INTEGRATION OF NANOTECHNOLOGY INTO THE UNDERGRADUATE ENGINEERING CURRICULUM

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Abstract *¾Today's advances and rapid growth in the fields of nanotechnology provide challenges to our academic communities to prepare engineering students with an ability to apply knowledge of mathematics, science and engineering to design, analysis and manufacture of nanocomponents, nanodevices and nanosystems. Nanotechnology is truly interdisciplinary; it involves manipulating and controlling individual atoms and molecules to design and create new materials, nano-machines, and nano-devices for application in all aspects of our lives. Our challenge is to provide an interdisciplinary education to students with a broad understanding of basic sciences (atomic physics, molecular chemistry, microbiology, genetics, etc.), engineering sciences (mechanical, electrical, chemical, biochemical, computer etc.), and information sciences (molecular coding, data analysis, imaging and visualization, bio-computation, molecular modeling and simulation of complex structures, etc.), and their application to nanotechnology. A methodology is proposed to integrate nanotechnology education into mainstream undergraduate engineering curricula. Strategies for teaching nanotechnology are also presented.*

Index Terms ¾ curriculum, engineering, nanocomponents, nanosystems, nanotechnology.

INTRODUCTION

The emerging field of nanoscience and nanotechnology is leading to a technological revolution in the new millennium. The application of nanotechnology has enormous potential to greatly influence the world in which we live. From consumer goods, electronics, computers, information and biotechnology, to aerospace defense, energy, environment, and medicine, all sectors of the economy are to be profoundly impacted by nanotechnology.

In the United States, Europe, Australia, and Japan, several research initiatives have been undertaken both by government and members of the private sector to intensify the research and development in nanotechnology. [1] Hundreds of millions of dollars have been committed.

Research and development in nanotechnology is likely to change the traditional practices of design, analysis, and manufacturing for a wide range of engineering products. This impact creates a challenge for the academic community to educate engineering students with the necessary knowledge, understanding, and skills to interact and provide leadership in the emerging world of nanotechnology.

In this paper, the current status of nanoeducation in the United States is discussed. A methodology is proposed to integrate nanotechnology into the mainstream undergraduate engineering curriculum and sample content for undergraduate nanotechnology courses is presented. Also articulated are strategies for teaching nanotechnology inside and outside of the classroom.

CURRENT STATUS OF NANOTECHNOLOGY EDUCATION

The academic community is reacting slowly to prepare the workforce for emerging opportunities in nanotechnology. Currently, a small number of universities in the USA, Europe, Australia and Japan offer selective graduate programs in nanoscience and nanotechnology in collaboration with research centers.

In the United States of America, federal and state governments, academic institutions, industry and various for profit and non profit organizations have developed partnerships to establish nanotechnology research centers. The primary mission of these centers is to conduct research and development in the area of nanoscience and nanotechnology. Some research centers also support an associated graduate program within the patron university. In addition, faculty members in various institutions conduct and manage research programs in the areas of nanotechnology and nanoscience supported by funding organizations such as the NSF, DoD, NIH, DARPA, etc.

In the United States, the following universities offer either graduate or undergraduate courses in nanoscience or nanotechnology. [1]

Clarkson University
Clemson University
Cornell University
Penn State University
Renssellear Polytechnic Institute
Rice University
State University of New York at Buffalo
University of Notre Dame
University of Washington
University of Wisconsin, Madison
Virginia Commonwealth University

A handful of universities offer undergraduate engineering degrees in conjunction with undergraduate

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courses in nanoscience or nanotechnology. They are Virginia Commonwealth University, Penn State University and Flinders University in Australia. In order to prepare our students to solve the technological challenges of the new millennium, the education of nanotechnology should be incorporated into the mainstream undergraduate engineering curriculum.

INTEGRATION OF NANOTECHNOLOGY INTO THE UNDERGRADUATE ENGINEERING CURRICULUM

The fundamental objective of nanotechnology is to model, simulate, design and manufacture nanostructures and nanodevices with extraordinary properties and assemble them economically into a working system with revolutionary functional abilities. Nanotechnology offers a new paradigm of groundbreaking material development by controlling and manipulating the fundamental building blocks of matter at nanoscale, that is, at the atomic/molecular level. Therefore, in order for our student to face the challenges presented by nanotechnology, the following educational goals should be applied:

- Provide understanding, characterization and measurements of nanostructure properties
- Provide ability for synthesis, processing and manufacturing of nanocomponents and nanosystems
- Provide ability for design, analysis and simulation of nanostructures and nanodevices
- Prepare students to conduct research and development of economically feasible and innovative applications of nanodevices in all spheres of our daily life.

In order to achieve these goals, the following three courses in nanotechnology are proposed for integration into undergraduate engineering curricula.

Nanotechnology I: Fundamentals of Nanoscience

This is an introductory course and should be required for all engineering students. This course should be taught at the sophomore level. Pre-requisites should include General Physics, General Chemistry, Calculus I and II. Sample topics for this course are listed below.

A) Introduction and Overview of Nanotechnology [2,3,4]

- The macroscopic and microscopic world
- Molecular manufacturing
- Self assembly
- Impact on the society

B) Nanoscience/Nanotechnology of organic materials [5]

- Building blocks of living organisms
- The cell
- DNA, RNA and genes
- Protein synthesis and protein engineering
- Biosensors
- Recombinant techniques
- Genetic engineering

C) Nanoscience/Nanotechnology of inorganic materials [6,7]

- Introduction to molecular chemistry
- Introduction to solidstate physics
- Introduction to quantum mechanics and statistical mechanics
- Chemical, electrical, mechanical, magnetic, optical and thermal properties of nanomaterials
- Structure-property-application relationship of nanomaterials

Nanotechnology II: Synthesis, Processing and Manufacturing of Nanocomponents and Nanosystems

This could be a junior/senior level elective course. However, for students in electrical engineering and engineering materials, this could be a required course. Sample topics for this course are listed below: [8,9,10,11]

- Molecular manufacturing and mechanosynthesis
- Nanomechanics
- Self-assembly
- Nanosystem components
- Microelectromechanical systems (MEMS)
- Synthesis and processing of nanostructures
- Molecular manufacturing
- Nanofabrication

Nanotechnology III: Design, Analysis and Simulation of Nanostructures and Nanodevices

This is an advanced nanotechnology course and geared for engineering seniors and graduate students. This could be an elective course. Sample topics for this course are listed below: [8,9,10,11]

- Modeling of nanostructures and nanodevices
- Simulation of nanostructures and nanodevices
- Sensors, intrumentation and microcontrol techniques
- Optimization of nanosystems
- Design and product development

Nanotechnology I course content can also be introduced through current chemistry, biology, physics and freshman engineering and material science courses traditionally required for all engineering graduates. Please refer to Table I. Contents of Nanotechnology II and III can also be integrated into several upper division science and engineering courses as shown in Tables II and III.

TABLE I
INTEGRATION OF NANOTECHNOLOGY I WITHIN INTRODUCTORY SCIENCE AND ENGINEERING COURSES

Nanotechnology I: Fundamentals of Nanoscience	
Course Content	**Corresponding Science and/or Engineering Course**
The macroscopic and microscopic world	Freshman Engineering
Molecular manufacturing	Freshman Engineering
Self assemble	Freshman Engineering
Impact on the society	Freshman Engineering
Building blocks of living organisms	Biology
The cell	Biology
DNA, RNA and genes	Biology
Protein synthesis and protein engineering	Biology
Biosensors	Biology
Recombinant techniques	Biology
Genetic engineering	Biology
Introduction to molecular chemistry	Chemistry
Introduction to solidstate physics	Physics and Materials Science
Introduction to quantum mechanics and statistical mechanics	Physics
Chemical, electrical, mechanical, magnetic, optical and thermal properties of nanomaterials	Materials Science
Structure-property-application relationship of nanomaterials	Chemistry and Materials Science

TABLE II
INTEGRATION OF NANOTECHNOLOGY II WITHIN JUNIOR AND UPPER DIVISION SCIENCE AND ENGINEERING COURSES

Nanotechnology II: Synthesis, Processing and Manufacturing of Nanocomponents and Nanosystems	
Course Content	**Corresponding Science and/or Engineering Course**
Molecular manufacturing and mechanosynthesis	Molecular Biology, Physical Chemistry, Organic Chemistry and Mechanics of Materials
Nanomechanics	Physical Chemistry, Dynamics, Mechanics of Materials and Mechanics of Continuous Media
Nanosystem components MEMS, Self-assembly	Electronics, Thermodynamics, Quantum Mechanics, Bioengineering
Synthesis and processing of nanostructures	Engineering Materials, Microelectronic Processing
Molecular manufacturing	Microelectronics, Semiconductor Manufacturing
Nanofabrication	Microelectronic Processing

TABLE III
INTEGRATION OF NANOTECHNOLOGY III WITHIN UPPER DIVISION AND GRADUATE LEVEL ENGINEERING COURSES

Nanotechnology III: Design, Analysis and Simulation of Nanostructures and Nanodevices	
Course Content	**Corresponding Science and/or Engineering Course**
Modeling of nanostructures and nanodevices	Modeling and Simulation, Engineering Design
Simulation of nanostructures and nanodevices	Modeling and Simulation, Engineering Design
Sensors, intrumentation and microcontrol techniques	Instrumentation and Controls
Optimization of nanosystems	Optimization and Engineering Design
Design and product development	Microchip Design, Engineering Design

TEACHING STRATEGIES

Nanotechnology should be taught by creating both knowledge-centered and learning-centered environments [12] inside and outside the classroom. Because the technology is advancing so fast, activities that encourage creative thinking, critical thinking and life-long learning should be given the highest priority.

Nanotechnology is truly interdisciplinary. An interdisciplinary curriculum that encompasses a broad understanding of basic sciences intertwined with engineering sciences and information sciences pertinent to nanotechnology is essential. Introductory nanotechnology courses should be taught more from the perspectives of concept development and qualitative analysis rather than mathematical derivations. Every effort should be made to convey the big picture and how different learning exercises fit together to achieve course objectives. Each course should be taught at the appropriate level with required pre-requisites.

Teachers should begin introducing the concept of nanotechnology during freshman and sophomore engineering courses and continue throughout the subsequent engineering science curriculum. Junior and senior design courses, specifically the capstone design courses, should integrate modeling, simulation, control and optimization of nanodevices and nanosystems into the course objectives. In reality, nanotechnolgy is a branch of engineering and because design is the essence of engineering, every effort should be made to integrate concepts related to nanotechnology into all design courses.

Interactive learning should be the hallmark of nanotechnology education. Technology can play a powerful role in facilitating interactive learning both inside and outside the classroom. Students can participate in nanotechnology research development projects and laboratory experiments all over the world via the Internet. Students should be given opportunities to work directly with established nanotechnology research centers (local, regional, national, international) to gain hands-on experience. University faculty members must collaborate with industry in order to educate and train students in the field of nanotechnology. Utilizing a team of faculty members specializing in appropriate disciplines to teach nanotechnology courses is highly desirable. The inclusion of guest speakers from industry and research centers enhances the quality of available courses.

It is important to educate engineering faculty rooted in the traditional disciplines regarding the advances in nanotechnology and the ways in which all engineering disciplines will be impacted in the future. Governmental bodies, industry and universities must take the initiative to allocate additional funds toward faculty development in the areas of nanotechnology.

CONCLUSION

It is necessary to prepare undergraduate engineering students with an ability to design, analyze and manufacture nanocomponents and nanosystems, to create nanodevices for economically feasible, innovative applications of nanotechnology in all spheres of our daily life. Nanotechnology education should be integrated into mainstream undergraduate engineering curricula. Government, industry and university bodies should foster collaboration among themselves in order to educate students in nanotechnology.

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