BOOTSTRAPPING NANOSCIENCE AND ENGINEERING EDUCATION AT NC A&T STATE UNIVERSITY

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Abstract
Nanoscience and engineering principles are being incorporated into the existing curriculum and into new courses at North Carolina A&T State University (A&T). This is been done in an interdisciplinary manner, in several departments across two colleges on this campus. This bootstrapping effort has been invigorated by a recently initiated research and educational partnership with the University of Illinois – Urbana-Champaign (UIUC) in an NSF Nanoscale Science and Engineering Center (NSEC) entitled "Nanoscale-Chemical-Electrical-Mechanical Manufacturing Systems." The education and outreach component of this work require the incorporation of nanoscience fundamentals and research outcomes into undergraduate and graduate curricula, as well as exposure of K-12 students and teachers to the opportunities and challenges in this nascent field. Educational modules introducing concepts of nanotechnology and nanomaterials have been developed by school teachers attending NSEC summer teacher workshops where they were exposed to cutting-edge research and facilities. These modules have been deployed at summer enrichment camps at A&T. Program evaluation is being done by collaborators from the University of North Carolina – Greensboro (UNCG) and UIUC's College of Education. The paper discusses A&T's coverage of nanoscience and engineering in multiple courses and our experiences with these modules as well as work towards integrating nanotechnology concepts into existing courses at A&T as we enter this exciting 21st century research arena.

Introduction
Nanoscience is the study of matter of the size scale of approximately one nanometer (1×10^{-9} m) to several hundred nm. Nanoengineering and technology[1] enable the manipulation of molecules and atoms to produce nanoscale materials with novel properties due to their very small size. The potential benefits of nanoscience and engineering are extremely broad-based, spanning areas as

diverse as nanoelectronics, medicine, the environment, chemical and pharmaceutical industries, agriculture, biotechnology and computation.

The potentially explosive economic impact promised by nanoscience requires a workforce trained in the fundamentals and applications of this rapidly evolving area. Nanoscience concepts must be introduced at all levels of structured and formal learning – from schools through undergraduate education to graduate and doctoral education. Faculty members in the Department of Mechanical and Chemical Engineering at A&T have already introduced nanoscience and engineering in several courses in the undergraduate and graduate curricula. A major research and education collaboration with the NSF Center for Nanoscale Chemical-Electrical-Mechanical Manufacturing Systems[2] (Nano-CEMMS) at UIUC, as well as an NSF Nanoscale Interdisciplinary Research Team headed by one of the authors (D. Kumar) entitled "Science and Technology of Self-assembled Magnetic and Superconducting Nano Arrays," have synergetically added great impetus to our efforts in the Center for Advanced Materials and Smart Structures[3]. A&T has an established track record in graduation of the nation's largest number of African-American students in engineering at both the undergraduate and graduate level. Many of the doctoral engineering students at A&T have focused on advanced materials for their research. The collaboration between UIUC and A&T grew out of common research interests in the areas of nanoparticulate filled polymers and sensors and the desire to go beyond research into the undergraduate and graduate classroom. The following sections outline the curricular components and outreach activities that address nanoscience and engineering education. In addition, students from A&T will participate in UIUC's REU programs and graduate students work in NanoCEMMS labs on UIUC's campus.

Undergraduate curriculum

Materials Science (MEEN 260)

At the undergraduate level, broadest impact is being achieved in the bread-and-butter sophomore-level Materials Science course required of all engineering majors. This two-credit course now has as one of its primary objectives that 'The student will have an understanding of, atomic and crystal structure and chemical bond types, and understand how these affect material properties and aspects of nanotechnology.' This is being achieved by supplementing the classroom lectures and text[4] with guest lectures by researchers from UIUC as well as A&T's CAMSS.

Manufacturing Processes (MEEN 446)

This junior-level course, required of all mechanical engineering majors, uses a textbook[5] that devotes a chapter to small-size manufacturing technologies and discusses the two approaches of molecular engineering and nanofabrication. In addition to materials issues, the students are made aware of the tremendous mechanical and electrical engineering challenges posed by nanomanufacturing such as accurate and repeatable positioning and sensing. This class too is supplemented by UIUC/A&T guest lecturers and trips to the research labs.

Graduate curriculum

Nanomaterials Science and Engineering (CHEN 655)

This course, originating within the Chemical Engineering program, explains the current and the most promising nanotechnologies in the chemical industries. Students learn to apply topics in nanoscience and nanoengineering to industrial applications. Graduate students learn to generate novel, innovative nanotechnologies for future applications. The course uses a textbook[6] supplemented by handouts. Industrial topics include Microelectronics-Photolithography, Chemical Power Systems-Sensors-Electrochemical Engineering, Photovoltaics-Photonic Systems, Microreactors-Advanced Catalyst Systems, Nanomanufacturing-MEMS, and New Drug Delivery Systems-Advanced Medical Sciences. Technical topics include Nanofluidics, Thin Film/Interfacial Phenomena, Quantum Chemistry, Shape Selective Catalysis-Nanocatalysts, Nanotoolbits-Nanobots, and Nanobiotechnology-Nanobioengineering.

New Methods in Thin Film Synthesis (MEEN 660)
This course, aimed at entering graduate students, is available to undergraduate seniors as a technical elective. The course covers thin film techniques and fundamental mechanisms governing the nucleation and growth of thin films. Students also learn about the common techniques used for the determination of physical properties, especially in thin film form (fabrication of multilayers / superlattices at the nanoscale). The students get to understand and interpret the reasons behind the superior properties of thin film materials with respect to their bulk counterparts. Topics covered include thin film nucleation and growth, fundamentals of vacuum techniques including evaporation, sputtering, laser ablation, chemical vapor deposition and molecular beam epitaxy, nanocluster deposition and nanoparticles self-assembly, relationship between deposition parameters and film properties, photolithography, physical and mechanical properties of thin films, and applications of thin film synthesis in microelectronics, nanotechnology and mechanical devices.

Fundamentals of Thin Film Phenomena (MEEN 785)
This course educates the students about the role of thin film materials as a focal point for developments in virtually all areas of engineering and applied science. The course includes the following topics: overview of materials science and thin films, preparation of thin films, substrate surfaces and thin film nucleation, film structure and its determination, physical properties of thin films. Each student is required to submit a term paper on thin film materials covering a topic agreed upon by the individual student and instructor.

Outreach Activities

The school-level instructional activities were developed by UIUC's Nano-CEMMS[2] in summer 2004 and were delivered to over 70 middle school students and teachers from the Partnership In Education and Research (PIER) and Para-Researcher Program (PRP) summer camps at NCA&T. Minority and female students made up over 90% of the student audience for these programs at A&T. Formal evaluation was conducted at all sessions. Table 1 shows a sampling of the activities:

Table 1. Examples of outreach activities in nanoscience education

The Scale of a Nanometer	
Description	Students visualize scale by expanding the circumference of a human hair to a large circle in the room and looking at several "balls" (beach ball, baseball, golf ball, marble, and grain of sand) to guess and then determine the relative size of a nanometer.
Audience	Middle or high school students
Time needed	3 minutes

Thinking Small	
Description	This PowerPoint presentation defines nanotechnology, delivers the concept of “snapping” atoms together in various configurations to make products with unique properties. Students see products that currently use nanotechnology and experience their unique properties (glasses, fabric, zinc oxide). Students also brainstorm nanotechnology solutions to common societal problems (space exploration, shipping, medicine).
Audience	Middle or high school students
Time needed	10 minutes
Working Small	
Description	A brief PowerPoint presentation precedes a video presentation. Students visualize themselves in nanotechnology roles at the U of I. The following concepts are covered: ▫ What areas of nanotechnology are being researched at Illinois? ▫ What is the nanotech work environment like? ▫ What is a clean room? ▫ Why is a clean room necessary? ▫ What kind of equipment is used? ▫ What kinds of people do this work? ▫ What is unique about the University of Illinois Environment?
Audience	Middle or high school students
Time needed	12 minutes

Program Evaluation

Systematic evaluation of A&T’s nanoscience education programs are being conducted by Dr. Bartz of UNCG in concert with the College of Education at UIUC. A pilot survey was conducted for Dr. Roberts’ CHEN 655 course taught at A&T in Fall 2004. The students in the course were evenly split, male female and over eighty percent of the students were African-American. Survey questions referred to their nanoscience/nanotechnology experiences previously and in this course. Responses were requested on a 5 point Likert scale, Strongly Agree to Strongly Disagree with Not Sure/No Response as the final category. The survey questions and responses are given in Table 1. This format is being used in other courses too. The students in the course were either seniors in the Chemical Engineering program or graduate students. All but one of the students indicated that they had not taken a formal course in nanoscience/nanotechnology. When we asked question whether they had a “strong” knowledge base, the assumption was that they had had some introduction but would not feel that they were strong in the area and wanted to verify that information. Overall, the students felt that this course had given them a strong introduction to the field and that it had increased their knowledge of nanoscience/nanotechnology. Seven of the students indicated that this course had greatly increased their interest in pursuing an advanced degree in nanoscience/nanotechnology. They also indicated that they would like to take another course and that they would be interested in a program that allows students research opportunities in nanoscience/nanotechnology.

Table 1. Course Evaluation (Post-Completion) of CHEN 655 (Fall 2004)

	Response (Number and %)					
Survey Question	**Strongly Agree**	**Agree**	**Disagree**	**Strongly Disagree**	**Not Sure**	**Total**
Before this course I had a strong knowledge base in nanoscience/nanotechnology			7 53.8%	5 38.5%	1 7.7%	13 100%
Before this course, I was already very interested in nanoscience/nanotechnology	1 7.7%	8 61.5%	1 7.7%	2 15.4%	1 7.7%	13 100%
This class greatly improved my knowledge of nanoscience/nanotechnology	5 38.5%	7 53.8%	1 7.7%			13 100%
This course offered me a chance to explore various areas of nanoscience/nanotechnology	6 46.2%	7 53.8%				13 100%
This class greatly increased my interest in pursuing an advanced degree in nanoscience/nanotechnology	1 7.7%	6 46.2%	4 30.8%		2 15.4%	13 100%
This class greatly increased my interest in pursuing a career in nanoscience/nanotechnology	2 15.4%	5 38.5%	5 38.5%		1 7.7%	13 100%
The nanoscience/nanotechnology content in this course has increased the likelihood of me taking another course	1 7.7%	8 61.5%	3 23.1%		1 7.7%	13 100%
I would be interested in a program that allows students research opportunities in nanoscience/nanotechnology	6 46.2%	5 38.5%	1 7.7%		1 7.7%	13 100%
I would recommend this course or other courses in nanoscience/nanotechnology to classmates or the students in my major	5 38.5%	7 53.8%			1 7.7%	13 100%
I feel that there are enough courses offered in the nanoscience/nanotechnology fields at NC A & T		1 7.7%	7 53.8%	3 23.1%	2 15.4%	13 100%

Conclusions

We believe a multi-pronged approach is essential to bootstrap nanoscience and engineering education – not just at the research (graduate) level but to prime this research pipeline by impacting K-12 education and undergraduate education at A&T and in the Piedmont Triad of North Carolina. We believe that the activities described above will make a significant contribution in furthering this goal.

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