A Multidisciplinary Undergraduate Nanotechnology Education Program

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Dr. Carlen Henington is a nationally certified school psychologist, an associate professor, and a program coordinator of the Mississippi State University School Psychology programs. She completed her doctoral work at Texas A&M University and her internship at the Munroe Meyer Institute for Genetics and Rehabilitation at the University of Nebraska Medication in Omaha. She received the Texas A&M Educational Psychology Distinguished Dissertation Award in 1997, the Mississippi State University Phi Delta Kappa Outstanding Teaching Award in 1998, the Mississippi State University Golden Key National Honor Society Outstanding Faculty Member Award in 2000, and the Mississippi State University College of Education Diversity Award in 2011. She has served as an outside reviewer for several federally funded educational grants and works as a consultant to the Mississippi Department of Education. She is a member of the Mississippi Governor's Inter-agency Coordinating Council for Early Childhood. She serves as a reviewer for program accreditation for the American Psychology Association and program approval for the National Association of School Psychologists. She has served as a grant reviewer for the U.S. Department of Education, National Science Foundation, and Safe School/Healthy Schools Imitative.

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Abstract

At the nanoscale many scientific fields merge together and much of the research and development in nanotechnology is multidisciplinary. However, undergraduate instruction in nanotechnology tends to be dispersed among various courses that are discipline specific, and few courses are dedicated to nanotechnology. Therefore, a multidisciplinary undergraduate education program is being developed with support from an NSF NUE grant to address this deficiency. This program is being implemented as a nanotechnology concentration for an existing Materials Certificate Program.

The program integrates nanoscience education throughout the curriculum through an introductory seminar course, the incorporation of nanotechnology topics in existing courses, the development of discipline specific courses in nanotechnology, and a multidisciplinary capstone experience. This program's introductory course, NanoExposed!, aims to excite freshmen and sophomores about nanotechnology, while showing them the applications and multidisciplinary nature of nanotechnology. The inclusion of nanoscience topics in existing courses ranges from cellular biology to engineering thermodynamics. The program's discipline specific nanotechnology courses in chemical, electrical, and mechanical engineering discuss fundamental concepts, fabrication, characterization, modeling, design, and applications of nanomaterials or nanostructures. A particular emphasis is placed on unique attributes of nanomaterials that make them useful in many applications. Since the capstone course has not been offered yet, the paper will focus on the other courses in the program.

This paper presents current results from this program, which started in January 2011. The discussion focuses on the discipline specific courses such as the nanochemistry and the nanoelectronics courses. It also includes student data such as the number of students enrolled in each nanotechnology course.

Introduction

Nanoscience studies phenomena and properties of nanoscale materials and structures, while nanotechnology aims to manipulate material structure at the nanoscale to produce the desired properties for practical applications. Therefore, nanotechnology requires an understanding of nanoscience. Due to the number of nanotechnology researchers and workers increasing from 25,000 to 150,000 in the United States, and the U.S. market value of products incorporating nanotechnology increasing from 13 to 80 billion U.S. dollars [1] between 2000 and 2008, it is clear that there needs to be more research and education in nanotechnology. The US government established the National Nanotechnology Initiative (NNI) in 2000 to coordinate nanotechnology development across more than 20 government agencies [1]. As part of the NNI, the National Science Foundation (NSF) initiated the Nanotechnology in Undergraduate Education (NUE) program.

Faculty realized that although there is nanotechnology research at Mississippi State University, there isn't a coordinated nanotechnology education program. Therefore, as a result of NSF NUE funding, a new nanotechnology curriculum is being developed. Mirroring the multidisciplinary nature of nanoscience and nanotechnology, faculty from biological sciences, and from chemical, electrical, and mechanical engineering are developing the courses. These courses are offered as part of a materials certificate program and allow students to tailor a concentration in nanotechnology. Each course contributes to an undergraduate educational program in nanotechnology built on nanoscience fundamentals. More details on the entire program are given elsewhere [2]. Since details on the freshman nanotechnology seminar are available [2, 3], this paper discusses newly developed courses offered in 2012. Unlike the freshman nanotechnology seminar that meets 1 hour per week, each of these new courses are 3 credit courses that can be used as technical electives.

Nanotechnology in chemical applications

Nanotechnology in Chemical Applications is a new elective course developed for this NSF NUE sponsored program. The main goal of the course is to introduce fundamental concepts from colloid and interface science that will prepare students to work in the nanotechnology field. Since this does require basic knowledge in chemistry and physics, basic courses in chemistry, physics and calculus are required as prerequisites. The course is primarily based on *Principles of Colloid and Surface Chemistry* [4], but this is supplemented with applications to nanotechnology. This survey course covers fundamental concepts, measurement and characterization techniques, synthesis methods, and applications as shown in Table 1. Fundamental concepts include traditional surface science topics such as surface tension and contact angle, surface forces, Gibbs and Langmuir monolayers, and DLVO theory. Measurement and characterization techniques range from surface tension measurements with a Langmuir balance to characterization with electron microscopes and atomic force microscopy. The limits of light microscopy are discussed, and the basic concepts behind the characterization techniques are introduced as well as the limitations.

Table 1.

Surfaces a. surface tension, contact angle b. Langmuir monolayers c. Gibbs adsorption d. measurement techniques
Surface forces a. van der Waals forces b. electrical double layer, Debye-Hückel
Colloid characterization a. modern analytical instruments b. data representation for size and shape
Self assembly, association, stability a. Stern layer, zeta potential, DLVO theory b. stability, coagulation c. association colloids micelles, self assembly
Emulsions a. Pickering emulsions b. o/w, w/o, o/w/o

In addition to explaining that surface science inherently occurs at the nanoscale, nanotechnology is emphasized by connecting synthesis methods and applications to colloid and surface science concepts. One example is the synthesis of gold nanoparticles through a bottoms-up approach where the nanoparticles are grown from solution. Other synthesis methods include the formation of nanoparticles and nanocrystals through microfluidic devices. An example of this is using the Langmuir-Blodgett approach, a standard surface science technique, to assemble an ordered pattern of nanocrystals or nanowires on a solid substrate [5]. One application of associated colloids is the use of liposomes as drug carriers [6]. Another example is the application of DLVO theory to the stability of colloidal suspensions. Although surface tension and self assembled monolayers (SAMs) are traditional surface science topics, it is emphasized that they play a significant role in small devices such as microelectromechanical systems (MEMS) and nanoelectromechanical systems (NEMS). At the micro and nano scales, SAMs are sometimes used to control surface properties of these devices.

At the end of the course the students are aware of the advantages and limitations of selected characterization techniques and are able to choose a technique for a particular application. They also have a better understanding of attractive and repulsive forces and how these forces affect stability and coagulation of colloidal dispersions.

Nanoelectronics

This Introduction to Nanoelectronics course is a new elective course developed for this NSF NUE sponsored program. Course objectives are to introduce students to (1) synthesis of semiconductor nanostructures, (2) fabrication of nano-scale semiconductor devices, (3) nano-scale solid state electronics (electronic transport, non-equilibrium carriers, and interface phenomena inside nanostructures), and (4) characterization of nano-structures and nano-electronic devices. The laboratory part of the course will be based on computer simulation assignments requiring students to apply device simulation software currently used in the instructor’s research. Demonstrations use existing materials growth, photolithography, and device fabrication facilities.

Similar to core courses, Introduction to Nanoelectronics is offered as a three credit course. This is a split level course that may be taken by undergraduate and graduate students. Due to the various student backgrounds, necessary fundamental topics are taught at the beginning of the semester before covering the more advanced materials. Fabrication techniques ranged from top-down to bottom-up methods. Although the course focuses on nanoelectronics, it does include multidisciplinary topics such as electrical detection methods for biological molecules.

Smart materials

A course in Mechanical Engineering “Introduction to Smart Materials” includes multi-functional materials with modules that address nanotechnology, nanomaterials, and nanomechanics. The goal of this course is to expose the students to the general area of smart materials with an emphasis on novel materials and emerging applications. Students learn the potentials of smart sensors and actuators, the challenges associated with their uses, and the approaches to address these challenges. This interdisciplinary course provides an integrative treatment of smart materials covering material fundamentals, fabrication, applications, design, and modeling. The course progresses from macro and microscale materials and structures to nanoscale materials and structures. For example, the course begins with piezoelectric materials at the microscale before progressing to nanoparticles, nanotubes, and nanostructures; and it also discusses MEMS before progressing to NEMS. The use of nanoparticles to improve the performance of golf clubs is discussed and this example is used to demonstrate challenges in applying finite element modeling for structural analysis. Specifically, students learn the difficulty caused by scale when nanoparticles are integrated into the macroscopic golf club shaft. Although demonstrated with the golf club shaft, this modeling across multiple length scales has many applications [7]. Smart Materials also emphasizes smart sensors and actuators, the challenges associated with their uses, and the approaches to address these challenges. This interdisciplinary course covers material fundamentals, fabrication, applications, design, and modeling, including modules on MEMS, NEMS, and biomimicry.

Course resources include journal articles [7-9] and modules from NanoInk's NanoProfessor [10]. The course combines lectures with finite element modeling, and guest lectures from researchers in both academia and industry.

Preliminary results

The Nanotechnology in Chemical Applications course was taught for the first time during the Spring 2012 semester. The 21 students enrolled in the course included 2 graduate students, 12 seniors, 5 juniors, and 2 sophomores. The Smart Materials Couse had 7 students enrolled in the course during the Fall 2012 semester. The Nanoelectronics course had 3 undergraduate students and 2 graduate students enrolled in the class during the Fall 2012 semester.

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