Nanotechnology Applications: Issues in Implementing Engineering Technology Curriculum

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A. Introduction

Nanotechnology deals with working on matter at the molecular scale. It promises to revolutionize the way in which we live and change our world for ever. From the design and manufacture of electronics products to production of medicine and treatment of patients, nanotechnology offers enormous advantages over other technologies employed thus far. Educational institutions can help shape the way in which nanotechnology is employed in industry by educating engineers and technologists and providing leadership in research and technology transfer. Academic programs in nanotechnology will be interdisciplinary in nature and will require far larger resources than required in the past of traditional technology programs. This paper will provide a brief account of nanotechnology, present the worldwide activities in the development and application of nanotechnology and the need to prepare engineers and technologists for nanotechnology implementation in industry. It will then outline the curricular elements leading undergraduate and graduate level education in nanotechnology. It will also discuss the key issues relating to the development and implementation of a nanotechnology curriculum. In view of the current state of development of nanocomposites and their role in many industries, special emphasis will be placed on the development of a lab for nanocomposities. The broader curricular elements that will be dealt in the paper are:

Topics in Nanoprocessing and Biomedical Technology
Topics in Micro and Nanofabrication
Bio Nano Manufacturing Processes
Bio Nano Manufacturing for Pharmaceutical Applications
Nano Materials and Composites Manufacturing
Nano Scale Electronics Manufacturing

B. Nanotechnology

Nanotechnology is the creation of functional materials, devices, and systems through control of matter on the nanometer (1 to 100+ nm) length scale and the exploitation of novel properties and phenomena developed at that scale. Nanotechnology represents a scientific and technological revolution that is based upon the ability to systematically organize and manipulate matter on the nanometer scale. It gives us the tools to build things out of molecules and atoms at dimensions below 100 nanometers. It offers endless possibilities and potentials for product design, development and manufacturing. It is reported that while nanotechnology would enable us to manufacture smaller, and faster computers and other products, it would help us create lighter, and stronger materials and medical implants that are more friendly to the human body. Nano products can be made in two ways. The "top-down" approach is essentially a continuation of the miniaturization process that has been under way for decades, where material is removed selectively to arrive at a functional product. The "bottom-up" approach is the futuristic one, in that functional products are built up by assembling materials at atomic and molecular dimensions. The two areas that are affected in a major way by nanotechnology are: semiconductor manufacturing and biomedical technology. With tens of billions of dollars spent in public and private funding for nanotechnology research worldwide in 2003, it is expected that hundreds of thousands of jobs will be created in the next ten to fifteen years. Even as the research and development efforts in nano manufacturing are underway, there is an acute shortage of trained engineers and technologists to implement nanotechnology in electronics and biomedical industries.

C. Worldwide Developments in Nanotechnology

As the application of nanotechnology is growing fast in many areas, it is still considered to be at its early stages of growth. It is estimated that at this time in excess of 2000 companies in about 35 countries are involved in the development of products and processes using nanotechnology. The majority of the people involved in nanotechnology at this stage deal with fundamental or applied research, product and process development, and possibly, in the development of manufacturing methods. Since the early 1990s, concerted efforts have been made by industry and academic institutions all over the world to develop and apply nanotechnology. Governmental support in the USA, Asia and Europe has been a major factor in worldwide research and product development in nanotechnology. In the private sector in the USA, large multinational companies in chemical, biological, pharmaceutical, electronic and other areas have led the research efforts in nanotechnology. In 1997 the governmental agencies in the USA, led by the National Science Foundation provided $116 million for projects related to nanotechnology research. Since then, the government support for fundamental research and industry investment in applied research and product development have resulted in more than 100 fold increase in funding for nanotechnology.

In Japan, formal research on nanotechnology started in the 1980s. By 1996, the Ministry of International Trade and Industry (MITI) and its sub agencies started spending about $120 million annually for nanotechnology research. In China, a ten-year program known as the "Climbing Project on Nanometer Science" (1990-1999) and a series of advanced materials research projects with more than 3000 engineers and scientists started the core of nanotech research and manufacturing activities. Similarly, countries like Korea, Singapore, Taiwan and Australia in the far east have allocated considerable resources for nanotech research since the early 1990s.

In Germany, the Federal Ministry of Education, Science, Research, and Technology (BMBF) has provided substantial national support for nanotechnology. The Fraunhofer Institutes, Max Planck Institutes, and several universities have formed centers of excellence in nanotechnology. It is estimated that starting in 1997, the BMBF has supported programs on nanotechnology with a budget of $50 to 80 million a year. In the UK, a network program known as the LINK Nanotechnology Program launched in 1988 started the nanotechnology research with an annual budget of about $2 million per year. The governmental funding for Nanotechnology in the UK has grown since then to over a billion dollars in 2002. In France, the Centre National de la Récherche Scientifique (CNRS) has developed research programs on nanoparticles and nanostructured materials at about 40 physics laboratories and 20 chemistry laboratories. The CNRS projects in nanotechnology started in 1996 with an estimated budget of about $40 million a year. During the same period, Sweeden has spent $10 million a year for nanotechnology research. Further, the governmental support has been strong for nanotechnology research in countries like Swizerland, Italy, and Denmark.

D. Nanotechnology Education in the USA

In the USA, the early research initiatives by the government has helped create major nanotechnology facilities at Cornell University, Stanford University, Pennsylvania State University, University of California- Santa Barbara, Howard University, Rice University, and Northwestern University. As national institutions, their focus was on multidisciplinary research, and laying the foundations for further work in nanotechnology. Since the early days, as an extension of ongoing research in physics, chemistry, electronics, biology, materials, medicine, instrumentation, manufacturing and other disciplines, many national centers of excellence in nanotechnology have been created in educational institutions and governmental labs. Further, industry's interest in and the need for focused research and development have also led to the creation of industry based centers for nano materials and processing around the country. Most of the early national centers of research have focused primarily on pushing the frontiers of science of nanotechnology. Activities pertaining to nanotechnology education have focused for the most part on preparing research scientists and engineers and providing support for fundamental and applied research. There has been very little progress in the preparation of engineers and technologists with formal undergraduate programs in nanotechnology. Presently, no known engineering technology degree programs focusing on nanotechnology exist at the associate or baccalaureate degree level.

While the country produces more than 60,000 engineers, there are about 15, 000 engineering technicians and technologists coming out of the community college and four year degree granting institutions annually. Due to the historical nature of the programs, and their evolution to the current status, the engineering technology programs at the associate and the baccalaureate degree level are far less integrated with the centers of research compared to the programs in engineering. The lack of integration between research and engineering technology education is a major factor contributing to the lack of adequate number of engineering technologists in such industries as electronics manufacturing and biomedical technology. When it comes to nanotechnology, there has been very little curricular activity at the associate or baccalaureate level to address the needs of industry for technicians and technologists.

E. Need for Nanotechnology Personnel

The evolution of nanotechnology has not reached the stage, where mass production using this technology can be contemplated for a few years. However, it is common knowledge that at this stage of application of nanotechnology, the resources ranging from people to advanced scientific equipment and technologies are focused on the use of small dimensions to fabricate structures, devices, and systems with unique properties. Such fabrication requires integrated processing using complex tools, knowledge of interaction between processes, and development of new techniques to make the new object of interest possible. One of the major factors determining the rate of growth of the nanotechnology industry in the coming years will be the availability of an adequately trained technical work force.

Projections made by the Bureau of Labor Statistics in 2001 showed that the US economy will be able to support 167.75 million jobs in 2010 but anticipated only 157.72 million people being available to fill them. Further, as the U.S. manufacturers continue to shift unskilled and low-skilled work from domestic plants to those at off shore locations, the manufacturing jobs that are going to be available are going to be more sophisticated than the 'traditional' manufacturing sector jobs. According to an industry projection that in the next ten years, there will be a shortage 300, 000 technicians in the electronics industry alone. In fact, in such industry sectors as pharmaceutical, electronics, precision machining and biomedical technology there is already a shortage of highly skilled technical workforce. It is in these industries, the impact of technological advances in nanotechnology is already felt. It is expected that as nanotechnology evolves, large multinational companies in pharmaceutical, biomedical and electronics will recognize the need to prepare the technical work force and would take actions on their own, while their suppliers, sub contractors and others in the medium and small scale operations will face serious competition for skilled engineers and technologists. It is becoming a national imperative that a highly skilled technical work force be prepared to meet the current and future needs of the nanotechnology industry. The need to prepare a technical work force for the nanotechnology industry translates into the need for outreach to K-12 students, technology exposure to middle school and high school students, recruitment of students for nanotech programs, and preparation of high school, community college and university faculty. More importantly, it involves the need to develop model curricula, instructional material and laboratory infrastructure and make them available to the public.

F. A Curriculum in Nanotechnology

Traditionally, the educational institutions have followed industry in creating curricula and establishing academic programs. In order to be more effective in implementing technology and be responsive to the needs of industry in a timely manner, the educational institutions should establish means to forecast the needs and develop programs far sooner than has been the norm. The growth of nanotechnology has reached a point, where the educational institutions should not only to contemplate the creation of programs in nanotechnology, but move forward to develop and implement them. A curriculum in nanotechnology should be able to cross traditional boundaries of education and must include areas such as biology, chemistry, electronics, materials, mechanics, manufacturing and systems. In this section, a partial menu of topics that must be considered for inclusion in a nanotechnology curriculum is presented.

1. Topics in Nanoprocessing and Biomedical Technology

Material processing
Microscopy applications
Surface analysis
Analysis of mechanical properties
Forming micro patterned cell cultures
Use lithographic patterning of surfaces to direct cell adhesion
Micro fabrication for manipulation of cells and directed tissue growth
Advanced microscopy techniques
Cell physiology
Cell Cultures
Microscale Physical Measurements
Nano structured surfaces
Nanopatterning
Physical and chemical patterning of surfaces at sub-cellular scales
Application of Nanostructured Surfaces in Medicine and Biotechnology
Nano structured surfaces of conducting and semi conducting materials
Use of laser-induced patterning to direct adhesion molecule distribution
DNA Microarrays

2. Topics in Micro- and Nanofabrication

Micro and nano fabrication techniques
Preparation of biomaterials
Characterization of biomaterials
Use of nanofabrication for biomedical devices
Fabrication for electrophoresis
Fluorescence microscopy in biomedical technology
Microscopic practices
Application of microscopy for analysis of cellular structures
Mass spectrometry applications in biomedical technology
Atomic spectroscopy applications
Mass spectrometry and Protein analysis
High speed chromatography and mass spectrometry
Isolation and purification of protein pharmaceuticals
Formulation and delivery of pharmaceutical proteins
Digital Imaging
Imaging protein structures
Analysis of imaging data

3. Bio Nano Manufacturing Processes

Micro and nano fabrication techniques
Use of nanofabrication for biomedical devices
Use of nano process for pharmaceutical applications
Fermentation Processes
Protein purification / identification
Protein analysis
Biomaterial particle size reduction processes
Biosensors
Diagnostic devices

4. Bio Nano Manufacturing for Pharmaceutical Applications

Isolation and purification of protein pharmaceuticals
Formulation and delivery of pharmaceutical proteins
Particle size reduction and delivery of proteins
Nano particle suspension and drug delivery processes
Nano patterning and drug delivery systems
Nano materials and process for dental applications
Nano manufacturing for surgical implantation
Manufacture of industrial enzymes
Bio Manufacturing and Environmental issues

5. Nano Materials and Composites Manufacturing

Micro and nano scale manufacturing
Nano scale materials and properties
Nano processing for composites manufacturing
Physical property enhancement with nano particles
Nano composites and micro alloying
Nano material characterization
Nano composites - Process and testing equipment
Nano composites manufacturing for aerospace applications
Nano composites for automotive applications
Nano compoisties for surgical applications
Current research topics in nano composites

6. Nano Scale Electronics Manufacturing

Nano scale manufacturing in electronics industry
Photolithography processes
Electron beam lithography processing
Chemical vapor and thin film deposition
Wirebonding and packaging
Wafer bonding, ion implant, and chemical polish

Thin film etching and packaging
Carbon nanotubes
Nano electronics equipment and applications
Process equipment and Characterization
Nano manufacturing applications
Atomic-level imaging
Nano patterning, and processing of semiconductor nanostructures

G. Nanotech Research

The following illustrates the nature of research projects that are being carried out currently in industry and in academic research labs:

Nano-structured films for Mass Spectroscopy
Molecular Pores
Nano-channels
Polymer Filaments
New Nanofabrication Methodologies
Nanofabrication and Characterization Tools
Development of Silicon Immersion Gratings and Grisms
Helium Implantation Induced Nano-Cavities in Silicon
Mesoscopic Physics in Disordered Superconductors
Microcontact Printing
Molecular Electronics
Molecular Ruler for Scaling Down Nanostructures
Molecular Ruler for Scaling Down Nanostructures - Formation of Precisely Defined Electrode Spacings
Nanostructured Thin Films
Novel Materials - New Deposition Approaches for Novel Materials and for Low Processing Temperatures
Novel Materials - Organic Films and Polymers
Novel Materials - Unique Morphology Property Materials
Optoelectronics
Self Assembling Beads
Thin Film Transistors

H. Issues in Implementing a Nanotechnology Curriculum

Nanotechnology is multi disciplinary in nature and would require far greater resources than is the norm in implementing a traditional degree program. The implementation of a nanotechnology curriculum at the undergraduate level would require partnership involving multi units within a university, multi university involvement, participation and support from government, extensive industry involvement and partnership and collaboration with the national labs. The following lists the key issues to be addressed in developing and implementing a curriculum in nanotechnology:

- preparing faculty to teach in a technology that is still evolving and yet broader in scope
- practical experience and continued industry involvement for faculty
- developing an interdisciplinary curriculum
- arranging unconventional means to gain access to laboratory facilities at partner institutions
- need to focus on a specific aspect of nanotechnology
- need to share personnel, laboratory and other resources with partners
- outreach programs for students
- co-op and internship arrangements aimed at real world experience for the students
- developing partnerships with education, industry and government
- securing resources to develop curriculum, faculty, labs, and technical support

I. A Lab for Polymers and Nanocomposites

In this section, we will provide a brief description of a lab for polymers and nanocomposites. Such a lab must be capable of material characterization, processing and testing. There are a wide range of tests and techniques available for the analysis of mechanical and thermal properties, and for molecular characterization and separation. The following are some of the analytical and characterization techniques used for polymer and nanocomposites:

Mechanical properties*:* Many types of instruments and techniques are available for determining the mechanical and rheological properties of polymers. The properties that can be measured include tensile and toughness properties, time-dependent properties (such as stress relaxation), and solution and melt flow properties. The ability to characterize and thus elucidate the underlying causes of the fracture behavior of a specimen is often important in product liability lawsuits.

Thermal analysis*:* Many techniques are available to characterize the thermal and physical properties of materials; including glass transition temperature, crystalline melting temperature, percent crystallinity, specific heat, phase transition enthalpies, kinetic constants, degradation temperature, viscoelastic properties, percent weight loss, material softening temperature, and thermal expansion coefficient.

Barrier properties*:* Gas and vapor transmission measurements, combined with thickness measurements, can be utilized to determine permeation rates through flat films, flexible packages, and non-flexible packages made from various materials.

Microscopy: Various instrumental techniques are available. The magnification can range from x20 by optical microscopy or scanning electron microscopy to x500,000 by transmission electron microscopy. Specific determinations include the distribution of phases, melt and phase behavior, porosity, concentrations and average sizes of particles, size distributions of particles, crystallization kinetics, and fracture analysis.

Molecular characterization*:* Many instrumental techniques are available to determine the structure and identity of organic and inorganic molecules. Specific determinations include unknown identification, purity determination, functional group analysis, molecular weight, and polymer analysis.

Separation science*:* Various techniques, including quantitative and qualitative determination of materials, solvents, purity, homogeneity, molecular weight, and molecular weight distribution, are used to characterize mixture compositions.

Basic Process Equipment for Composites Lab

- Autoclave working chamber capable of at least 100 psi/350°F cures.
- 3axis filament winder, with such specifications as 6"dia. x 30"long mandrel..
- Low pressure CVD to 1250°C with pulsed flow.
- Hot press (20 tons or above) capable of 425°C processing.

Test Equipment

- 10,000 lb load frame with environmental chamber and fixturing capable of temperatures from 150°C to +425°C.
- Single filament tensile tester.
- High cycle impact fatigue test apparatus
- Creep test apparatus.
- Metallograph with polarized light
- Microscope with bright field/dark field illumination.
- Computer image analysis on microscopes.
- Thermal Analyzer
- Distortion measurement on panels and angle brackets to at least 200C
- Chromatography along with mass spectrometric detection for molecular characterization.

Possible Applications in the Lab

- Mechanical testing with test temperature capabilities from -150°C to +425°C.
- Component failure analysis.
- Metallographic specimen preparation and analysis of composites.
- Quantitative "Image Analysis" of metallographic specimens or images.
- Thermal Analysis of matrix materials.
- Custom composite specimen fabrication.
- Design of custom composite components.
- Redesign of components for fabrication in composite materials.
- Development of composite manufacturing processes and process parameters.
- Measurement, prediction and control of manufacturing distortion in fiber reinforced composites.

J. Non-traditional Approaches to Hands-on Education

The technological developments in industry and the ensuing need for human resources have made it essential for the educational institutions to develop curricula and labs, and provide students with hands-on experience in new technologies. However, the cost associated with the establishment of labs, and the resource limitations on faculty and staff have made it necessary to consider such approaches as use of shared lab facilities, and formalized clinical work in national research labs, and utilizing internships and co-operative education in industry as means to provide hands-on education. In the last five years, numerous educational initiatives around the country have created unique opportunities to provide hands-on education in nanotechnology. They include the provisions made by such funding agencies the National Science Foundation and National Institutes of Health to use of shared bio and nanotechnology facilities, and the opportunities offered by the national research labs and industry entities to undergo internships and clinical work experience.

Under the National Nanotechnology Infrastructure Network (NNIN), institutions such as Pennsylvania State University and Northwestern University have created shared nanotechnology user facilities for education and research. Supported by the National Science Foundation, they serve the educational and research needs of nanoscale science, engineering and technology. NNIN provides users across the nation, in academia, small and large industry, and government, with open access, both on-site and remotely, to leading-edge tools, instrumentation, and capabilities for fabrication, synthesis, characterization, design, simulation, and integration, to help enable their individual research projects. Some of the community colleges and four year institutions around the country have established formal means to utilize shared nanotechnology facilities in major universities. Others have provisions to utilize such public lab facilities as Brookhaven National Lab, Scandia Lab and others for hands-on education. In the case of educational institutions with a long history of co-op and internship education, experiential learning in industry is utilized as a formal means to complement classroom education. Although there is no substitute for hand-on education using formal lab set ups, due to resource limitations, non-traditional approaches to hands-on education have become common practice when it comes to subject like nanotechnology.

K. Conclusions

The growth of nanotechnology will have far reaching impact on the society than any other technology that came into being in the recent past. Every aspect of industry, from medicine to manufacturing, and from electronics products to processed food will be affected by the implementation of nanotechnology. Enormous opportunities and challenges await the educational institutions interested in nanotechnology. Developing partnerships with industry, government and other educational institutions, and devising unconventional means to deliver programs will be key to implementing a nanotechnology education. In order to be effective in implementing the technology, the educational institutions will have to explore ways to cross traditional boundaries and lead the industry efforts in preparing a technological work force.

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