Integrating Nanoscale Science and Engineering Concepts into Undergraduate Engineering Classrooms

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***Abstract* - Teaching modules devoted to nanoscale science and engineering concepts have been developed and integrated into key introductory and advanced undergraduate courses in the College of Engineering at the University of Wisconsin - Madison. In addition to one new course on *Micro- and Nanoscale Mechanics* that was created under this effort, existing courses were modified to include cutting-edge content based on current research and emerging applications in nanotechnology. For example, in the *Introduction to Engineering* course, the traditional dissection laboratory (commonly performed on a toaster or blender) was replaced with dissection of a liquid crystal display watch. Beyond learning about liquid crystals and their properties, students explore how a new technology impacts design through this laboratory. Additionally, a Template Synthesis of Nickel Nanowires laboratory was included in several laboratory courses, including *Materials Science Laboratory II* (Materials Science & Engineering), *Chemistry across the Periodic Table* (Chemistry), and *Nanostructures in Science and Technology* (Physics). The course syllabi and new experiments that were developed are available through the web-based resources of the University of Wisconsin - Madison Materials Research Science and Engineering Center at http://www.mrsec.wisc.edu/edetc/nano.**

Index Terms – Laboratory, Materials science, Mechanics, Nanotechnology

INTRODUCTION

By observing and manipulating materials at the nanoscale, researchers have been able to develop new materials with novel and extreme properties. These properties have been optimized and exploited, allowing industry to realize nanotechnology-based consumer products such as stain resistant clothing, self-cleaning windows, and computer hard disks. Because of the diversity of disciplines pursuing research and applications in nanoscale science and engineering, nanotechnology has the potential to make an exceptionally broad impact [1]-[2].

The importance of this emerging technology to society and industry requires that colleges and universities take steps to adapt their curricula to ensure a capable future workforce as well as a more scientifically literate general population [3]-[4]. Some experts predict a shortage of qualified and skilled nanotechnology workers in the next 10 to 15 years, when approximately 800,000 to 900,000 nanotechnology workers will be needed in the US [2]. This demand for a skilled workforce coupled with the projected $3 trillion nanotechnology market by 2015 make nanotechnology education a significant issue [2]. Science and engineering undergraduates will need a focused education in their discipline that also includes nanotechnology in order to navigate successfully the challenges of the 21st century. The interdisciplinary nature of nanotechnology is both a benefit and a challenge as faculty need to balance the breadth and depth of coursework in order to develop a technically-trained workforce [2],[4].

A number of colleges and universities are meeting the challenge of integrating nanotechnology into the curriculum. In recent years, numerous education and outreach efforts have been developed to educate and inform students and the general public about nanotechnology [5]-[7]. In addition, courses in nanotechnology have begun to appear in college catalogs, and nanotechnology concepts have been incorporated into undergraduate general chemistry, physics and engineering courses [4],[8]-[9].

This paper describes efforts undertaken at the University of Wisconsin – Madison (UW-Madison) to integrate nanotechnology into the undergraduate engineering curriculum through a National Science Foundation-funded grant on Nanotechnology Undergraduate Education. Some modules that were developed are not only applicable to the undergraduate level, but with proper modification are

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applicable at the high school and graduate levels as well. The approach taken is two-fold in that it has impact on existing undergraduate engineering courses and creation of new courses. Table 1 lists some of the courses that were affected by the effort. These courses cover a broad cross-section of students in a variety of disciplines. Included in this list is a new mechanics-oriented nanotechnology course, *Micro- and Nanoscale Mechanics*, which was developed in the Department of Engineering Physics and taught over the course of the Spring 2003 and Spring 2005 semesters [10]-[11].

Integrating nanotechnology-based educational modules into selected existing courses in a manner which is consistent with the goals and structure of the courses was emphasized over injecting nanotechnology activities in an incongruous manner. Tailoring of the chosen modules to fit the needs and level of audience understanding is necessary to maintain the fluidity of the course and to ensure that the nanotechnology-based concepts and examples are incorporated into the curriculum over the long term rather than just making modifications to a course during that particular semester.

TABLE I
UNIVERSITY OF WISCONSIN – MADISON COURSES MODIFIED TO INTEGRATE NANOTECHNOLOGY INTO THE ENGINEERING CURRICULUM

Course Title	Target Audience	Nanotechnology Module Integrated
Introduction to Engineering (EPD 160)	Undeclared freshmen	• LCD watch dissection • Careers in nanotechnology
Introduction to Modern Materials (MSE 250)	Undeclared freshmen or sophomores	• Intro to nanotechnology • LCD watch dissection • Remote AFM • Synthesis of colloidal gold
Chemistry Across the Periodic Table (Chem 311)	Sophomores and Juniors	• Nickel nanowire synthesis
Materials Laboratory II (MSE 361)	Sophomores in MS&E	• Nanoscale structures using the Bragg bubble-raft • Nickel nanowire synthesis
Materials Laboratory III (MSE 362)	Juniors in MS&E	• Synthesis of nanoparticles • Shape memory alloys • AFM
Advanced Mechanics of Materials (EMA 506)	Juniors, Seniors, and graduate students in Engineering Mechanics, graduate students in Civil Engineering	• MEMS devices (design project) including nanoscale adhesion and friction effects • Use of contact mechanics at the nanoscale
Fracture Mechancis (EMA 519)	Juniors, Seniors, and graduate students in Engineering Mechanics, graduate students in Civil Engineering, MS&E, Biomedical Engineering	• Molecular dynamics simulations of fracture • Nanoscale size effects in fracture
Micro- and Nanoscale Mechanics (EMA 601)	Seniors and graduate students in MS&E, Engineering Mechanics, and ME	• Synthesis of nanoparticles • Nanofilter device - including surface modification • Nanoscale fracture using the Bragg bubble-raft • Shape memory alloys • AFM
Cellular Scale Explorations (BME 601)	Seniors and graduate students in Biomedical Engineering	• Nanofilter device - including surface modification
Advanced Mechanical Testing of Materials (EMA 611)	Seniors in Engineering Mechanics	• AFM instrumentation • Principles of nanomechanical measurements • Modification of surface properties using self-assembled monolayers
Nanostructures in Science and Technology (Physics 801)	Graduate students in physics and engineering	• Nickel nanowire synthesis • Self-assembled monolayer on silver • Synthesis of colloidal gold

APPROACH

The authors come from a variety of disciplines (Chemical Engineering, Chemistry, Materials Science, Mechanics, and Physics) and all have substantial research experience in nanoscale science and engineering as well as teaching experience at the undergraduate level. Their joint experience base also includes background in developing educational modules and dissemination of nanoscale concepts to a wide range of audiences.

Existing educational tools and experiments on nanoscale science that have been developed by the Interdisciplinary Education Group of the UW - Madison Materials Research Science and Engineering Center (MRSEC) on Nanostructured Interfaces have been leveraged by modifying and expanding these materials to make them more relevant to the engineering classroom. New experiments on nanoscale engineering have been developed and were incorporated into the dissemination avenues developed by the MRSEC. One key component of this existing infrastructure is the MRSEC web site [12], particularly the *Laboratory Manual for Nanoscale Science and Technology*, which currently contains sixteen experiments for high-school and college-level lab classes, and the *Nanoworld Cineplex*, which contains movies of demonstrations of nineteen nanotechnology topic areas.

INTEGRATION OF NANOTECHNOLOGY INTO EXISTING COURSES

The incorporation of nanoscale science and engineering concepts, educational modules, and educational tools into existing courses provides the most reliable means of institutionalizing the teaching of nanoscale science and engineering concepts to a broad cross-section of students. The advantage of this approach over the development of new courses is that existing courses are already integral components of the engineering curriculum. Because many of the existing nanoscale science and engineering educational tools and experiments available from the UW-Madison MRSEC were developed in collaboration with the chemistry departments at UW-Madison, Beloit College, and Christian Brothers University, the modules had been tailored for use in chemistry education [13]. The translation of these chemistry-based nanoscale science and engineering tools and experiments into the engineering setting has naturally enhanced the interdisciplinary nature of these materials.

The courses modified were selected utilizing two criteria: a diverse cross-section of students and/or large number of undecided engineering students; and whether or not the course could benefit from the integration of nanoscale science and engineering concepts. The courses chosen for modification are, for the most part, required courses for at least one engineering major. Additionally, the freshman-level courses chosen for modification have a large student population. Using existing courses also naturally emphasizes the broad range of subject matter in which nanoscale science and engineering will play an important role in the future.

Courses incorporating these modules include the Engineering Professional Development course *Introduction to Engineering* (for freshmen who are interested in learning about engineering as a major); Materials Science courses *Introduction to Modern Materials* (freshmen magnet course to expose students to materials science) and *Materials Laboratory II & III* (sophomore and junior lab courses in synthesis, characterization, and understanding of materials and their properties); and the Engineering Mechanics courses *Micro- and Nanoscale Mechanics* (introduction to mechanics on the micro and nanoscale for seniors/first-year grad students) and *Advanced Mechanical Testing of Materials* (theory and practice in measuring stress, strain, hysteresis energy, and materials properties at deformation and fracture). In particular, the *Introduction to Modern Materials* and *Introduction to Engineering* courses are taken by freshmen and have a great potential for impacting a large number of students and attracting them to fields where nanoscale science and engineering is of developing importance. Table 1 shows a sample of the breadth of courses that have been modified. Details of the laboratories and how they can be implemented into science and engineering classes can be found in references [14]-[16].

CONCLUSIONS

Nanotechnology is an increasingly important aspect of many fields of science and engineering. Today's students will be expected to have a background in nanotechnology in order to be effective when they enter the workforce. To this end there is an effort underway nationwide to incorporate nanotechnology into the engineering curriculum. At UW-Madison we have integrated nanotechnology modules into a broad array of courses deigned to affect as many students in as many engineering disciplines as possible.

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