Nanotechnology in Education and General Framework of Nanomanufacturing

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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. Also this paper represents brief introduction on nanotechnology and introduces a general framework for nano-manufacturing. Note that, the development of nano-manufacturing leads to produce new nano technological products. Also note that nano-manufacturing describes approaches and methods to product nano scale materials that can be basically define top-down and bottom-up

Keywords— Nanomanufactureing, Nanotechnology, Nanoeducation.

I. 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.[3]

Manufacturing of nanoscale structures, devices and systems will be performed with a high degree of process control in sensing, assembling, and positioning matter at the nanoscale in order to achieve prescribed levels of performance in production and service. Hierarchical integration will be used across dimensional scales, from atoms to molecules to the human length scale, to incorporate nanostructures into microscale architectures and macroscale products. [4-5] The development of nanomanufacturing technologies will lead to potential breakthroughs in manufacturing of new industrial products. Nanoscale products with unique mechanical, electronic, magnetic, optical and or chemical properties, opens the door to an enormous new domain of nanostructures and

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integrated nanodevices. They have a variety, of potential applications such as nanoelectromechanical systems (NEMS) and DNA computers etc. Nanomanufacturing requires positioning of nanoparticles in complex 2D or 3D structures. The techniques for nanomanufacturing can be classified into “bottom-up” and “top-down” methods. Self-assembly in nanoscale is the main promising “bottom-up” technique which is applied to make regular, symmetric patterns of nanoparticles. [12]

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 [4].

II. Nanoscience and 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.[3]

Nanotechnology covers all aspects of the production of devices and systems by manipulating matter at the nanoscale[8]. Nanotechnology is a cross-disciplinary area of technology that involves physics, chemistry, biology, molecular biology, medicine, materials science and other disciplines. In the simplest terms, nanotechnology is defined as the ability to work at the atomic, molecular and supramolecular levels at a scale of 0.1-100 nm for the purpose of designing, manufacturing, manipulating and applying materials, components and systems with new physical, chemical and biological functional properties. These new properties emerge because of the small scale of the structures, and can therefore not be obtained in other ways. Integration with other scales of length and areas of application will often be essential to technological applications. Nanoscience is concerned with obtaining an understanding of fundamental phenomena, properties and functions at the nano-scale, that are not scalable outside the nanometre domain. A nanometre (nm) is one thousand millionth of a metre. For comparison, a single human hair is about 80,000 nm wide, a red blood cell is approximately 7,000 nm wide and a water molecule is almost 0.3nm across. People are interested in the nanoscale (which we define to be from 100nm down to the size of atoms (approximately 0.2nm) because it is at this scale that the properties of materials can be very different from those at a larger scale. nanoscience defined as the study of phenomena and manipulation of materials at atomic, molecular and macromolecular scales, where properties differ significantly from those at a larger scale; and nanotechnologies as the design, characterisation, production and application of structures, devices and systems by controlling shape and size at the nanometre scale. In some senses, nanoscience and nanotechnologies are not new. Chemists have been making polymers, which are large molecules made up of nanoscale subunits, for many decades and nanotechnologies have been used to create the tiny features on computer chips for the past 20 years. However, advances in the tools that now allow atoms and molecules to be examined and probed with great precision have enabled the expansion and development of nanoscience and nanotechnologies.

The properties of materials can be different at the nanoscale for two main reasons. First, nanomaterials have a relatively larger surface area when compared to the same mass of material produced in a larger form. This can make materials more chemically reactive (in some cases materials that are inert in their larger form are reactive when produced in their nanoscale form), and affect their strength or electrical properties. Second, quantum effects can begin to dominate the behaviour of matter at the nanoscale - particularly at the lower end - affecting the optical, electrical and magnetic behaviour of materials. Materials can be produced that are nanoscale in one dimension (for example, very thin surface coatings), in two dimensions (for example, nanowires and nanotubes) or in all three dimensions (for example, nanoparticles) [13].

The invention of new devices (STM and AFM) in past two decades has enabled scientists and engineers to extend their studies to objects at the atomic level [10-14]. With the latest scanning probe microscopes, it is now possible both to "see" individual atoms and molecules and to move them around, there by creating new nanostructures in a controlled manner. This has led to a paradigm shift in our research into the nanocosmos and today we are in principle in a position to construct new materials atom by atom and molecule by molecule, analogously to building a model out of Lego bricks. However, there are a number of major challenges on the path from being able to perform such operations in the research laboratory to being able to use them in large-scale industrial production. If we can tackle those challenges, the reward is the prospect of a large number of very promising possibilities for the use of nanotechnology to help increase growth and welfare, and to meet some of society's major challenges in the areas of health, energy and the environment [15]. Fig. 1 below illustrates the diversity of current nano-products and prospective second-generation nano-applications.

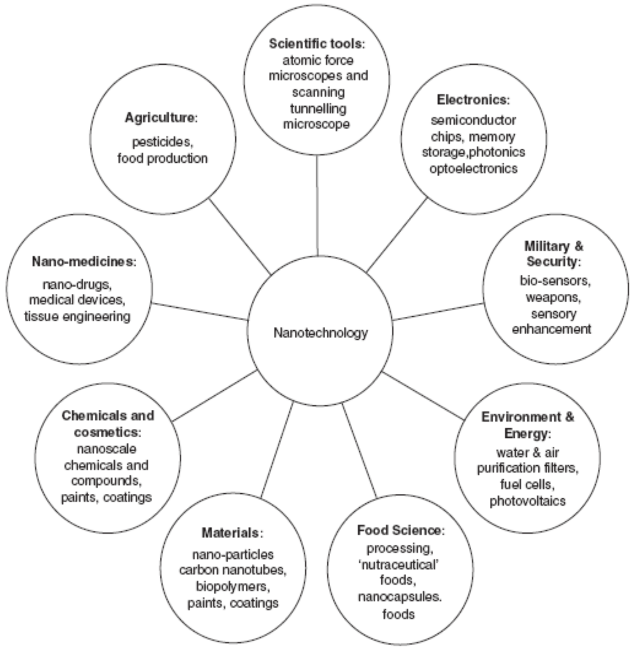

Fig.1. Diversity of current nano-products and prospective second-generation nano-applications

So far, the relatively small numbers of applications of nanotechnologies that have made it through to industrial application represent evolutionary rather than revolutionary advances. Current applications are mainly in the areas of determining the properties of materials, the production of chemicals, precision manufacturing and computing. In mobile phones for instance, materials involving nanotechnologies are being developed for use in advanced batteries, electronic packaging and in displays. The total weight of these materials will constitute a very small fraction of the whole product but be responsible for most of the functions that the devices offer. In the longer term, many more areas may be influenced by nanotechnologies but there will be significant challenges in scaling up production from the research laboratory to mass manufacturing. In the longer term it is hoped that nanotechnologies will enable more efficient approaches to manufacturing which will produce a host of multifunctional materials in a cost-effective manner, with reduced resource use and waste. However, it is important that claims of likely environmental benefits are assessed for the entire lifecycle of a material or product, from its manufacture through its use to its eventual disposal [9].

A. A brief history of nanotechnology

The history of nanotechnology began in 1959, when Richard Feynman (a physicist of the California Institute of Technology), in his famous lecture "There is Plenty of Room at the Bottom", proposed the concept of nanotechnology. It suggested that the frontiers of knowledge and technology at which people should be aiming could be found not only in physics, but also in nano-sized fields. In the 1980s, the invention of the scanning tunneling microscope (STM), a computer imaging system with a surface probe, enabled the manipulation of atoms and molecules, by which most significant change has been brought in this field. Since then, developments in nanotech continued with significant discoveries of nanomaterials such as fullerenes and carbon nanotubes. A pathway of major nanotechnology discoveries is presented in Fig. 2.

An important revolution in analytical instruments, preceding discoveries and subsequent technological advancement [16], stimulated the exploration of nanoscale structures and the developments of nanoscale technologies. It has been estimated that nanotechnology is currently at a level of development similar to early commercial applications of information technology in the late 1960s or to the emergence of biotechnology in the 1980s [17], and further impressive discoveries, transforming the affected technological domains, are to be expected.

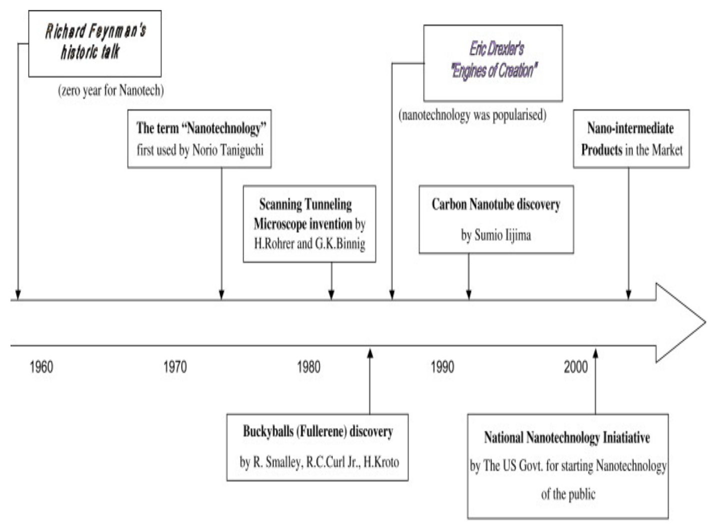

Fig.2 Pathway of major nanotechnology discoveries.Diversity of current nano-products and prospective second-generation nano-applications

B. Nano- manufacturing and Basic Elements

The ability to manufacture and use materials, devices and systems integrated from the nanoscale is one of the most important promises of nanoscale science and engineering. New paradigms are expected in industry, economy, healthcare, environment and security. As an example, gears have been studied and used for millennia as a macroscale mechanism to transmit mechanical power and information [18]). However, carrying the design of a gear transmission to the nanoscale is challenged not only by dominant effects of their high surface/volume ratio, and the problems of friction, stiction, surface tension, electrostatic forces etc. during operation, but also by major hurdles in their manufacturing at the nanoscale in a repeatable, economical and high rate for industrial production. At the same time, nature offers robustly producible, effective molecular mechanisms, such as the actin-myosin filament walk-along interactions in our muscle fibers for linear motion [19] and F1-ATPase biomotor for rotational motion [20]. Such biomimetic paradigms open up exciting research opportunities not only in the analysis of biological archetypes for generating physical movements, but also in the design and manufacturing of bio-inspired devices and their large-scale production for efficient and reliable transmissions at the nanoscale.

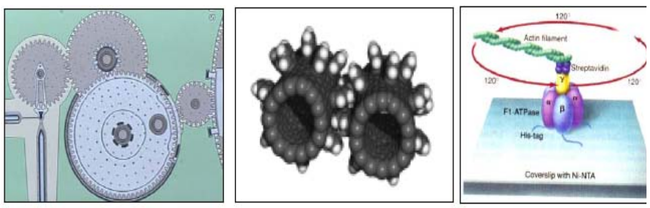

Fig. 3. a. Microscale gear (Sandia National Labs. 1990); b. Nanoscale gear (E. Drexler – simulation); c. Biological nanomotor (H. Noji, Science 1998)

Nanoscale manufacturing encompasses all materials, processes and equipment aimed toward building of nanoscale structures, features, devices, and systems in one, two and three dimensions. It melds both bottom-up assembly of nanostructure building blocks with top-down processes for economical devices and systems with complex functions. Manufacturing techniques at the nanoscale have equal relevance as novel components of traditional industries, and as engines for revolutionary technologies enabling new products and services. They promise to increase in quality, productivity and efficiency of existing technologies, and to establish industries and markets that would have not been possible otherwise. Advances in manufacturing at the nanoscale are anticipated to accelerate commercialization of products such as: nanostructured materials with novel and improved properties; information technology nanodevices including advanced semiconductors, molecular electronics and spintronics; nanobiotechnology and pharmaceutics – diagnostics, implants, new drugs and their therapeutic delivery; measuring devices and tools for manufacturing; higher performance safety and security technology including sensors, adsorbents, filters and decontaminants; and nano-electromechanical systems (NEMS) [21].

There are a wide variety of techniques that are capable of creating nanostructures with various degrees of quality, speed and cost. These manufacturing approaches fall under two categories ‘bottom-up’, and ‘top-down’. These approaches can define as basics elements of nanomanufacturing. In recent years the limits of each approach, in terms of feature size and quality that can be achieved, have started to converge. A diagram illustrating some of the types of materials and products that these two approaches are used for is shown below in Figure 4.

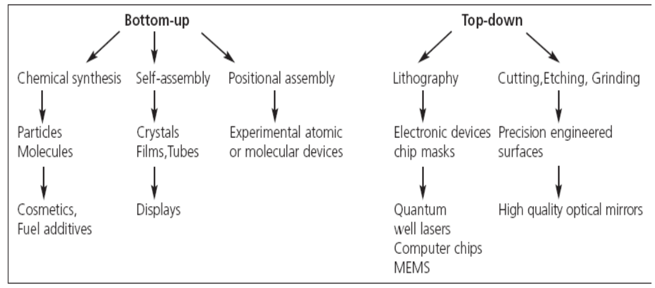

Fig. 4. The use of bottom-up and top-down techniques in manufacturing

C. Bottom-up manufacturing

Bottom-up manufacturing involves the building of structures, atom-by-atom or molecule-by-molecule. The wide variety of approaches towards achieving this goal can be split into three categories: chemical synthesis, self-assembly, and positional assembly. As discussed below, positional assembly (with its many practical drawbacks as a manufacturing tool) is the only technique in which single atoms or molecules can be placed deliberately one-by-one. More typically, large numbers of atoms, molecules or particles are used or created by chemical synthesis, and then arranged through naturally occurring processes into a desired structure

D. Top-down manufacturing

Top-down manufacturing involves starting with a larger piece of material and etching, milling or machining a nanostructure from it by removing material (as, for example, in circuits on microchips). This can be done by using techniques such as precision engineering and lithography, and has been developed and refined by the semiconductor industry over the past 30 years. Top-down methods offer reliability and device complexity, although they are generally higher in energy usage, and produce more waste than bottom-up methods. The production of computer chips, for example, is not yet possible through bottom-up methods; however, techniques using bottom-up (or hybrid top-down/bottom-up) methods are under exploration.[9]

E. General Framework

Nanomanufacturing production systems are becoming more and more important instead of traditional manufacturing systems. Since it is a new area of research and technology development, there is still need for systematic approaches and scientific methodologies to handle nano materials and nano processes as well as their impact on human life. There is also a need for understanding nanoscale leads and support for the development of nano technology. In this part a frameworl for the nanomanufacturing systems are developed which will help to researchers on this area. Framework for nanomanufacturing has represented below.

The techniques for nanomanufacturing can be classified into “bottom-up” and “top-down” methods. Self-assembly in nanoscale is the main promising “bottom-up” technique which is applied to make regular, symmetric patterns of nanoparticles [22]. However, many potential nanostructures and nanodevices are asymmetric patterns, which cannot be manufactured using self-assembly.

A “top-down” method is desirable to manufacture complex nanosuuctures. Atomic force microscopy (AFM) [23] has been proven to be a powerful technique to study sample surfaces down to the nanometer scale. Not only can it characterize sample surfaces, it can also change the sample surface through manipulation [24], [25], which is a promising “top-down” nanofabdcation technique. In recent years, many kinds of nanomanipulation schemes have been developed [26], [27], [28] to position and manipulate nanoobjects. The main problem with these manipulation schemes is that they go through the scan-design-manipulation scan cycle manually which is time-consuming and makes mass production impossible. In order to increase the efficiency in nanomanufacturing, automated manipulation using collision-free paths is necessary. However, automated tool path planning for nanomanufacturing does not receive much attention. Makaliwe [29] developed a path planning algorithm for nanoparticle assembly. Object assignment, obstacle detection and avoidance, path finding and sequencing are addressed. The obstacles discussed in the paper are polygons, which do not occur often in nanoworld. In AFM manipulation, NmS around obstacles should be avoided since turns may lose nanoparticles during maniputation. To generate a path for nanomanufacturing, destination, object and obstacle avoidance have to be considered. To make Nano manufacturing efficient using nanomanipulation, it is desirable to develop a general framework to manufacture nanostructurs and nanodevices. In this paper, a general framework for nanomanufacturing is developed. Simulations will perform to test the generated paths for real time nanomanufacturing to manufacture nanostructures.

In this framework, first step defined as nanomaterials. Different kind of nano materials can use as an input material which will produce nano device or other nano materials and process steps follow the nano materials step. Two different process type is defined in the second step. These processes can be called nano manipulation. First process includes nano manufacturing techniques and methods. As it mentioned before there are two important technique that can use all in nano process which they called top-down and bottom up techniques. Another process step includes nano manufacturing devices which will direct manipulate to nano materials after positioning and path planning. Some of this manipulation device can make own positioning and planning but generally it needs manually image scanning, positioning and path planning. Some of ASM devices integrated CAD computer systems to manage all this steps in a device. Last step will give a new nano material or nano device which can be use them agin in this process. Also end of all this process will produce a new nano production that can be use customers. Fig 5 below illustrated a nano manufacturing framework.

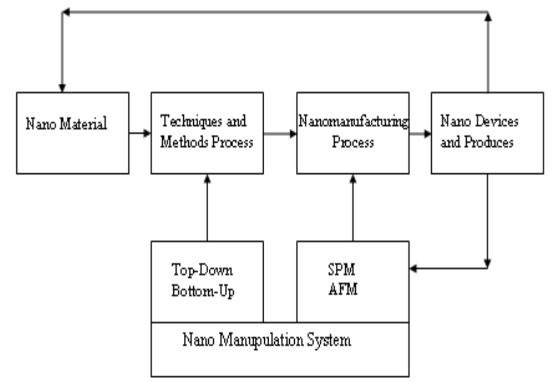

Fig. 5. Nano manufacturing Framework

III. Nanotechnology in Education

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 [6, 9]. 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 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].

In the world, the following universities offer either graduate or undergraduate courses in nanoscience or nanotechnology [5].

TABLE 1. NANOSCIENCE OR NANOTECHNOLOGY COURSES IN THE WORLD [15]

Country	University	Programs		
		BS.	MS.	PhD
Brazil	Universidade Federal do ABC		X	X
	Centro Universitário Franciscano, UNIFRA		X	
Mexico	Instituto Nacional 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	

TABLE 1. NANOSCIENCE OR NANOTECHNOLOGY COURSES IN THE WORLD [15]

Country	University	Programs		
		BS.	MS.	PhD
United States	University of North Carolina at Charlotte			X
	Louisiana Tech University	X	X	X
	Rice University		X	
	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	M.Tech,NanoScience & NanoTechnology		
	Panjab University, Chandigarh			
	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	X	
		Integrated		
	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	

IV. 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 [6, 4, 30]. The topics and material covered in the undergraduate and graduate courses are quite diverse. 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.

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 [6, 4, and 8]. 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 [7, 31].

V. TEACHING STRATEGIES

Nanotechnology should be taught by creating both knowledge-centered and learning-centered environments [10] 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, 32, 33].

VI. 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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