AC 2007-1087: ROAD TO NANO-TECHNOLOGY EDUCATION IN ENGINEERING TECHNOLOGY: AN AREA OF INTERDISCIPLINARY STUDIES

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Road to Nano-Technology Education in Engineering Technology: An Area of Interdisciplinary Studies

Abstract

"Nano-scale science and engineering most likely will produce the strategic technology breakthroughs of tomorrow," says David Swain, Senior Vice President of Engineering and Technology at Boeing. The development of micro-scale engineering in the area of electronics and computer technology demonstrates low cost and high efficiency technology advancements in miniaturization. These efforts have led to the emergence of nanotechnology dealing with a wide range of engineering applications at the nano scale. Nanotechnology has future impacts in the application markets such as medicine, healthcare, biotechnology, communications, and electronics. Due to rapid development and broad impact of nanotechnology, education and training of a new generation of workforce skilled in this field will play an important role in the development and applications of nanotechnology. It is a challenge for educators, especially for engineering technology educators, to provide an appropriate curriculum and effective learning environment including state-of-the-art laboratories for students who want to enter the nano field after their graduation. This paper will discuss the objectives of nano-technology education in the field of engineering technology at the baccalaureate level and point to the key issue of the interdisciplinary nature of nanotechnology. An analysis is made of the demands for laboratory facilities, faculty, and functions of other service departments to deliver an engineering technology curriculum in nanotechnology. Guidelines are provided for an innovative curriculum that draws upon collaborations among faculty, departments, and laboratories. The suggested guidelines can be modified to address the evolving needs of nano-technology education without loss of focus on engineering technology education.

Introduction

In 1959, Richard Feyman set the stage for research at the nano scale. Since then, the development of micro-scale engineering in the area of electronics and computer engineering has demonstrated low cost, and high efficiency technology advancements in miniaturization. These efforts have led to the emergence of nanotechnology dealing with a wide range of engineering applications at the nano scale. During the last two decades, there have been many advances in research, development, and commercialization of nanotechnology. Nanotechnology is concerned with the design, characterization, and fabrication of new materials, devices, and systems on the nanometer scale, with their properties dramatically improved from their bulk counterpart. Nanotechnology converge several disciplines including physics, chemistry, biology, and engineering, and covers the use of quantum effects, synthesis and processing of nanoparticles, self-assembly of nanostructure, fabrication of nanostructure and devices including chemical and biological sensors. Nanoscale science and technology impact application markets such as medicine, healthcare, biotechnology, communications, electronics, etc. Realizing the potential impact of nanotechnology on science and technology and economy, all industrialized nations and some developing countries have developed a national strategy for developing nanotechnology ranging from a general science research strategy to applications-motivated strategy. This has resulted in an increase in the levels of government funding as well as investments from the private companies.

With the fast advancements in the field of nanotechnology, it is estimated that about two million scientists, engineers, and skilled workers in nanotechnology-related fields will be needed worldwide in the next decade[1]. Therefore, education and training of a new generation of technicians and engineers in nanotechnology is extremely important. However, due to the interdisciplinary nature of nanotechnology, there is a major challenge for engineering and technology educators to modify the existing curricula that primarily focus on one single discipline. Although some efforts have recently been devoted to develop undergraduate programs in nanotechnology, only a few exist in the two-year programs, and none in the four-year engineering technology programs[2]. It is therefore vital to develop nanotechnology programs under the umbrella of engineering technology to supply the needed workforce in the nanotechnology.

The following sections describe research and education efforts in nanotechnology. Also are discussed the challenges that the engineering technology educators face in teaching nanotechnology as it relates to undergraduate education. The guidance for curriculum design for a baccalaureate-level nanotechnology program in the realm of engineering technology is provided, and specifically three possible models are discussed to facilitate curriculum design.

Education for Nanotechnology

With the increase of impact of nanotechnology on all aspects of our daily life and the increased demand for workforce trained in nano science and technology fields, the educational institutions around the world face a big challenge – how to integrate the nano science and technology content into the existing curriculums or to develop a new curriculum to meet the need of the fast growing field. Some universities in developed countries in Europe and North America have developed a variety of nano science and technology programs[3]. These programs are mostly based on physics, chemistry, or biology, and are separated from mathematics and engineering. The developing countries, such as China and India, are also building up their research and education efforts related to nano science and technology although specific programs in nanotechnology are lacking. China started research in nanotechnology in the mid 1980s. With strong support from the central and local governments and recently from the private sector, several nation-wide nano research centers have been developed[4,5]. To date, more than 50 universities are engaged in research and development of nanoscience and nanotechnology in China. Several centers for research and development of nanoscience and technology have been established which include centers at Peking University, Tsinghua University, Nanjing University, Jiaotong University, East China University of Science and Technology, Fudan University, Zhejiang University, and others. The education for nanotechnology in China focuses on graduate education based on research activities in their universities and research centers. Currently, there are no nanotechnology programs in China at the undergraduate level except for programs in materials science, microelectronics, etc.

USA is in the leadership role in the world in the field of nanotechnology because of its commitment, investment, and dedication of its scientists and engineers. The United States is also in the forefront in nano science and technology education because of funding assistance from the National Science Foundation (NSF), the National Nanotechnology Infrastructure Network (NNIN), and the National Nanotechnology Initiative (NNI). A variety of nanotechnology related courses or programs have been developed at the undergraduate and graduate levels. The National Nanotechnology Infrastructure Network (NNIN), an integrated networking partnership of thirteen universities supported by the NSF, provides user facilities serving the resource needs of nanoscale science, engineering and technology, and supports a wide range of educational programs[6]. The National Nanofabrication User Network (NNUN), with Cornell University as the lead institution, offers undergraduate and graduate courses and laboratory services for nanotechnology community. The National Center for Learning and Teaching in Nanoscale Science and Engineering (NCLT) was established at the Northwestern University, with a partnership between Northwestern, Purdue University, the University of Michigan, Argonne National Laboratory, and the University of Illinois at Chicago and Urbana-Champaign, to develop educators to introduce the nanoscale science and engineering concepts into schools and undergraduate classrooms[7,8]. All the noted efforts and programs focus on science and engineering education. However, there are only a few projects, which address the challenges in technological education for nanotechnology. The projects include the "regional center for nanofabrication manufacturing education" created at the Pennsylvania State University with a grant support from the state and NSF. A partnership between the state, universities and community colleges inside Pennsylvania has been established to deliver an associate degree program in Nanofabrication Technology via new curricula at community colleges[9]. Another project in technological education for nanotechnology sponsored by NSF is the A.A.S. Degree program in Nanoscience Technology led by Deb Newberry at Dakota County Technical College, Minnesota[10]. There is still a big gap for nanotechnology education in engineering technology even though it is an extremely important issue for the sustainable development and commercialization of nanotechnology.

Nano-Technology Education in Engineering Technology

With huge investments from the government and private sector, nanotechnology has developed at a great pace during the last two decades, and so has the commercialization of nanotechnology. A key challenge to sustain this development trend is to provide needed researchers and skilled workers with interdisciplinary backgrounds. Although many courses and programs have been developed for universities and research centers in this field to train future engineers and scientists, limited efforts have been made to train technologist and technicians. It is this great challenge that the engineering technology educators face to develop a new curriculum for nanotechnology education.

As the size goes down to nano scale, we need to deal with atoms interacting with each other; this is why many programs are based on chemistry and physics. On the other hand, design of devices and application of technology requires understanding of the principles of engineering; this leads to involvement of engineering in development of nanotechnology. The interdisciplinary nature of the nanotechnology field encompasses biology, chemistry, physics, materials science, engineering, computer sciences, and mathematics. A program in nanotechnology in the realm of engineering technology should provide its graduates with the ability for critical understanding, characterization, and measurements of nanostructure properties; it should provide its graduates with the ability for synthesis, processing, and manufacturing of nanodevices and nanosystems. These educational objectives require students and faculty to have a thorough understanding of the basic theory and experience with hands-on activities in the nano field. The traditional curriculum has defined boundaries between these disciplines. It is a key challenge to develop nanotechnology experts with interdisciplinary skills. Engineering technology programs traditionally are less theoretical and more hands-on. A thorough grounding in physics, chemistry, biology, and mathematics is a basic requirement for nanotechnology programs, and is a great challenge for both students and educators. A variety of equipment and techniques from different disciplines is used in the development of materials and devices at the nanoscale. Many of the advanced facilities are too expensive for one individual investigator or program to own when it is not being used frequently. Therefore, collaborations between labs from different disciplines are strongly encouraged.

Although nanotechnology is interdisciplinary in nature, one however, needs to be trained in a home discipline. One cannot be an interdisciplinarian without a home discipline. Therefore, a baccalaureate degree (B.S.) in engineering technology for nanotechnology should have a different concentration depending on the home discipline. The curriculum for nanotechnology program, as shown in Table I, should consist of four categories:

A. General Studies Courses (In a 124 Credit Hour Baccalaureate degree, 42 – 46 credit hours for general studies are recommended).
B. Interdisciplinary Fundamental Courses
C. Core Courses in mathematics from college algebra through calculus in the range of 12 to 14 credit hours in addition to major courses such as, Introduction to Nanotechnology, Engineering Computations, Materials in Nanotechnology, Nanotechnology in Engineering, and Ethical and Social Issues in Nanotechnology (Core courses will depend on different concentrations). For nanoelectronics, the required courses may include Introduction to Solid-State Electronics, Fundamentals of Quantum and nanoelectronics, Silicon and Advanced Material Devices, and Introduction to Micro Electro Mechanical Systems; for materials, chemistry, and bioengineering, the required courses may include Introduction to Materials Science, Physical Chemistry, Biomaterials and Engineering, Material Chemistry, Fundamentals of Polymers, Instrumental Methods.
D. Hands-on capstone courses are comprised of Basic Nanofabrication Materials and Equipment, Thin Film Processes, Nanostructure Characterization and Packaging, and Colloid Assemblies, etc.

Table I: The Curriculum and Resources for a Nanotechnology Program

Category	Resource	Collaboration
General Studies	Lectures for general studies	Within the university
Interdisciplinary Fundamentals	Lectures and/or labs	Partnership between departments within the university
Core Courses	Lectures/labs within a given concentration	Collaborate inside and/or outside university
Hands-on Capstone Courses	Labs in different concentrations	Collaborate between universities

In order to accomplish the curriculum requirements for nanotechnology education in engineering technology, a much broader collaboration is often required, as shown in Table I. Due to resource limitations of the engineering technology programs, especially the lack of advanced equipment and facilities, and sometimes faculty in the nano field, collaborations from outside of the program is advisable. The interdisciplinary fundamentals, including the basic principles of chemistry, biology, physics, mathematics, and computer science, can be accomplished with partnerships between individual departments within the university. The faculty from the various diverse fields should, in general, teach the core courses relative to different concentrations.

For the hands-on capstone courses, a partnership between different universities is advisable due to requirements for utilization of many advanced facilities in the program. Three models can be applied to carry out the hands-on capstone courses, refer to Table II. In the acronyms of the programs listed below, namely HPU, HVI, and HSI, H stands for Hands-On, PU stands for Partner University, V stands for Virtual Classroom/Lab, S stands for Simulation, and I stands for Internship.

- HPU Model: Students spend one or two semesters in a partner university to finish the capstone courses. This partner university could be one of the universities of the National Nanotechnology Infrastructure Network (NNIN) and the National Nanofabrication User Network (NNUN). The students can fully utilize the nanotechnology infrastructure sponsored by federal agencies.
- HVI Model: Uses virtual collaboration for courses and hands-on experience through intensive internship. The students stay at their home university for lecture/laboratory classes and share resources of the advanced laboratory using virtual reality techniques through internet. This normally needs close collaboration with host universities and developing virtual lab. A distributed interactive studio house (DISH) is the collaborating effort among University of Arkansas, University of Nebraska, and Oklahoma State University. IN-VESS at Arizona State University provides interactive visualization of nanomaterials. Students also spend two months at the nano facilities in the partner university for an intensive internship.
- HSI Model: Involves hands-on experience through intensive internship and coursework taught by home university faculty. The students will have an internship as in the second model though the courses are taught by faculty with the aid of simulation software and/or other teaching software to facilitate understanding. TCAD simulation software from Silvaco International and Videos from Silicon Run Productions may be used for nanofabrication courses. More interactions occur between students and faculty, and thus enable students achieve better understanding compared to the second model.

Table II: Implementation of Hands-On Capstone Courses

Models	Home university	Partner university	Hands-on experience
HPU	No lecture/lab	Lecture/Lab	One or two semester at partner university
HVI	Lecture / lab (virtual)	Lab	Intensive internship at partner university
HSI	Lecture / lab (simulation)	Lab	Intensive internship at partner university

Designing an innovative curriculum for nanotechnology in engineering technology is a complex task and requires a high level of integration. The students, the faculty, collaborating labs and participating institutions, must all work collaboratively. The graduates from this kind of a program will provide the needed workforce in nanotechnology field for the 21st century. The best advantage is that the graduates could enter the job market in a variety of areas, such as nanobio, nanoelectronics, medicine, materials, environment, etc.

Conclusion

Due to rapid development and broad impact of nanotechnology in engineering and sciences, education and training of a new generation of workforce skilled in nanotechnology will play an important role in the development and applications of nanotechnology in the future. Because of the interdisciplinary nature of nanotechnology, to devise a mechanism to integrate nanotechnology into one's home discipline in engineering technology education is a challenge for the engineering technology educators. The curriculum and capstone course models discussed in this paper for the delivery of nanotechnology education can serve as a model for the design of curriculums in a variety of engineering technology curriculums at the baccalaureate level. It remains a great challenge for engineering technology educators to develop innovative content and novel teaching and learning tools for nanotechnology education. It remains equally challenging to prepare the new generation of engineering workforce for the emerging nanoscale technology but it is a challenge that is worth taking, and it is worth taking now.

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