education led to the formulation of engineering sciences, which still constitute the core curricula of engineering education in all disciplines. Thus, graduating engineers are no longer simply proficient in current engineering practices. They have been instilled with a solid engineering science foundation that enables them to cope with fast-changing technologies. In parallel, the engineering professoriate, whose main goal throughout much of the twentieth century was to create the engineering sciences using “tough quantitative and mathematical” tools, imparted “academic, scientific respectability” to the profession (Simon, 1969).

An inevitable by-product of the science revolution was that engineering design, because it did not have a formalized, quantitative, teachable core body of knowledge, was largely purged from engineering curricula. Engineers were expected to learn design on the job. Indeed, the development of a formalized approach to engineering design remains an open challenge to the engineering professoriate.

Fusion of Science and Technology

Historically, the scientific revolution preceded the industrial-technological revolution by about two centuries. Until the end of the nineteenth century, the two movements ran on parallel tracks with little interaction between them. Their objectives were different, and they were led by different kinds of people. The objective of the industrial movement was to develop new technologies and improve old ones; this movement was led by craftsmen, artisans, and visionary entrepreneurs, such as James Watt and other inventors.[4] The objective of the scientific movement was to understand nature and was led by philosophers and scientists.

At the beginning of the twentieth century, the two revolutions began to converge, reinforcing and catalyzing each other.[5] By the end of the century, they had effectively fused into a single entity, igniting a new science-technology (*scitech*) revolution, with more profound consequences for the human condition than either of the revolutions that preceded it. The scitech revolution is the cause, source, and *alma mater* of all high technology, globalization, and the subsequent explosive developments in worldwide economics. Scitech has blurred the distinction between basic and applied research; obliterated the classical linear innovation model (whereby it was assumed that the fruits of basic research lead in a linear fashion to industrial application); and decreased the time span between invention and application. Scitech mandated multidisciplinarity in leading-edge research on the micro, nano, molecular, atomic, and even subatomic levels, and it made the research university the wellspring of technological innovation.

If the hallmark of engineering education in the twentieth century was the science revolution, which led to curricula designed to teach engineers[6] science-based, all-embracing, fundamental principles, we must ask ourselves how the ongoing fusion of science and technology, and the consequent scitech revolution, will affect engineering disciplines in the twenty-first century. If science and technology are indeed fused into a new entity, doesn't this blur the distinction between engineering and science? Perhaps we should not be talking about applying scientific methods to engineering, but rather inventing new curricula in which there is *no separation* between science and engineering.

In other words, perhaps we should reconsider engineering curricula in the most fundamental way and create entirely novel science-engineering (*scieng*) or engineering-science (*engsci*) curricula.[7] From this perspective, the twenty-first century could herald the next revolution in engineering education. The dictionary definition of the engsci engineer or scigineer could be: a person who uses scientific knowledge and microscopic building blocks to create products, materials, and processes that are useful to man.

Molecular Engineering: A Case in Point

In May 2002, an international workshop (Touchstones of Polymer Processing), was held at the Polymer Processing Institute, New Jersey Institute of Technology. Leading researchers in the field examined long-term trends of their profession and concluded that the relatively new discipline of polymer processing and engineering, which had split off from chemical engineering in the United States and mechanical engineering in Europe, rather than converging into a well defined, separate engineering discipline as had been expected for decades, was, in fact, diverging into a broad, multidisciplinary activity. Of course, the divergence of disciplinary research into a multidisciplinary approach is characteristic of most engineering disciplines, but polymer processing, a latecomer to the engineering discipline arena, had diverged before it had a chance to converge into a separate, well defined entity.

As polymer processing becomes increasingly multidisciplinary, and looking from "inside the profession out," the participants concluded that the name macromolecular engineering and science (MMES) described the current character of the profession better than polymer processing.[8] Moreover, MMES is, in fact, part of a broader scene. On the fundamental level, the boundaries of MMES merge with molecular biology, complex fluids, polymer chemistry, polymer physics, chemical engineering, and other disciplines. At the research university level, this could lead to the creation of an entirely new engsci or scieng undergraduate curriculum called molecular engineering.

As shown in Figure 2, the molecular engineering curriculum could branch out in the junior year into three separate engsci disciplines: chemical molecular engineering (formerly chemical engineering), macromolecular engineering (formerly polymer engineering and science and polymer processing), and biomacromolecular engineering (formerly biochemical engineering and biotechnology). A scieng or engsci curriculum would require five years of study, rather than the current four, and would lead directly to an M.S. degree.

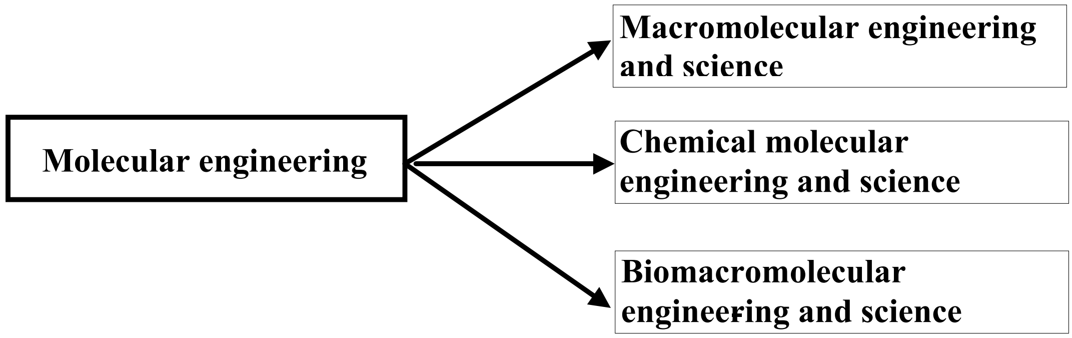

FIGURE 2 The new engsci discipline of molecular engineering, which breaks up in the junior year into three separate engsci disciplines.

The philosophy of engsci curricula should be radically different from current engineering curricula. The engsci point of view, perspective, and mind-set should lead from the molecular toward the macroscopic, and not the other way around. The latter begins by examining a macroscopic process, analyzing it and, if need be, looking all the way down to the molecular scale, whereas the former begins with a process on the molecular scale and examines its macroscopic implications and consequences. This bottom-up perspective should lead not only to a more in-depth understanding of processes, but also to fresh insights and the application and production of a multitude of novel artifacts that serve useful purposes.

A follow-up to the Touchstones Workshop, held in Leeds, United Kingdom, was supported by the Center for Advanced Engineering Fibers and Films at Clemson University and NSF. At this workshop, the first steps were taken toward constructing an engsci curriculum and exploring the possibility of its multi-university implementation. The workshop participants formulated a first draft of a curriculum for molecular engineering designed to produce graduates who consider molecular issues before designing a process or product and then use molecular information to increase the accuracy of the design (Edie, 2003).

The workshop participants concluded that educating students to view problems from the molecular level first would require restructuring and reordering many existing courses, as well as developing a number of new courses. Thus, additional funding would be required to formulate in detail and implement molecular engineering, even as a multi-university effort. To this end, proposals have been and are being submitted to NSF and other agencies to fund course development and program implementation.

Conclusion

It is important to remember that a revolutionary redefinition of engineering disciplines into engsci, scieng, or scigineering disciplines at the research university level will not mean that conventional engineers in chemical, electrical, mechanical, and other fields of engineering are no longer needed. In fact, they continue to be crucial for current industrial needs, and colleges and other institutions of higher education must continue to educate them. Research universities, however, should focus on educating scigineers, who will be equipped with the knowledge and skills to shape and contend with the industries of the twenty-first century.

In the author's judgment, with the explosion of knowledge in all relevant fields, it is no longer possible to educate engineers in just four years. The time has come to implement a five-year curriculum at all research universities, and perhaps at other institutions as well (Augustine, 1999; Tadmor et al., 1987). The M.S. degree should be an engineer's first professional degree, and certainly the first degree of an engsci graduate.

Acknowledgements

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Notes

[1] *The Encyclopedia Britannica* of 1779 defines an engineer as "one in the military art, an able expert man who by perfect knowledge in mathematics, delineates upon paper or makes upon the ground all sorts of facts and other works for offense and defense."

[2] In 1769, James Watt patented his steam engine with a separate condenser, which vastly improved the Thomas Newcomen machine and thus helped launch the industrial revolution.

[3] It is worth noting that many of these institutes had a broader perspective than teaching just industrial arts.

[4] Eli Whitney, Samuel Morse, Alexander Graham Bell, William Henry Perkins, Guglielmo Marconi, Thomas Edison, George Eastman, Leo Baekeland, Charles Goodyear, John Wesley Hyatt, Orville and Wilbur Wright, and Nicola Tesla are among the inventors who catalyzed the industrial revolution.

[5] Historians of technology consider GE Laboratories, established in 1900, the first laboratory where science was systematically applied for the promotion of technology. During World War II, the interaction was greatly accelerated by the application of science to the war effort, yielding important developments such as radar, synthetic rubber, and, of course, the atomic bomb. This experience convinced the government that "science is power" and is thus worthy of public support. The recommendations in Vannevar Bush's famous report to the President, *Science: The Endless Frontier*, which was submitted shortly after the war, were enthusiastically accepted and implemented. This led to the creation of the National Science Foundation (NSF), which signaled the beginning of massive support for science that continues to the present day.

[6] The current *Webster's Dictionary* definition of *engineer* is: (a) a member of the military group devoted to engineering work; (b) a designer and builder of engines; (c) a person who is trained in or follows a profession in a branch of engineering. *Engineering* is defined as: (a) the art of managing engines; (b) a science by which the properties of matter and the sources of energy are made useful to man.

[7] Prof. Ellad B. Tadmor, who reviewed this paper, suggested that just as Disney coined the term "imagineering," we could adopt the word "scigineering."

[8] Similar conclusions were suggested at an earlier NSF-Department of Energy cosponsored workshop, "Interdisciplinary Macromolecular Science and Engineering"(MMES) chaired by S.I. Stupp, May 13-15,1997 and held at NSF Headquarters Arlington VA, which concluded that, at the interface between macromolecular science, chemistry, physics, and biology, a new field of MMES is emerging that "requires a new kind of polymer processing"**.**

Professor Zehev Tadmor is Distinguished Professor Emeritus of Chemical Engineering at the Technion Israel Institute of Technology. He is President Emeritus of the Technion and currently is the Chairman of the Board of the S. Neaman Institute for Advanced Studies in Science and Technology at the Technion. His main research interest is polymer processing, and he helped convert the embryonic engineering field of polymer processing into a solid engineering science. He has published several books, numerous papers, and received many patents in this field. His other interests are national public policy in science and technology, engineering education, and university history, management and organization. Professor Tadmor is member of the Israel Academy of Sciences and Humanities and the National Academy of Engineering of the United States. He received an Honorary Doctorate from the University of Bologna, and numerous prizes among them the USA Society of Plastics Engineers (SPE) Extrusion Divisions Distinguished Service Award, the Fred O. Conley Award for Outstanding Achievements in Plastics Engineering and Technology of the SPE, and was inducted into the Polymer Processing Hall of Fame. He also received the Rotary prize for Outstanding Contribution to Higher Education in Israel and was recently awarded the prestigious EMET prize by the Prime Minister of Israel for his outstanding research work in Chemical Engineering.

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