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Need of nanotechnology in education

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Abstract: The emerging field of nanoscience and nanotechnology are becoming more and more popular everyday. Nanotechnology is truly interdisciplinary; it involves manipulating and controlling individual atoms and molecules to design and create new materials, nanomachines, and nanodevices for application in all aspects of our lives. Recent advances and envisioned developments in enabling nanotechnology provide challenges to academia in educating and training a new generation of skilled engineers and competent scientists. These engineers and scientists should possess the ability to apply knowledge of mathematics, science, and engineering in order to design, analyze and fabricate nanodevices and nanosystems, which are radically different when compared with traditional technological systems. In this paper, the current status of the progress and developments in nanotechnology and nanoeducation is briefly reviewed, from the perspective of its applications. Strategies for teaching nanotechnology are also presented with a few basic samples.

Keywords: Nanoscience, Nanotechnology, Nanoeducation

1. Introduction

Nanotechnology and research on this area are becoming more and more popular everyday. 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. [2]

Nanotechnology deals with materials, devices, and their applications, in areas such as engineered materials, electronics, computers, sensors, actuators, and machines, at the nano length-scale. Atoms and molecules, or extended atomic or molecular structures, are considered to be the basic units, or building-blocks, of fabricating future generations of electronic devices, and materials. At the nano-meter length scales, many diverse enabling disciplines and associated technologies start to merge, because these are derived from the rather similar properties of the atomic- or molecular- level building blocks. For example, on the one hand, the DNA molecular strands are these days proposed as the self-assembling templates for bio-sensors and detectors, molecular electronics, and as the building blocks of all biological materials. On the other hand, some synthetic inorganic materials, such as carbon, boron-nitride or other nanotubes or nanowires, may also have similar functionalities in some respects, but could also be exceptionally strong and stiff materials. The cross-correlation and fertilization among the many constituent disciplines, as enabling technologies for molecular nanotechnology, are thus essential for an accelerated development.

Researches and developments in nanotechnology will 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 students with the necessary knowledge, understanding, and skills to interact and provide leadership in the emerging world of nanotechnology [4]. Recent advances and envisioned developments in enabling nanotechnology provide challenges to academia in educating and training a new generation of skilled engineers and competent scientists. These engineers and scientists should possess the ability to apply knowledge of mathematics, science, and engineering in order to design, analyze and fabricate nanodevices and nanosystems, which are radically different when compared with microdevices and microsystems. Atomic and molecular comprise nanodevices and nanosystems, exhibit distinctive quantum phenomena and unique capabilities that must be utilized. Therefore, advanced theories, methods, tools and technologies should be comprehensively covered and effectively delivered [5].

2. General Framework of Nanotechnology

In the simplest terms, the subject of nanoscience technology is defined as the science and technology of the direct or indirect manipulation of atoms and molecules into functional structures, with applications that were never envisioned before. The prefix “nano” corresponds to a basic unit on a length scale, meaning 10^{-9} meters, which is a hundred to a thousand times smaller than a typical biological cell or bacterium. At the nanometer length scale, the dimensions of the materials and devices begin to reach the limit of 10 to 100s of atoms, wherein entirely new physical and chemical effects are observed; and possibilities arise for the next generation of cutting-edge products based on the ultimate miniaturization or so called “nanoization” of the technology. The earliest impetus to the scientific and technological possibility of coaxing individual atoms into the making of useful materials, devices and applications was given by the late Nobel- prize winning physicist Richard Feynman, in a land mark lecture: “There’s Plenty of Room at the Bottom,” delivered at the American Physical Society (APS) meeting at Cal Tech in 1959, in which he said, “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”. Indeed, scanning probe microscopes (SPMs), in recent years, have already given us this ability in limited domains, and spurred a tremendous growth in the pursuit of nanotechnology in the last two decades. A series of scientific and technological discoveries and progresses in a variety of areas in 1970s and 1980s, and the enunciation of visionary scenarios by Eric Drexler in a possible molecular nanotechnology-enabled world, have revived the field in the 1980-90s.

The real progress in the last decade, has been due to a series of advances in a variety of complementary areas, such as: the discoveries of atomically precise materials such as nanotubes and fullerenes; the ability of the scanning probe and the development of manipulation techniques to image and manipulate atomic and molecular configurations in real materials; the conceptualization and demonstration of individual electronic and logic de vices with atomic or molecular level materials; the advances in the self-assembly of materials to be able to put together larger functional or integrated systems; and above all , the advances in computational nanotechnology, i.e., physics- and chemistry- based modeling and simulation of possible nanomaterials, devices and applications. It turns out that at the nanoscale, devices and systems sizes have shrunk sufficiently small, so that, it is possible to describe their behaviors fairly accurately. The simulation technologies have become also predictive in nature, and many novel concepts and designs have been first proposed based on modeling and simulations, and then were followed by their realization or verification through experiments [3].

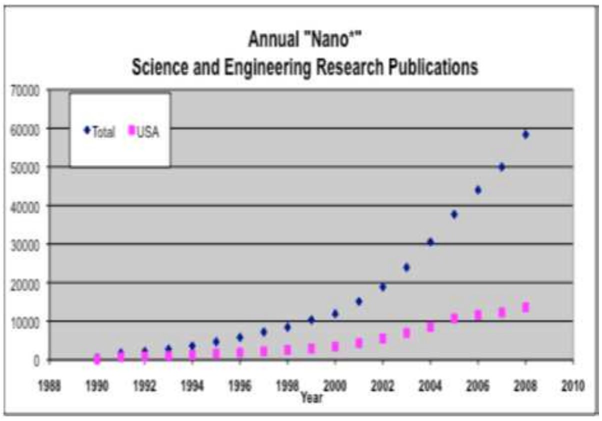

Figure 1. *Nano research publication*

3. Current Status of Nanoeducation

Many attempts have been pursued to develop interdisciplinary engineering and science curricula that will allow undergraduate and graduate students to successfully enter and master the engineering and science fields [7, 10]. To meet academic and industrial challenges, different curricular, program, tracks and course models have been introduced. It becomes increasingly difficult to achieve educational objectives and goals without a coherent unified theme. Recent advances and envisioned developments in enabling nanotechnology provide challenges to academia in educating and training a new generation of skilled engineers and competent scientists. These engineers and scientists should possess the ability to apply knowledge of mathematics, science, and engineering in order to design, analyze and fabricate nanodevices and nanosystems, which are radically different when compared with microdevices and microsystems. Atomic and molecular comprise nanodevices and nanosystems, exhibit distinctive quantum phenomena and unique capabilities that must be utilized. Therefore, advanced theories, methods, tools and technologies should be comprehensively covered and effectively delivered.

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 nonprofit 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] Items for specific attention:

1. There is a need to link community colleges with high schools on the one side, andwith undergraduate institutions on the other. A closer and more effective linkbetween these organizations will enable more effective communicationtechniques. It will also result in more appropriate science educational activitiesand provide for a well-prepared and diverse work force for the nanotechnologyand other emerging STEM fields.
2. Take advantage of the media favored by children and young adults: games,texting, internet, and other popular communication venues have not been fullyexploited by science educators as a means to increase interest in science andnanotechnology
3. Engagement with teachers at all levels and institutions should be enhanced byreaching out to national teachers' unions, research and academic societies(AAAS, NAS, MRS, APS, ACS) and other similar groups. In the world, the following universities offer either graduate or undergraduate courses in nanoscience or nanotechnology. [6]

Table 1. *Nanoscience or nanotechnology courses in the world [12]*

Country	University	Programs		
		BS.	MS.	PhD
Brazil	Universidade Federal do ABC		X	X
	Centro Universitário Franciscano, UNIFRA		X	
Mexico	Instituto National de Astrofisica, Opticay Electronica		X	X
	Universidad de las Américas	X		
Czech Republic	Technical University of Ostrava	X	X	
Denmark	University of Aalborg	X	X	X
	University of Aarhus	X	X	X
	Copenhagen University	X	X	X
	Technical University of Denmark	X	X	X
France	Master Nanotech		X	
Germany	Munich University of Applied Sciences		X	
	University of Ulm		X	
Israel	Technion		X	X
Italy	University of Venice		X	
Netherlands	Leiden University		X	
	Delft University of Technology		X	X
Norway	Norwegian University of Science and Technology		X	
	University of Bergen	X		
Spain	Master en Nanociencia y Nanotecnologia Molecular		X	
Sweden	Lund University		X	
	Chalmers University of Technology		X	
Switzerland	Eidgenosslsche Technische Hochschule		X	X
United Kingdom	University of Sussex	X		
	University of Leeds	X	X	
	University of Manchester			X
	University of Cambridge		X	X
	Cranfield University		X	X
	Imperial College London		X	
	University College London		X	
	University of Oxford	Post Graduate Certificate		
Turkey	Bilkent University		X	
United States	University of North Carolina at Charlotte			X
	Louisiana Tech University	X	X	X
	Rice University		X	

Country	University	Programs BS.	MS.	PhD
	The State University of New York		X	X
	Dakota County Technical College	Associates degree		
	Chippewa Valley Technical College	Associates degree		
	Richland College	Associate degree		
	University of Central Florida	X		
	North Dakota State College of Science	Associate degree		
Australia/New Zealand	Flinders University	X		
	University of Wollongong	X		
	RMIT University	X		
	University of New South Wales	X		
	Curtin University	X		
	University of Technology, Sydney	X		
	University of Western Sydney	X		
	University of Queensland	X		
	La Trobe University, Melbourne	X Double Degree		
	The University of Melbourne		X	
	Massey University, New Zealand	X		
	Massey University, New Zealand	X		
Canada	University of Alberta	X		
	University of Toronto	X		
	University of Waterloo	X		
	McMaster University	X		
India	Andhra University,Visakhapatnam		X	
	Nano Indian: India's nanotechnology education and research portal Panjab University, Chandigarh	M.Tech,NanoScience & NanoTechnology		
	University of Madras	M.Sc., M.Tech Dual Degree in Nanoscience and Nanotechnology		
	Indian Institute of Science - Masters		X	
	Jadavpur University at Kolkata - Masters, PhD		X	X
	Amity University, Noida	X Integrated	X	
	Vellore Institute of Technology, Vellore, Tamilnadu		X	
	University of Rajasthan at Jaipur		X	
Singapore	National University of Singapore	X		
Thailand	Chulalongkorn University	X		
	Mahidol University - Center of Nanoscience and Nanotechnology		X	

3. Nanoeducation Curriculums

The focus on microscopic consideration and nanotechnology reflects curriculum changes in response to the engineering enterprise and entreaties of evolutionary industrial demands. Nanotechnology has been introduced to attack, integrate and coherently solve a great variety of emerging problems in engineering, science and technology. A diverse education community has apparently different visions for what to target, emphasize, cover and deliver in nanotechnology courses. Different approaches have been pursued by various engineering, liberal art, science, technology and other schools and departments [7, 5]Some nanotechnology-named courses embed and cover traditional quantum physics, organic chemistry, microscopy, metrology, electronics and other conventional science and engineering topics using nano as a magnification prefix. A consensus has yet to be reached within the research and education communities for a definition of nanotechnology.

Table 2. *Nanotechnology interdisciplinary curriculum*

Course Category	Course Names
Basic courses	1. General Intro: state of the art 2. Nanoelectronic fundamental 3. Nanomaterials and chemistry
Advanced and practical courses	4. Intro quantum physics/chemistry 5. Biosphere and ecosystem 6. Bio/Molecular electronics 7. Nanofabrication materials/processes 8. Single electron devices
Hands-on lab/projects	9. DNA structure and computing 10. Nano-characterisation (lab) 11. Nano-devices hands-on test(lab)
Meta-physical courses	12. Culture and technology 13. Ethics and intellectual property

An example of a nanotechnology teaching curriculums shown in Table 2. There are four categories namely:

· Basic courses;
· Advanced and practical courses;
· Hands-on laboratory/projects;
· Metaphysical courses.

This has been designed primarily for a graduate curriculum, so advanced and practical courses maybe dropped from the undergraduate curriculum. Basiccourses are recommended for the high level

Engineering and science curricula integrate general education, science, engineering and technology courses. Students typically have some deficiencies in various aspects of quantum physics, engineering mathematics, chemistry and biology. Multidisciplinary courses and curricula represent a major departure from the conventional curricula. The attempt to substitute basic courses can create significant challenges. An interdisciplinary education encompasses and requires a broader coverage of cornerstone science in addition to the specialized in-depth topics, engineering design and fabrication. It is difficult, if not impossible, to substitute the cornerstone basic science and engineering courses by multidisciplinary courses which do not duplicate the basic courses. The need for traditional courses, such as Biology, Calculus, Chemistry and Quantum Physics is not eased, but is rather strengthened [7, 5, and 9]. This factor should be counted in the nanotechnology curriculum developments. Introductory nanotechnology topics can be introduced and emphasized through the required chemistry, biology, physics and freshman engineering courses. This provides a meaningful starting point for students. An interdisciplinary curriculum encompasses a broad understanding of basic and engineering sciences pertinent to nanotechnology. The nanotechnology-centered research and education initiatives require close collaboration between departments and colleges in order to provide viable educational and training opportunities. The unified studies of engineering and science potentially can be advanced and enhanced through nanotechnology curricula. In order to prepare students to solve nanotechnological challenges, the nanotechnology education should be coherently incorporated into the mainstream undergraduate engineering and science curriculum by:

1. Coherently integrating nanotechnology within traditional and modern science and engineering courses;
2. Developing new multidisciplinary courses complementing not substituting and duplicating) traditional courses;
3. Procuring adequate infrastructure and advanced facilities to comprehensibly support learning and scholarship;
4. Developing an interdisciplinary research opportunities and educational collaborations;
5. Disseminating best practices;
6. Developing the student and faculty exchange programs [8]

4. Web Sites with NanoEducation Content

1. American Chemical Society community.acs.org /nanotation/
2. European Nanotechnology Gateway www.nanoforum.org
3. Institute of Nanotechnology www.nano.org.uk/CareersEducation/education.htm
4. McREL Classroom Resources www.mcrel.org/NanoLeap/
5. Multimedia Educ. & Courses in
6. Nanotech www.nanopolis.net
7. NanoEd Resource Portal www.nanoed.org
8. NanoHub nanohub.org/
9. Nanotech KIDS www.nanonet.go.jp/english/kids/
10. Nanotechnology News, People, Events www.nano-technology-systems.com/nanotechnologyeducation/
11. NanoTecNexus www.Nanotecnexus.org
12. Nanozone nanozone.org/
13. NASA Quest quest.nasa.gov/projects/nanotechnology/resources.html
14. National Science & Technology
15. Education Partnership nationalstep.org/default.asp
16. Nanoscale Informal Science Education
17. Network Network www.nisenet.org
18. National Nanotechnology Initiative
19. Education Center www.nano.gov/html/edu/home_edu.html
20. National Nanofabrication Infrastructure
21. Network Education Portal www.nnin.org/nnin_edu.html
22. National Science Foundation
23. Nanoscience Classroom Resources www.nsf.gov/news/classroom/nano.jsp
24. PBS – Dragonfly TV pbskids.org/dragonflytv/nano/
25. Taiwan NanoEducation
26. See also presentation
27. www.nano.edu.tw/en_US/
28. www.iat.ac.ae/downloads/NTech/UAE_Workshop_Pamphlet2.pdf
29. The Nanotechnology Group Inc www.tntg.org
30. Wikipedia en.wikipedia.org/wiki/Nanotechnology

5. Text Books Addressing Nanoscale Science, Engineering and Technology

1. An Introduction to Nanotechnology Poole 2003
2. Introduction to Nanoscale Science and Technology DiVentra 2004
3. Applied Physics of Carbon Nanotubes Rotkin 2005
4. Nanotechnology: Basic Calculations for Engineers and Scientists Theodore 2005
5. Principles of Nanotechnology Mansoori 2005
6. Block Copolymers in Nanoscience Lazzari 2006

7. Nanophysics and Nanotechnology: An Introduction to Modern Concepts in Nanoscience Wolk 2006
8. Nanostructures – Fabrication and Analysis Nejo 2006
9. Polymer Nanocomposites: Processing, Characterization, and Applic Koo 2006
10. Core Concepts in Supramolecular Chemistry and Nanochemistry Pitcher 2007
11. Fullerenes: Principles and Applications Langa 2007
12. MEMS and Nanotechnology for Kids Bourne 2007
13. Nanocharacterization Hutchison 2007
14. Nanostructured Soft Matter Zvelindovsky 2007
15. Nanotechnology 101 Mongillo 2007
16. Nanotechnology in Biology and Medicine Vo-Dinh 2007
17. Nanotechnology: Understanding Small Systems Rogers 2007
18. An Introduction to Nanoscience Hornyak 2008
19. An Introduction to Nanosciences and Nanotechnology Nouailhat 2008
20. Applied Scanning Probe Methods VIII Bhushan 2008
21. Biomimetic Nanoceramics in Clinical Use Vallet-Regi 2008
22. Fundamentals in Nanotechnology Hornyak 2008
23. Introduction to Nanoelectronics: Science, Nanotechnology,Engineering Applications Mitin 2008
24. Nanoscience and Nanotechnology: Environmental and Health Impacts Grassian 2008
25. Nanotechnology: Health and Environmental Risks Shatkin 2008
26. Nanotherapeutics: Drug Delivery Concepts in Nanoscience Lamptrecht 2008
27. Semiconductor Nanostructures Bimberg 2008
28. Soft Machines: Nanotechnology and Life Jones 2008
29. What is What in the Nanoworld: A Handbook on Nanoscience and Nanotechnology Borisenko 2008
30. Nanocomputing: Computational Physics for Nanoscience and Nanotechnology Hsu 2009
31. Nanoscale Devices: Fabrication, Functionalization and Accessibility for the Macroscopic World
32. Cerofolini 2009
33. Nanoscale Phenomena: Fundamentals and Applications Hahn 2009
34. Nanoscience and Nanotechnology in Engineering Varadan 2009
35. Nanoscience and Technology of Renewable Biomaterials Lucia 2009
36. Nanoscience: Colloidal and Interfacial Aspects Starov 2009
37. Nanoscience: Nanobiotechnology and Nanobiology Boisseau 2009
38. Nanostructured Materials, Vol 1 Wilde 2009
39. Polymer-Based Nanostructures: Medical Applications Broz 2009
40. Single Semiconductor Quantum Dots Michler 2009
41. Science at the Nanoscale: An Introductory Textbook Wee 2009

6. Reference Books

1. Springer Handbook of Nanotechnology Bhushan 2006
2. Handbook of Nanoscience, Engineering, and Technology Goddard 2007
3. Dekker Encyclopedia of Nanoscience and Nanotechnology Contescu 2008
4. Oxford Handbook of Nanoscience and Technology Narlikar 2010.

7. Cyber and Virtual Innovations

Dr. Sean Brophy, Purdue University, and Dr. Miriam Heller, Computing Research Association

The nanoscience and nanotechnology centers have spawned several valuable cyberinfrastructure resources, some targeting education. The NanoEducation and STEM education communities need to become more aware of these cyberinfrastructure resources. Also, these cyberinfrastructure resources must become more integrated with each other for easier discovery. For instance, despite nanoHUB's widespread use with over 92,000 annual users, many workshop participants were not familiar with it or its capabilities. NanoHUB capabilities need to be better publicized regarding accessibility, content and updates, targeted user levels, customizability to targeted audiences and individual user interface, interoperability with other systems, and end-user.

8. Teaching Strategies

Nanotechnology should be taught by creating both knowledge-centered and learning-centered environments [11-15] 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 prerequisites.

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, nanotechnology 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. [2]

9. Conclusion

Basic science innovations, engineering developments and envisioned nanotechnological advances have brought new challenges to academia. As a result, many schools have revised their curricula to offer relevant courses. Attempts to introduce nanotechnology have been only partially successful due to the absence of coherent strategy and diverse views of what nanotechnology means. Coordinated efforts should be sought. It is necessary to educate engineering and science students with an ability to design, analyze and synthesize nanosystems. 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. This paper will help to other researchers

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