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# Guest Editorial

## CHALLENGES IN ENGINEERING EDUCATION OF NANOTECHNOLOGY

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1951, Richard Feynman stated in his classic talk 'There's Plenty of Room at the Bottom' that 'Atoms on a small scale behave like nothing on a large scale, for they satisfy the laws of quantum mechanics. So, as we go down and fiddle around with the atoms down there, we are working with different laws, and we can expect to do different things. We can manufacture in different ways . . . . At the atomic level, we have new kinds of forces and new kinds of possibilities, new kinds of effects. The problems of manufacture and reproduction of materials will be quite different . . . . The principles of physics, as far as I can see, do not speak against the possibility of maneuvering things atom by atom. The problems of chemistry and biology can be greatly helped if our ability to see what we are doing, and to do things on an atomic level, is ultimately developed—a development which I think cannot be avoided.'

1981, K. Eric Drexler stated in 'Molecular Engineering: an approach to the development of general capabilities for molecular manipulation' that 'Development of the ability to design protein molecules will open a path to the fabrication of devices to complex atomic specifications, thus sidestepping obstacles facing conventional microtechnology. This path will involve construction of molecular machinery able to position reactive groups to atomic precision. It could lead to great advances in computational devices and in the ability to manipulate biological materials. The existence of this path has implications for the present.'

Fifty years after Feynman's speech and twenty years after Drexler's, Nanotechnology is taking the center stage of the science and technology. In the past fifty years, the microelectronic based technology enabled the realization of computers, wireless communication, and microelectromechanical systems, and its profound impact changed the way information is exchanged, shared, and utilized. However, we start to see the limits of further reducing the feature sizes of microelectronics, and in the next generation, Nanotechnology must be realized to catalyze the next industrial revolution. Numerous research groups and enormous amount of funding are directed towards developing the required technologies across disciplines, across institutional boundaries, and across nations to realize the implication of nanotechnology. Apparently, both science and technology in the 21st century will require major breakthroughs to control nano-scaled structures and functions and further improve computing, imaging, chemical synthesis, drug delivery, and genetic engineering, among other things. Obviously, the research field is broad, and its realization is challenging. To accelerate the advancement in this area, innovative partnerships that integrate research and education must be implemented.

To maintain the speed at which innovations and inventions are generated, there is an unprecedented demand of highly educated and trained engineers in the field of Nanotechnology. However, the traditional engineering education training is inadequate in preparing the students for the challenges presented by this industry's dynamic environment, and insufficient to meet the employer's criteria in hiring new engineers. To bridge the gap between fast-paced researches and current educational programs, we need to reform the curricula starting at the undergraduate degree level and aiming at all degree levels.

This special issue of the International Journal of Engineering Education examines the establishment of degree programs and courses in Nanotechnology. A key element in educating engineers in Nanotechnology is to emphasize the bottom-up approach in assembling bio- and nano-materials while still take advantage of the top-down approach widely used in electronics manufacturing. The new engineering curricula need to provide students with a broad knowledge base and crosscutting programs in interdisciplinary fields. In this special issue, we present the effort in USA, Europe, and Australia in transforming the existing engineering education programs and courses to meet the requirements in the era of Nanotechnology.

The first invited paper by Dr. Mihail Roco at National Science Foundation estimated that about 2 million workers will be needed worldwide in Nanotechnology in 10–15 years, and showed that specific education models and the institutionalization of Nanotechnology curriculum are central to the engineering education of future generations.

The next five papers discussed the establishment of degree programs in Nanotechnology, at the Ph.D., Masters, and Undergraduate levels.

Professors Viola Vogel and Charles Campbell described in detail a newly launched doctoral degree program in Nanotechnology at University of Washington to prepare students as leaders in engineering nanoscale phenomena, in disciplines of science, engineering, and medicine.

Professor Robert Kelsall explained a Masters Training Package in Nanoscale Science and Technology at the Universities of Leeds and Sheffield in the United Kingdom, which is a highly interdisciplinary and research-oriented program for training students in physics, chemistry, electronic engineering and materials science.

Professor Joe Shapter introduced the first Nanotechnology undergraduate degree at Flinders University in Australia, with an emphasis on developing and delivering this degree program out of a traditional physical sciences environment and the impact of this program.

Professor Emily Allen *et al.* described a new interdisciplinary curriculum in Microelectronics Process Engineering at San Jose State University. This new program serves as a template for future Nanotechnology curriculum and emphasizes on hands-on thin-film fabrication experience.

Professors Paul M. Hallacher, Douglas E. Fenwick, and Stephen J. Fonash introduced the Pennsylvania Nanofabrication Manufacturing Technology partnership. This program originated as a state government response to the Nanotechnology workforce and research needs of industry and grew into a unique team effort involving over 30 institutions of higher education, secondary schools, and private industrial companies.

For engineering education reform in the 21st century, restructuring the courses and the usage of computer modeling and the internet are trends and necessities. While virtual university (electronic platform) and interactive multimedia are being established, it is important to note that faculty involvement is essential to effective knowledge transfer and student learning. The following four papers addressed courses related to Nanotechnology, including the use of computer animation and internet for interactive learning.

Professor Zdenek Weiss *et al.* discussed a Ph.D. student course focusing on analytical training in the field of nano-scale materials, including computer modeling of nano-structured systems and nano-scale surface analysis.

Professor Art Ellis *et al.* presented various examples of shaping matters at the nano-scale and materials and devices whose properties depend on nano-scale control. These examples are designed for incorporation into the classrooms and laboratories of introductory college chemistry courses.

Professor Christos Takoudis *et al.* focused on a web-based course on the fundamentals and design of micro- and nano-electronics processing, through which students learn to master the engineering principles of Nanotechnology. This paper discussed the impact, challenge, and experience of using the internet in the field of engineering education.

Professor Timothy Chang *et al.* detailed a web-based distance experiment on the control of a two-degree-of-freedom monolithic piezoelectric nanopositioner. The examples of case studies where students learned on-line to improve the control algorithm are adequate for implementation in undergraduate laboratory courses.

On behalf of all the authors, we wish this special issue stimulates the idea and experience exchange, and promotes curriculum reform in engineering education to address the challenges engineering students have to face in the era of Nanotechnology. Finally, I give my most sincere appreciation and acknowledgement to all the authors and referees who have made this special issue a success.

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