Nanotechnology in Engineering Education

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Abstract

Nanotechnology is the science, engineering, and application of submicron matters that tie together unique biological, chemical, and physical properties of nanoscale materials in essentially new and beneficial ways. Nanoscience and nanotechnology involve the ability to see and to control individual atoms and molecules. The interest in nanotechnology arises from its potential to significantly affect numerous fields, including information technology, energy, healthcare, the environment, homeland security, national defense, and agriculture. Nanotechnology can be used across many fields, such as physics, chemistry, biology, material science, and engineering. This field will serve to trigger the next wave of the technology revolution.

As nanotechnology is emerging and beginning to impact many aspects of our lives, the opportunities for careers are expanding rapidly. A major challenge of this field is the training and education of a new generation of skilled workers. This paper studies different approaches that are used by different institutions of higher education to integrate nanotechnology concepts into their curriculum.

Introduction

Nanotechnology is the science, engineering, and technology that deals with various structures of matter that have dimensions on the order of a billionth of a meter. Nanotechnology is the ability to observe, manipulate, measure, and manufacture things at the nanoscale, which is about 1 to 100 nanometers. While the word nanotechnology is new and was introduced in the late 1970s, the existence of functional devices and structures of nanometer dimensions is not new, and actually such structures have existed on earth as long as life itself.[1]

It is not exactly known when humans first started using nanosized materials. However, Romans in the fourth-century A.D. used metal nanoparticles to make glass cups which change color from green to a deep red when a light source is placed inside of it. Italian used nanoparticles to make 16th century renaissance pottery. The presence of metal nanoparticles in the glass is responsible for the beautiful colors of the windows of medieval cathedrals.[1]

The idea behind nanoscience and nanotechnology started with Richard Feynman's (Father of nanotechnology) visionary talk "There is plenty of room at the bottom" at the 1959 meeting of the American Physical Society at the California Institute of Technology[3].

Nanotechnology is expected to have a large impact on many sectors of the world's economy. A strong nanotechnology economy can lead to new products, new businesses, new jobs, and even

new industries for many countries. The United States is committed to becoming a world leader in nanoscale science and engineering research,[6] as the applications of nanotechnology could have numerous implications for the economy. The National Nanotechnology Initiative (NNI) is a U.S. Government research and development (R&D) initiative involving the nanotechnology-related activities of 20 Federal department and independent agencies. The United States set the pace for nanotechnology innovation worldwide with the advent of the NNI in 2000. The NNI was officially created in 2003 when the 21st Century Nanotechnology Research and Development Act was passed by Congress and signed by President Bush into law. Since the inception of the NNI, Federal nanotechnology R&D funding has grown from $464 million per year to almost $1.5 billion requested in FY 2015. The U.S. is not the only country to recognize the remarkable potential of nanotechnology. Other countries are also investing in nanotechnology research. In 2008, it was estimated that the governments of the European Union (EU) and Japan invested approximately $1.7 billion and $950 million, respectively, in nanotechnology research and development. The governments of China, Korea, and Taiwan invested approximately $430 million, $310 million, and $110 million, respectively[5]. This compares to 2008 U.S. Government spending $1.55 billion. Approximately 60 countries have adapted nanotechnology research programs, making nanotechnology one of the largest and most competitive research fields globally.

The NNI calls something nanotechnology only if it involves all of the following[4]:

- "Research and technology development at the atomic, molecular, or macro-molecular levels, in the length scale of approximately 1 to 100-nanometer range.
- Creating and using structures, devices, and systems that have novel properties and functions because of their small and/or intermediate size.
- Ability to control or manipulate on the atomic scale."

"The vision of the NNI is a future in which the ability to understand and control matter at the nanoscale leads to a revolution in technology and industry that benefits society."[7] The following are four goals of the NNI in order to achieve its vision:

1. "Advance a world-class nanotechnology research and development program.
2. Foster the transfer of new technologies into products for commercial and public benefit.
3. Develop and sustain educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology.
4. Support responsible development of nanotechnology."[7]

The electronics industry crossed the nanoscale threshold in the late 1990s and was recognized as the first industry to do so. Over the last decade nanotechnology has influenced and been integrated into multiple industries. It is often referred to as an enabling technology and is a combination of the various sciences, engineering disciplines, and multiple industries. By scaling products down to the nanometer, one can make them smaller, cheaper, faster and better.

Nanotechnology is a key technology for the 21st century. Nanotechnology can offer better built, longer lasting, cleanser, safer and smarter products for home, computing, communications, medicine, transportation, agriculture, aerospace, energy, and information technology.

Advances in nanotechnology are helping to considerably improve, even revolutionize, many technology and industry sectors: information technology, energy, environmental science, medicine, homeland security, food safety, and transportation, among many others.

Job Prospects in Nanotechnology

There is potential to incorporate nanotechnology-enabled products and services into almost all industrial sectors and medical fields. The resulting benefits will include increased productivity, more sustainable development, and new jobs. Nanotechnology has already impacted the marketplace with estimated values of nanotechnology enabled products of $91 billion in the United States and $254 billion worldwide in 2009. Furthermore, this field is expected to grow at unprecedently levels -- the NSF estimates that nanotechnology-related items and services will achieve a market size of 3 trillion dollars globally and 1 trillion dollars in the US by 2020[5]. This expansion will further drive the need for additional effectively-trained professionals and academics.

A current application of nanoscience and nanotechnology, and career opportunities, exists in areas such as:

- Medical Fields and pharmaceuticals
- Environmental monitoring and control
- Food science including quality control and packaging
- Forensics
- University and Federal Lab Research
- Military and National Security
- Energy Capture and Storage
- Biotechnology
- Sporting Goods
- Electronics/Semiconductor Industry
- Material Science including textiles, polymers, etc.
- Auto Industries
- Aerospace Industries

As nanotechnology is emerging, there is a big demand for a new generation of nanotech literate students. Educational excellence requires exposing students to the current edge of research. To ensure that student projects are along the same trajectory that the industry is moving, educators must continually introduce emerging techniques, practices, and applications into the curriculum. The field of nanotechnology is growing rapidly and there is an increasing need and interest in

providing students with a foundation in this emerging field and preparing a new generation of accomplished students and engineers capable of solving complex problems. It is crucial that the emerging field of nanotechnology be integrated into the engineering curriculums. Following is examples of how different institutions of higher education have integrated nanotechnology concepts into their curriculum.

College of Nanoscale Science and Engineering (CNSE) at SUNY Polytechnic Institute:

CNSE is the world's first college to offer comprehensive Baccalaureate program in Nanoscale Engineering and Nanoscale Science[30]. One of the goals of the CNSE has been to develop and implement a comprehensive program to support a continuum of education and training necessary to build the foundations of a skilled technology workforce for the global economy of the 21st century. This goal is being accomplished by integrating an array of educational and training resources to meet the workforce training needs of equipment, materials, component suppliers and integrated nanodevice manufacturers. As such, CNSE presents unique opportunities to structure education and training resources around the nanotechnology industry by implementing a comprehensive workforce development model that will not only prepare employees for the nanotechnology industry but will engage students in pertinent mathematics and science disciplines[30].

One of the nation's formidable problems is a looming shortage of scientific and engineering personnel. Semiconductor companies worldwide are facing a critical shortage of technically trained employees. This shortage is expected to continue for the foreseeable future despite the cyclical history of the industry. In response, CNSE conducts multi-level programs that encourage science awareness in grades K-12 to help ensure the U.S. science and technology workforce of the future[30].

CNSE offers bachelor's, Master, and Ph.D. degrees in nanoscale engineering and the bachelor's, Master, and Ph.D. degrees in nanoscale science.

Nanosciences and Nanoengineering at UC Berkeley

The Berkeley Nanosciences and Nanoengineering Institute (BNNI) is the umbrella organization for expanding and coordinating Berkeley research and educational activities in nanoscale science and engineering[21]. UC Berkeley has over 90 faculty with active research programs in nanoscale science and engineering who are affiliated with the BNNI. UC Berkeley has educational initiatives in nanoscale science and engineering that includes graduate, undergraduate, K-12 education, and public outreach. Their designated emphasis allows students in ten different graduate programs to specialize in nanoscale science and engineering. Their SUPERB and URAP programs provide funding for undergraduate research in the field. They provide high-school apprenticeship summer program for juniors interested in hands-on research experience[21].

Nanotechnology Minor Program at North Carolina State University

A multidisciplinary undergraduate minor program in Nanoscience and technology is developed at North Carolina State University. This program was approved by their university in Spring 2013. Students were admitted to the program in Fall 2013. The minor is administered by the center for Advance Self-Powered Systems of Integrated Sensors and Technologies (ASSIST) which has been established in September 2012 as a Nanosystems Engineering Research Center (NERC) with funding from the National Science Foundation (NSF). ASSIST employs nanotechnology to develop wearable, energy-autonomous, health and environment monitoring systems. The curriculum for the program was developed by a multidisciplinary committee led by the education director of ASSIST and including faculty representative from each engineering department at the University. This minor requires 18 credit hours, which includes a junior level required introductory course, three technical electives, and two general education electives emphasizing diversity, ethics, and global issues. The technical electives come from a variety of engineering departments and taught by faculty performing research in nanoscience and technology. Students are required to choose at least one technical elective outside of their home department. From their preliminary evaluation results of their introductory course indicates that students' attitude toward nanoscience and technology is positive. Students from different disciplines of engineering took their introductory course. Of the 80 students, 27.5% were Chemical Engineers, 38.7% were Electrical and/or Computer Engineers, 6.25% were Materials Engineers, and 27.5% represented other engineering departments including Biomedical, Mechanical and Aerospace, Industrial, Computer Science and Nuclear Engineering departments[8].

Elective Nanotechnology Course at Purdue University, West Lafayette

In Spring of 2008, Department of Electrical and Computer Engineering Technology started offering an elective course called *Introduction to Nanotechnology*. This course is a three credit hour junior/senior elective course and the prerequisite for it is freshman biology, chemistry or Physics or approval of the department. This three credit hour course required two classes of 75 minutes and a two hour lab per week. The objectives of this course were:

- Understand the basic concepts behind nanotechnology
- Characterize electrical material at the nano regime.
- Analyze nanocomposite materials
- Understand the tools of nanotechnology

Overall, the course was a success and has resulted in a number of students pursuing research experience and/or graduate school[9].

Nanotechnology Track at Indiana University- Purdue University Indianapolis

At Purdue, they have developed a track in nanotechnology. This program is housed in the School of Engineering and Technology's Electrical and Computer Engineering and Mechanical Engineering departments. The track program consists of 12 credit hours, which are considered

as part of the elective courses within the degree programs, while they are considered as part of the track program. The first two courses in this track are undergraduate courses while the other two are dual level courses. The developed nanotechnology courses are cross-offered in the department of biomedical engineering, physics, and Chemistry[10]. These courses have also served as elective graduate courses toward graduate degrees. The establishment of the multidisciplinary nanotechnology program at Purdue has impacted five departments (Electrical and Computer Engineering, Mechanical Engineering, Biomedical Engineering, Physics, and Chemistry) in both teaching and research[10].

Nanotechnology at Wentworth Institute of Technology

Wentworth Institute of Technology has been able to introduce nanotechnology through engineering elective courses in different engineering disciplines[11]. Students from different engineering and science disciplines can take an introductory nanotechnology course to fulfill their elective requirements. They have designed two courses in nanotechnology. The two courses are Introduction to Nanotechnology and Advances of Nanotechnology[11].

NanoScience Concentration Program (NCP) at University of Texas at Brownsville

The goal of this program is to introduce nanoscience, nanoengineering, and nanotechnology through interdisciplinary approaches into undergraduate education. Their certificate program includes the following seven new undergraduate courses[13]:

1. Introduction to Nanoscience
2. Engineering of Nanomaterials
3. Nanofabrication and Nanoelectronics
4. Introduction to Bio-Nanotechnology
5. Environmental Nanotechnology
6. NanoOptics
7. Capstone Design

To complete the NCP and receive a Certificate in Nanoscience and Nanotechnology, students must complete 12 credit-hours of advance junior and senior level course[13].

Nanotechnology at Texas State University-San Marcos (Texas State) & University of Texas (UT) at Tyler

In a collaborative project between Texas State and University of Texas at Tyler, an introductory and advanced curricula was developed that addresses the “nanotechnology safety issues” that include social, ethical, environmental, health, and safety issues of nanotechnology. In this project they are designing course modules that are going to be infused into existing courses at Texas State ranging from philosophy and ethics to material engineering to industrial safety to

polymer nanocomposites. These modules are inserted in their existing courses at Texas States. University of Texas at Tyler is offering these modules in two courses online[16].

Models for Integration of Nanotechnology in Curriculums

Table 1 provides a survey of nanotechnology offerings of selected universities. Course offerings of forty four universities were studied. From this study, it can be seen that universities are using nine models to integrate nanotechnology concepts into their curriculum:

1. Offering undergraduate courses on Nanotechnology.
2. Offering Baccalaureate degree in Nanotechnology.
3. Offering an undergraduate track in Nanotechnology.
4. Offering a Minor in nanotechnology.
5. Offering a Master degree in Nanotechnology.
6. Offering Graduate courses in Nanotechnology.
7. Offering a Multidisciplinary Senior Design Project on Nanotechnology.
8. Integrating Nanotechnology concepts into their traditional courses.
9. Undergraduate Research in Nanotechnology.

Model 1 is used by eight universities such as the Wentworth Institute of Technology, and University of Cincinnati. Out of forty four universities that studied, seven are offering an undergraduate degree in the nanotechnology field such as University of Waterloo and Louisiana Tech University. Eight universities are using model 3 and offering an area of specialization or track on nanotechnology such as University of Central Florida and Drexel University. Majority of these programs are multidisciplinary and available to different engineering fields. Six universities are offering a minor in nanotechnology such as Rochester Institute of Technology and Michigan Technological University. Fifteen universities such as Rice University and University of Central Florida are offering master programs in the field of nanotechnology. The majority of universities that have graduate programs are offering graduate courses on Nanotechnology such as Carnegie Melon University. Model 7 is used by the Mississippi State University. They are offering a multidisciplinary senior design project course on nanotechnology. Some universities are integrating nanotechnology concepts as modules into their existing courses, as seen by the Texas State University. UC Berkeley uses model nine and their SUPERB and URAP programs provide funding for undergraduate research in the field of nanotechnology. Some universities are not introducing their students to the field of nanotechnology and are not using any of the nine models.

Universities	Under graduate Nano technology Courses	B.S. in Nanotechnology	Nanotechnology Track	Nanotechnology Minor	Master & Graduate Courses in Nanotechnology	Comments
Louisiana Tech		B.S. in Nanosystems			M.S. in Molecular	

University[27]		Engineering			Sciences and Nanotechnology	
Rochester Institute of Technology[28]				Microelectronics and Nanofabrication Minor		
Michigan Technological University[29]				Interdisciplinary Minor in Nanoscale Science and Engineering	Graduate Certificate in Nanotechnology	
Indian University-Purdue University Indianapolis[10]			Multidisciplinary Nanotechnology Track		ECE 59500 – Nanosystems Principles	
SUNY Polytechnic Institute[30]		B.S. in Nanoscale Science, B.S. in Nanoscale Engineering			MS in Nanoscale Science, MS in Nanoscale Engineering	
Rice University[31]		BA or BS in Material Science & Nanoengineering			M.S. in Material Science & Nanoengineering	Professional Science Master in Nanoscale Physics
Rutgers University[32]		B.S. in Nanomaterial Science and Engineering				
University of California (UC), San Diego[33]		B.S. Nanotechnology			M.S. Nanotechnology	
University of Central Florida[34]			B.S. in Nanoscience and Nanotechnology track		Professional Science Master in Nanotechnology	
Drexel University[35]			BS Materials Engineering with Specialization in Nanotechnology			
Excelsior College[36]			B.S. in Electrical Engineering Technology with Nanotechnology Concentration			
Northwestern University[37]			B.S. in Physics with Nanoscale Concentration			
Clarion				Minor in		Physics Dept.

University[38]				Nanotechnology		
University of California, Riverside[39]			B.S. in Chemical Engineering with Nanotechnology concentration			M.S. Nanoengineering
University of California, San Diego[33]		B.S. in Nanoengineering				M.S. Nanoengineering
University of Maryland[40]				Interdisciplinary Minor in Nanotechnology		Materials Science & Engineering
University of Tulsa[41]			B.S. with a Specialization in Nanotechnology		M.S. with a Specialization in Nanotechnology	Institute of Nanotechnology
Pennsylvania State University[42]				Minor in Nanotechnology		
Arizona State University[43]					Professional Science Master in Nanoscience	
John Hopkins University[44]					M.S. in Materials Science & Engineering with Nanotechnology Option	
North Dakota State University[45]					M.S. in Materials and Nanotechnology	
Radiological Technologies University (Indiana)[46]					M.S. in Nanomedicine	
University of Pennsylvania[47]					M.S. in Nanotechnology	
University of New Mexico[48]					M.S. in Nanoscience and Microsystems	
University of Texas at Austin[49]					MSc Engineering Nanomaterials	
Washington University[50]				Minor in nanotechnology		
Wentworth Institute of Technology[11]	Intro. To Nanotechnology Advances of Nanotechnology					Courses in Nanotechnology through technical elective offerings.

University of Waterloo[12]		B.S. in Nanotechnology Engineering				
University of Texas at Brownsville[13]			NanoScience Concentration Program			
University of Cincinnati[14]	Two Courses: Nanoscale Devices and Environmental Aspects of Nanotechnology					Offered Summer Institute for high school and junior high students (five-week program)
University of Bridgeport[15]	EE446 – Introduction to MEMS EE448 – Microelectronic Fabrication EE 451- Introduction to Nanotechnology					
University of Texas at Tyler[16]	Undergraduate courses on Nanotechnology Safety Issues					
Texas State University-San Marcos[16]						Modules on Nanotechnology Safety Issues in their existing courses
Utah State University (Electrical and Computer Engineering)[17]						No Course Offerings in Nanotechnology
University of Utah (electrical and Computer Engineering) [18]					ECE 6461 - Nanophotonics	No Course Offerings in Nanotechnology in undergraduate programs
Carnegie Melon University (Electrical and Computer Engineering)[19]					18-615 – Micro and Nano System Fabrication	No Course Offerings in Nanotechnology in undergraduate programs
Brigham Young University (Electrical and Computer Engineering)[20]						No Course Offerings in Nanotechnology in undergraduate programs
University of California at Berkeley (Electrical and	EEC235 – Nanoscale Fabrication				Nanoscale Devices, Nanoscale Modeling,	Ph.D with Designated Emphasis in Nanoscale

Computer Engineering)[21]					Nanoscale Characterization .	Science and Engineering
Ohio State University[22]	Micro/Nano Technology Research project course					For their honors freshman students they offer a research project course on Nanotechnology
Mississippi State University[23]	Multidisciplinary Capstone course, Nanotechnology in Chemical Applications, Nanoelectronics, Smart Materials					Multidisciplinary Undergraduate Program. Introductory Seminar course (nanotech in existing courses), Cellular biology, engineering thermodynamics- NSF Grant
Purdue University[24]	Introduction to nanotechnology.				Graduate courses on Nanotechnology	
University of New Haven[25]	Nanoscale Sciences Course, as an elective				Introduction to Nanotechnology (as elective)	
Georgia Tech[26]	CoE 3002- Undergraduate Elective Course in Nanotechnology					This course is intended for management, engineering, sciences (a course for all the majors)
Utah Valley University (Computer Engineering)[51]	None	None	None	None		None

Table 1: A Survey of Universities with Regard to Nanotechnology Offerings

Summary and Future Research

Nanotechnology is rapidly emerging as a fundamentally new scientific and engineering paradigm. A skilled science and engineering workforce, leading-edge instrumentation, and state-of- the- art facilities are essential to advancing nanotechnology research and development. The emerging field of nanotechnology has experienced explosive growth in recent years, making it crucial to provide advanced training to United States future workforce. In order to train future workforce, educational programs and resources are required to produce the next generation of

nanotechnologists, that is, the researchers, inventors, engineers, and technicians who drive discovery, innovation, industry and manufacturing.

The Integration of nanotechnology concepts in science and engineering curricula have started slowly in many universities worldwide. There are nine models that are used by the universities depending on the resources that were available to them. Majority of tier 1 universities that have state-of-art laboratories for nanotechnology are offering undergraduate and graduate programs in this exciting field. Other universities that have smaller laboratory facilities and resources usually offer an introduction course to nanotechnology or an elective course in this area. There are many universities and colleges that don't have any nanotechnology laboratories or faculty who can teach these concepts are not exposing their science and engineering students to the field of nanotechnology.

One might ask when nanotechnology concepts should be introduced into undergraduate engineering and science curricula. Some scientists believe that it should be introduced as early as possible by integrating the basics concepts in physics courses. Some believe that it should be offered as a senior level required course. The second option might be harder to implement, since adding a new course to the curriculum is not an easy task, as often times eliminating another course would be necessary. Offering it as an elective course is not a good option either, since every student is not going to get this experience. It seems that adding the concepts slowly as modules to existing courses is a good solution for integrating the nanotechnology concepts into the science and engineering curricula which is the approach that is used by Texas State University.

As the nanotechnology field is growing, tomorrow's scientists and engineers must be educated on the nanotechnology concepts. As educators, teaching nanotechnology concept today is vital to preparing our students for future jobs. It is crucial that nanotechnology topics be integrated into the science and engineering curricula.

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