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A Multidisciplinary Undergraduate Nanotechnology Education Program with Integrated Laboratory Experience

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Abstract

A multidisciplinary nanotechnology program is being developed with support from a National Science Foundation (NSF) Nanotechnology Undergraduate Education (NUE) in Engineering grant. The program is unique in that it coordinates nanotechnology instruction in chemical, electrical, mechanical and aerospace engineering as well as geological sciences. While a previous NSF NUE grant focused on lecture style classes, the goal of this grant is to add experiential learning through new nanotechnology modules added to existing courses, and through a new nano/micro technology laboratory class designed to accompany a recently developed nanotechnology class. The program focuses on nanomaterials and nanostructures, with an emphasis on applications. The experiential learning exercises being developed include synthesizing and characterizing nanomaterials and nanostructures in chemical engineering, geosciences, and electrical engineering; computer simulations in electrical and mechanical engineering (e.g. molecular dynamics); and interpreting the results of these studies. Not limited to nanotechnology-intensive courses, some of these modules are being implemented in lower level core courses that impact students from many majors. Also, many of these modules are designed to be portable and can impact students at other universities. In addition, some of these modules are transferrable to high schools.

This paper presents current results from this program, which started in January 2014. The paper includes a discussion of progress to date including a new bio-nano-electronics course, course modules developed, and other progress such as outreach activities. Student enrollment is included, as well as information on the diversity of the students impacted by these courses.

Introduction

Faculty at Mississippi State University developed a nanotechnology education program as a result of a previous NSF NUE grant (1042114). This resulted in the development and teaching of an introductory freshman-level seminar course, NanoExposed!; the new discipline specific courses Nanotechnology in Chemical Applications and Nanoelectronics; and multiple modules on nanomaterials and nanomechanics being added to the existing mechanical engineering Introduction to Smart Materials course[1-3]. One limitation of this program was that the students would not obtain practical experience through hands-on experiments or computer simulations. Other educators have noted that lecture courses are not sufficient for nanotechnology education, and that laboratory experience is needed[4]. Through NSF NUE support, the faculty started a new initiative that builds on and significantly improves the previous program by incorporating new laboratory and simulation modules into existing courses, and by developing a new laboratory course.

This paper reports on the first year's activities since the program's beginning in January 2014. The primary goal of this effort is to add experiential learning to the nanotechnology program. These laboratory experiences are performed across a range of departments, where the experiments and simulations are tailored to fit the subject matter of interest and the best method of implementation for each department. This program includes a new lecture course and new nanotechnology laboratory and simulation modules for existing courses. To educate students from a broader range of majors, faculty from various engineering and scientific disciplines are participating in this project.

New Courses

A new course was developed and taught during the Spring 2014 semester. This three hour lecture course, ECE 4990-01/6990-01: Special Topic in ECE - Bio-nano-electronics, was a split-level technical elective. This course on electrical/electronics engineering for the biomedical field included an overview of the human cell structure, nerve cells and neuron signaling, the latest developments in nano-fabrication, bio-sensors, nano-medicine, and neuro-electronic interfacing. The course was taken by 17 students (14 undergraduates and 3 graduates). The main challenge was to find a proper balance between offering an overview of the biomedical concepts (many of which were new for the ECE students) and teaching relevant electronics applications. It appears that this approach was a viable way of introducing ECE students to the bio-medical field. A more systematic coverage of biology and medicine (e.g., a separate class, even if tailored for ECE students) would have been discouraging for this particular audience. In contrast, presenting those topics as needed within a framework of electronics applications in biomedicine seems to have given students a sufficient background for learning those applications.

Preparations were made for the new nanotechnology laboratory course including procuring laboratory space, ordering some of the equipment and supplies, and performing preliminary testing of some of the experiments. Two undergraduate students performed preliminary testing of the silver nanoparticle synthesis experiments during 2014. The preliminary experiments were based on an existing technique for creating silver nanoprisms[5], and were designed to use one lab period to synthesize the silver nanoprisms and characterize them using spectrophotometry and a second lab period to characterize the particles using a transmission electron microscope (TEM).

Nanotechnology Modules

A nanotechnology module was developed for the split level technical elective ECE 4283-01/6283-01: Microelectronics Process Design. This module focused on modern techniques for the top-down fabrication of micro-/nano-electronic devices and integrated circuits. While the class had historically focused on the top-down fabrication techniques used in the microelectronics integrated circuit industry, the novel top-down (including self-assembly) techniques were added and covered in 1.5 lectures. In addition, new information on nano-fabrication aspects, predominantly but not limited to fabrication of sub-micron transistors, was incorporated in different topics/lectures covering different fabrication techniques. For this split-level course, a new module was tested on the graduate student enrolled during the Fall 2014 semester. A computational project using Sentaurus Process simulation software from Synopsis was assigned. It was confirmed that the user-friendly environment of the software allowed the student to obtain a hands-on exposure to the integrated-circuit fabrication process development without any of the complex logistics and safety issues that would be involved in offering a hands-on experimental experience with real hardware. Seventeen students including 16 undergraduates and 1 graduate took this course during the fall 2014 semester.

A new computational project and new computational labs were developed for the ECE 4293-01/ 6293-01, Nano-electronics course. The Medici 2D Device Simulator from Synopsis was used to develop templates of simulation scripts for modeling performance of micro-/nano-electronic devices to be covered in this class. Simulation assignments were not present in the previous offerings of this course. This is a new addition, which is within the scope of the NUE award. This split-level technical elective is to be offered in the spring 2015 semester.

Course modules for three courses, GG 1111 Earth Science I. GG 4114 Mineralogy and GG 4304 Principles of Sedimentary Deposition I are in preparation. Materials were ordered for precipitation experiments. Materials needed include filters, organic compounds, and disposable lab supplies. Preliminary work on the nanotechnology modules for geosciences showed that sterile solutions of Ca++, CO3=, and organic molecules (urease, beta-chitin, palmitic acid, and triacontonic acid) resulted in nanometer-scale textures that can be compared to textures found in nature including in stromatolites, tooth plaque and tartar, arterial calcification, dinosaur bones, or Martian meteorite ALH 84001. Surprisingly, control experiments containing no organic compounds, only Ca++ and CO3= ions, also produced precipitates with nanometer-scale anhedral crystals in the first 24 hours of crystal growth. The textures created by these nanometer-scale anhedral crystals were not consistent with our hypothesis and have provided an opportunity to expand the classroom exercises to review the scientific method in addition to our original intentions of teaching skills such as recognition of scale, observation of textures, and comparison of laboratory-generated samples with nature.

A nanotechnology course module was created and taught for EM 3413 Vibrations, a core course for aerospace engineering students. Excerpts from a review article[6] about the vibration properties and behavior of carbon nanotubes (CNTs) and nanocomposites were assigned for extra credit. This article was selected as it summarized current research about the vibration properties of CNTs and it also presented an overview of CNT physical characteristics, applications and challenges. To obtain full points for this project, the students were required to complete a pre and post survey. The survey tool was designed to determine the level of knowledge and interest regarding CNTs and their nanocomposites. In the fall 2014 semester, a total of 39 students participated in this exercise. After reading the excerpts from the journal article, preliminary results indicate that

(a) 60% of the students reported an increase in their knowledge level regarding nanoparticles and their composites.
(b) 22% of the students reported an increase in interest regarding nanotechnology.

Outreach Activities

From support of the NUE grant, new nanotechnology-related activities are being developed and integrated into the previously formed NanoClub outreach program as part of an NSF BRIGE Grant (NSF-CMMI 1032637). In 2011 the NanoClub was developed as a weekly afterschool outreach program at the local Boys and Girls (B&G) Club to expose underrepresented K-12 students to STEM activities in a fun, nurturing environment in an effort to increase their participation in engineering fields of study. During 2014, a new undergraduate student researcher was identified to coordinate and lead the NanoClub outreach activities. This student was hired in January 2015 to assist in molecular modeling and data analysis for another research grant but will also work directly with outreach students and serve as a mentor. Some activities that have been developed and improved include making thin film bookmarks, making candy DNA, and exploring scanning probe microscopy using shoeboxes and marshmallows. Through funding from the NUE grant, a video camera was purchased to capture nanotechnology-related educational activities and to share the outreach activities with the community through other venues, such as Facebook and YouTube.

A group web page for this NUE program was created on nanoHUB. The web page name is NanoSEEd at MSU (Nanotechnology in Science and Engineering Education at Mississippi State University). The web page name was chosen to reflect that this is a collaborative effort between the College of Arts and Sciences and the Bagley College of Engineering at MSU. The page is currently under construction, but materials developed under this grant will be added as the project progresses.

Student Enrollment and Diversity

Course enrollment and diversity data are summarized in Table 1 where approximately 97% of the students are undergraduate (UG) students and 3% are graduate (G) students. For the four courses where data is available, the population of the classes was approximately 6.7% African American and 13% other underrepresented minorities.

Table 1. Summary of 2014 nanotechnology course enrollment and demographics.

Course	UG	G	Male	Female	White	African American	Other Minorities	Total Enrolled
NanoExposed!	46	0	40	6	37	3	6	46
Bio-nano-electronics	14	3	13	4	15	1	1	17
Microelectronics Process Design	16	1	16	1	15	0	2	17
Vibrations	39	0	34	5	28	4	7	39
TOTAL	115	4	103	16	95	8	16	119

The outreach activities are focused on reaching approximately 125 primarily underrepresented and economically disadvantaged African-American students. Participants in the local Boys and Girls Club are approximately 97% African American.

Concluding Remarks

The specific goals for this project for the first year were to: (1) develop new nanotechnology modules for existing courses, and teach the freshman nanotechnology seminar; (2) include students from underrepresented minorities in the courses; (3) prepare for new nanotechnology courses; (4) prepare new nanotechology education modules for use with K-12 students; and (5) set up a group web page on nanoHUB. The specific objectives were met by 1) offering the freshman seminar and teaching new nanotechnology modules in Microelectronics Process Design and Vibrations courses; 2) including students from underrepresented minorities in these classes as described in the section on impact on human resources; 3) developing new nanotechnology activities for the NanoClub; 4) preparing for new nanotechnology courses by ordering supplies and performing preliminary experiments, and actually teaching the Bio-nano-electronics elective course; and 5) setting up the group web page on nanoHUB. The goal for the second year is to implement more of the activities and to add information on the web page.

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