AC 2012-3882: IMPACTING UNDERGRADUATE NANOSCIENCE AND NANOENGINEERING EDUCATION AT NORTH CAROLINA A&T STATE UNIVERSITY

Dr. Dhananjay Kumar, North Carolina A&T State University

Dhananjay Kumar is an Associate Professor of mechanical engineering at North Carolina A&T State University. His areas of research are thin films and nanomaterials. He teaches classes in materials science, advanced materials, and nanotechnology.

Dr. Devdas M. Pai, North Carolina A&T State University
Mr. Kwadwo Mensah-Darkwa
Dr. Robin Guill Liles, North Carolina A&T State University
Mr. Mainul Kader Faruque, North Carolina A&T State University
Miss Courtney Lambeth, North Carolina A&T State University

Courtney Lambeth, North Carolina A&T State University, is the Educational Assessment and Administrative Coordinator for the NSF Engineering Research Center for Revolutionizing Metallic Biomaterials.

Impacting Undergraduate Nanoscience and Nanoengineering Education

Abstract

In this paper, we report our three-pronged efforts toward enhancing undergraduate nanoscience and engineering education, with an emphasis on devices and systems. We are using the practical approach of direct engagement of the students in ongoing research in our advanced materials laboratories. These efforts have been primarily supported by two successive NSF Nano Undergraduate Education (NUE) projects. Our first activity for enhancing nanoscience and nanoengineering education was to introduce simple concepts of nanoscience and technology into existing required undergraduate engineering courses. These modules covered the core concepts of nanomaterials and unique phenomena at the nanoscale. Introducing the concepts of nanoscience and engineering at this early stage of undergraduate education was found to positively impact student interest in registering for a technical elective nanotechnology course that we developed as our second initiative. An interdisciplinary 3-credit nanotechnology course (Nanotechnology I) with a significant hands-on laboratory component was developed as a tech elective course for senior undergraduates and has attracted enrollments of 20-30, primarily from our graduating classes of approximately 50 mechanical engineers per year. The course offers a fundamental perspective related to the structure, stability and functional characteristics of nanoscale materials and systems, and also trains students in the application of available theoretical models in the interpretation of results. Under our third initiative, a limited number of undergraduates well-imbued with this foundational perspective were recruited and financially supported to engage in a semester-long research project related to nanotechnology. The course (Nanotechnology- II) was classified as “Independent Study” course under the department’s existing curriculum. Students were assigned to work for the entire semester with individual faculty members drawn from the Senior Personnel for the NUE project. The students of this class (Nanotechnology -II) were required to submit a final written report and make one mid-semester and one end-of- semester power point presentation. The students’ performance was evaluated by a panel of examiners consisting of all the NUE PIs. In brief, our three-pronged approach appears to have enabled and empowered the students very effectively with the knowledge of the fundamentals of nanoscience and engineering and proficiency to conduct research and develop economically-viable nano-devices with innovative applications.

Introduction

The design and development of advanced materials, devices and systems for the 21st century is starting to be dominated by the convergence of several rapidly-evolving advanced technologies such as nanotechnology, microelectronics, information technology and biotechnology. With the steady erosion of the traditional manufacturing base within the United States, it is imperative to maintain the country's traditional lead role in basic scientific and engineering research in the high-tech areas that will drive the economy of the future. The nation's commitment to this is amply demonstrated in the high level of funding for basic research from lead governmental agencies such as NSF and the Department of Energy. The need for qualified nanotechnology workers for the next two decades is estimated to be in the millions. Broad impact can be achieved by curricular enhancement and reform at the undergraduate level. Curricular enhancement, if it aims to be comprehensive, needs to ensure that students are exposed to the technical aspects as well as social, economic and ethical impacts of nanotechnology that numerous researchers are exploring seriously. This paper reports activities and findings of a team of engineering, science, and education faculty members, who are actively involved in nanomaterials-based research and have been collaborating with each other for the past several years to enhance undergraduate nanoscience and engineering education in the area of devices and systems. They have engaged undergraduate students directly in the advanced laboratories and ongoing research projects. This approach has enable/empowered the students more effectively with the knowledge of the fundamentals of nanoscience and engineering and proficiency to conduct research and develop economically-viable nano-devices with innovative applications in all spheres of daily life. The economic viability of these devices arises from the selection of chemically simpler and inexpensive materials such as titanium nitride (TiN). The simplicity and ease of operation of the sample fabrication method (PLD) also adds favorably to the lower cost of nanodevices.

The effectiveness of our approach arises from a better marriage between theory, experiment and applications. More hands-on exposure are provided to students in the areas of synthesis, processing and manufacturing of nano-components and nano-systems, characterization and measurement of nanostructured systems and devices, and the design, analysis and simulation of nanostructures and nano-devices. This is accomplished by providing students with classroom instruction heavily aided by hands-on laboratory learning, with a systems emphasis. An interdisciplinary nanotechnology course (Nanotechnology I) with a significant hands-on laboratory component has been developed as a preparatory course. This course is offered as a junior-level technical elective and is open to all engineering majors. Secondly, a few undergraduates well-imbued with this foundational perspective on nanotechnology are recruited to engage in a semester-long nanomaterials research project (Nanotechnology II). The students have the option to receive “Independent Study” or “Independent Research” course credit for this systematically mentored and monitored team activity. The team set-up is carefully designed to inspire the students to bring out their individual strengths and innovative abilities and contribute meaningfully to the team goals in a way that helps them find self-worth. Each Faculty and Student Team (FaST) consists of two students (one graduate and one undergraduate) and one NUE faculty member. Working in this type of team set-up has been found to promote the development of student-faculty interaction and student-student communication.

With our institution's status as the nation's leading producer of African-American engineers, the NUE efforts have provided a significant number of underrepresented minority students with training and mentoring focused on the economic and intellectual powerhouse area of nanotechnology. Besides the obvious benefit of attracting the best undergraduates into graduate research, our students are also engaged in passing on the learning downstream through helping with summer camps for K-12 educators and school visitations to help attract the enrollment of high-quality students from across the nation. The Nanotechnology I course is beginning to serve as a major (but not necessarily exclusive) feeder of talent to the semester-long team research experience. The students impacted by one and/or both of these initiatives are expected to form an excellent talent pool for traditional graduate engineering programs, as well as non-traditional graduate programs planned for the near future at our university, such as the graduate programs of the ERC-supported Bioengineering Department and/or Joint School of Nanoscience and Nanoengineering. The content organization of the paper is as follows: (a) Development of Nanotechnology-I: An interdisciplinary nanotechnology theory-cum-laboratory course, (b) Development of Nanotechnology-II: A semester-long hands-on research-based course, (c) Infusion of nanotechnology modules in existing undergraduate courses, (d) Organization of REU activities, and (e) Planning of a Special opportunity for an NUE student to visit an international laboratory. Given the highly interdisciplinary nature of nanotechnology, the team of instructors has been carefully formed with diverse backgrounds and expertise such as materials science, mechanical engineering, electrical engineering, solid state physics and chemistry.

A. Nanotechnology-I: Development Of An Interdisciplinary Nanotechnology Theory-Cum-Laboratory Course: This course was developed to provide more practical exposure to undergraduate students in the areas of synthesis, processing and manufacturing of nano-components and nano-systems, characterization and measurements of nanostructured systems and devices. The course is named 'Fundamentals of Nanoscience and Engineering.' The NUE project (2009-2010, NSF-EEC 0939344) refers this course as Nanotechnology-I. The Nanotechnology-I offered as a special topic course in the first year of project has now become a regular course in the Department of Mechanical Engineering, with the aforementioned course title. This course is now planned to be offered every fall semester in the Department of Mechanical Engineering. Fig. 1 shows a continuous increase in the number of student enrollment each semester with substantial increment in the student enrollment in the Fall-2011. It is not clear if this increase is due to the course getting the status of a regular course as opposed to a special topic course or the course being classified as an undergraduate course. Prior to the Fall-2011, Nanotechnology-1 course was offered at 600-level which allows

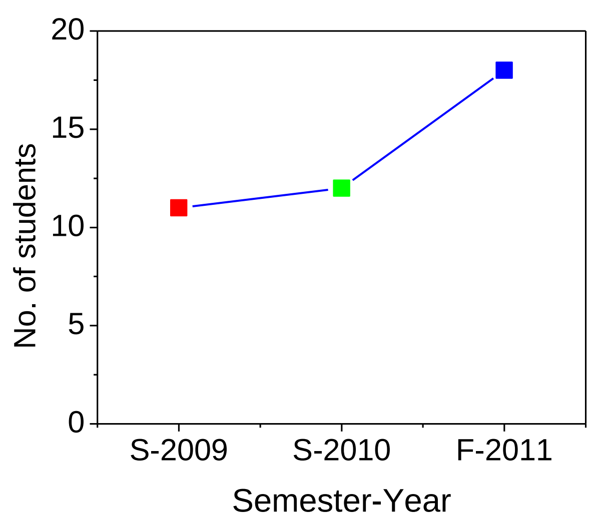


Fig 1. Number of students enrolled as a function of semesters and years, F: Fall, S: Spring

undergraduate as well graduate students to take a 600-level course. Fig. 1 has also the student enrollment data from our earlier NUE project (2007-2010, NSF-EEC 0634218).

A.1. Description Nanotechnology-I Course: This course offers a fundamental perspective in areas related to the structure, stability and functional characteristics of nanoscale materials and interpretation of results with the help of available theoretical models, with an emphasis on the interrelationship between materials properties and processing. This classroom instruction was also aided by relevant hands-on laboratory learning. Some of the pertinent topics of this course could be listed as: top-down and bottom-up approaches for nanoparticle synthesis, characterization of nano-materials, nanofabrication by self-assembly and self-organization, bio-inspired self-assembly of nanostructure, molecular electronics, geometry, synthesis and properties of nanoscale carbon. The outcome of the course was a broader understanding of nanoscience and engineering among undergraduate students. The students have acquired practical skills of nanomaterials synthesis and characterization after taking this course.

A.2. Required Textbooks

- "Introduction to Nanoscience and Technology" M.D. Ventra, S. Evoy, and J.R. Heflin, Springer, ISBN 1-4020-7720-3
- "Introduction to Nanotechnology" by C.P. Poole and F.J. Owens (ISBN 0-471-07935-9) ISBN: 978-0-470-12537-3

A.3. Assessment of Nanotechnology-I Course: To study the efficacy of MEEN 685, a mixed-method design was proposed. Undergraduate students completed content-specific, pre-/post-tests. Researchers in the nanotechnology domain have developed these content-specific assessment items, thus establishing beginning inventory face validity. In spring 2010 the inventory was piloted. There were 25 items, clustered across five domains, including: (a) Nanoscale Dimension and Basics (6 items); (b) Synthesis Methods (5 items); (c) Structural Characterization (7 items); (d) C-nanostructure and Bioengineering (4 items); and (e) Device Applications (3 items). An analysis of pre-assessment response rates between 2010 (*n=12*) and 2011 (*n=25*) cohorts (by domain) suggested acceptable reliability with coefficients ranging from 0.69 to 0.98. (Fig. 2).

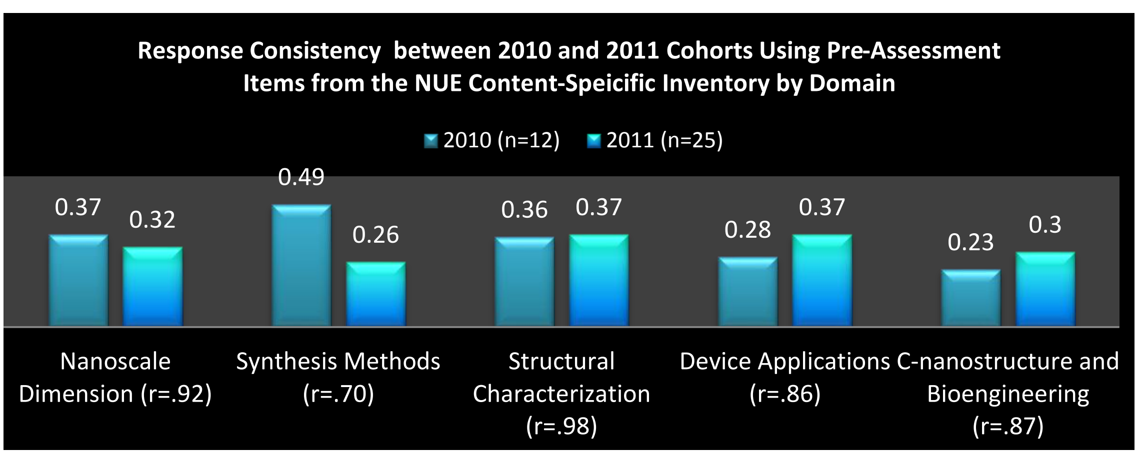
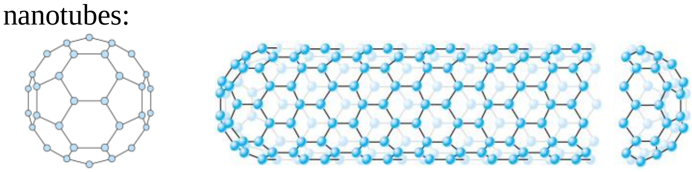


Fig.2. Response Consistency between 2010 and 2011 Cohorts in Pre-Assessment Items by Domain

A full copy of the inventory is presented in our 2011 NUE Annual Report to the Engineering Education and Centers (EEC) Division of the NSF [1,2]. A representative question from each of this category is presented in Table 1.

Table 1: Representative questions from course concept inventory

Category	**Examples Question**
Nanoscale dimensions and basics	The correct nanometer size scale in increasing order (smallest to largest) in terms of well-known species is (a) DNA, virus, proteins, bacteria (b) Proteins, DNA, virus, bacteria (c) bacteria, virus, proteins, DNA (d) DNA, proteins, virus, bacteria
Synthesis Methods	Which nanomanufacturing category do Pulsed Laser Deposition (PLD) and mechanical attrition (MA) fall under? a. PLD: Top Down, MA: Bottom-up b. PLD: Bottom-up, MA: Top-down c. Both PLD and MA: Top-down d. Both PLD and MA: Bottom-up
Structural Characterization	Atomic force microscopy (AFM) is the most widely used form of scanning probe microscopy for the characterization of nanomaterials, since it requires: (a) electrically conductive and optically transparent samples (b) neither electrically conductive nor optically transparent samples (c) electrically conductive and optically non-transparent samples (d) good vacuum
Carbon-Nanostructure and Bioengineering	What are the characteristics of C_{60} fullerene molecules that are used as capping materials for the two ends of a tube made from rolling a single sheet of graphite to make carbon nanotubes:  (a) They are solid spherical clusters of sixty carbon atoms with 20 hexagons and 12 pentagons with no two pentagons having a common side (b) They are hollows spherical clusters of sixty carbon atoms with 20 hexagons and 12 pentagons with both hexagons and pentagons having a common side (c) They are hollow spherical clusters of sixty carbon atoms with 20 hexagons and 12 pentagons with no two hexagons having a common side (d) They are hollow spherical clusters of sixty carbon atoms with 20 hexagons and 12 pentagons with two pentagons having a common side
Device Applications	The two main conditions for observing the quantum effect between two metallic nanodots due to the discrete nature of charge are: (a) barrier resistance (R_t) >> charging energy ($E_c = e^2/C$) and E_c >> thermal energy ($k_B T$), (b) R_t >> E_c and E_c << thermal energy (c) R_t << E_c and E_c << thermal energy (d) $R_t = E_c$ and E_c = thermal energy

A. 4. Other Developments in the Area of Assessment: Pre-assessment responses between 2010 and 2011 cohorts were analyzed to determine NUE Content-Specific Inventory internal consistency. As indicated in Figure 3, adequate reliability among items and across domains was established, as follows: Nanoscale Dimension (*r 0*.92); Synthesis Methods (*r=0*.70); Structural Characterization (*r=0*.98); Device Applications (*r=0.86*); C-nanostructure and Bioengineering (*r=0.87*). Subsequently and using the NUE Content-Specific Inventory, assessment data were collected to determine change in understanding and learning among 2011 (*n*=25) nanotechnology students. The inventory was administered at the beginning of the semester (pre-assessment) and at the end of the semester (post-assessment). A review of these data both by domain and across questions indicated a positive change in understanding related to nanotechnology content. Figure 2 demonstrates differences (pre-/post) in overall percentages of correct responses across questions. Students showed growth in their understanding of nearly all questions except Question 12 (Structural Characterization). The most growth was for Question 17 (Device Applications) and Question 2 (Nanoscale Dimension Basics). Similarly, Figure 4 depicts differences (pre-/post) in overall percentages of correct responses by domain. In this case, students showed the most growth in Nanoscale Dimension and Basics and Structural Characterization. It is notable that similar pre-/post-assessment data were collected in 2010. Though NUE Content-Specific Inventory reliability had not yet been established, similar results by question and domain were obtained. Thus, it is reasonable to suggest that positive change in understanding related to nanotechnology content also occurred with the 2010 cohort.

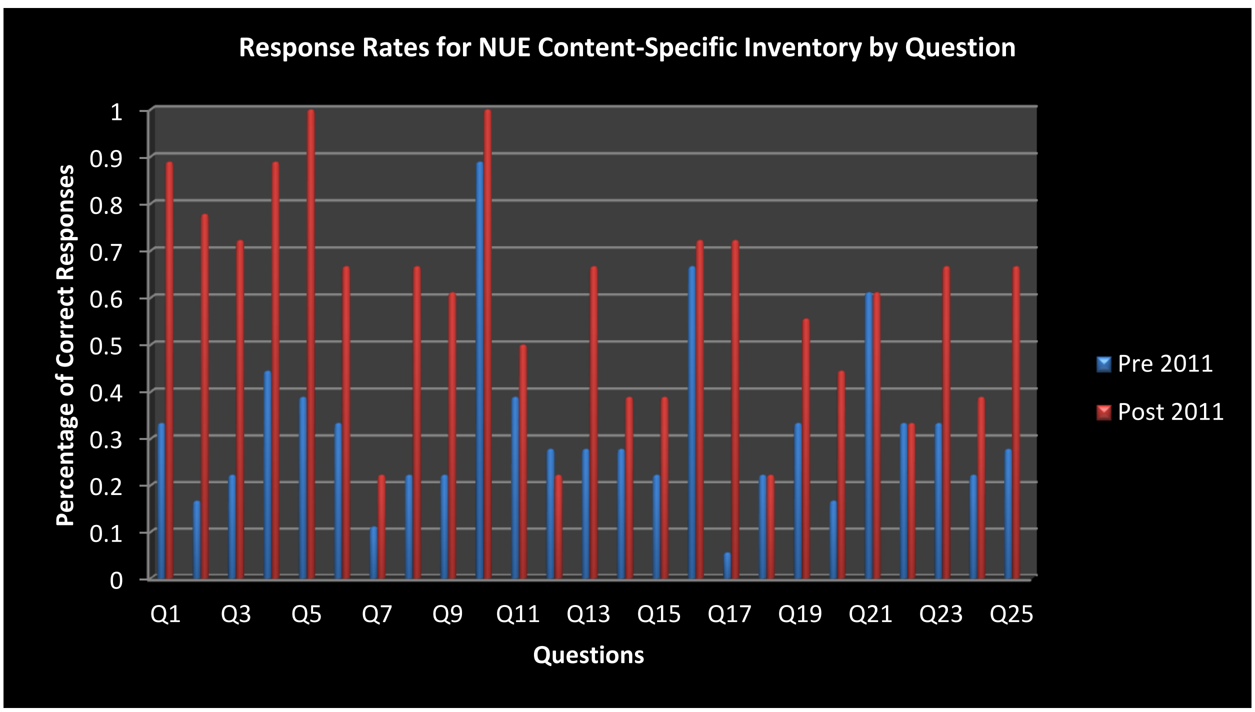


Fig.3. Response Rates for NUE Content-Specific Inventory by Question (2011)

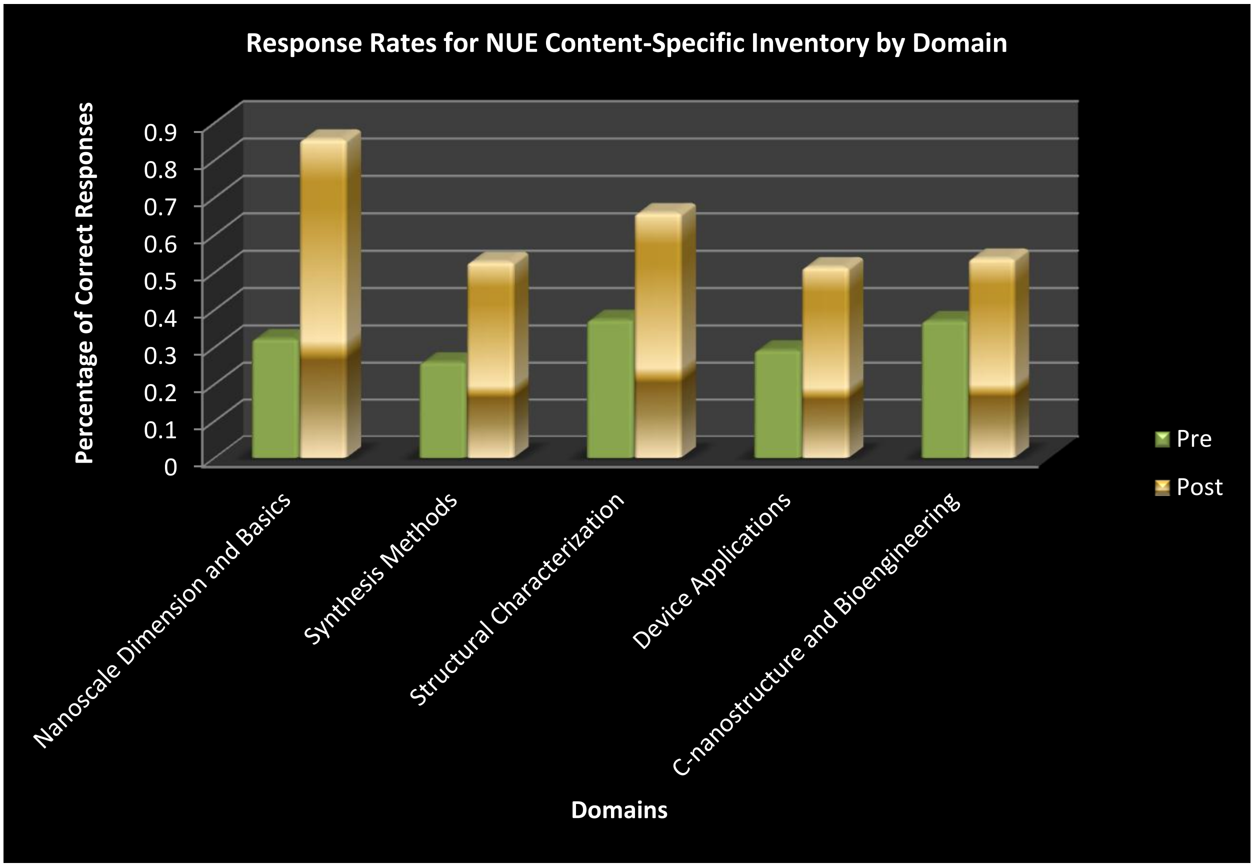


Fig. 4. Response Rates for NUE Content-Specific Inventory by Domain

As well and to continue the inventory validation process, qualitative information was gathered through exit focus groups. These qualitative data will be utilized to establish preliminary inventory concurrent validity. Whereas they are still under review, preliminary indicators suggest that there was positive change in understanding and learning among fall 2011 students. In particular, descriptive data from the exit focus groups informed student excitement and continued interest in nanotechnology and related course content.

B. Nanotechnology-II: Development of a semester-long hands-on research-based course: This course was offered for the first time diring Spring 2011 semster in the Department of Mechanical Engineering. The course was designed to enhance student participation in research conducted by NUE faculty members in the area of nanoscience and nanoengineering. Topics were both analytical and experimental in nature. The course also encouraged the students to engage in independent studies. The course required the submission of a written report by each student at the end of the semester. The course was offered as MEEN 596.001: Independent Study. The course prerequisite was senior standing and consent of instructor. The student learning objectives were: (i) to develop abilities to explain relationships between nanomaterial structures and their properties and to understand the working principles of various nanomaterials synthesis and characterization methods and (ii) to provide hands-on work experience with selected state-of-the-art nanomaterials synthesis and charactrization equipment. Students enrolled in this class received “P” for “Satisfactory” or “F” for “Unsatisfactory” grades.

This course has a cap of five undergraduate students per semester. This cap has been set to ensure sufficient supervision and personal guidance to each undergraduate student and to ensure that each project makes significant progress in the given time and lab facilities. In order to impact more students with the NUE project, we have planned to offer this course for the next two semesters: Spring 2012, and Fall 2012. The number of students enrolled for the Spring 2011 semester was four. The number of students enrolled in Fall 2012 is at the maximum enrollment capacity i.e. 5.

Each undergraduate student enrolled in this course is assigned an individual research project. The project lasts for a semester. A list of actual projects offered during Spring 2011 and Fall 2012 is presented in Table 2. The students are paired with a graduate student who coordinates their research developments on a day to day basis. Each undergraduate and graduate student team is supervised by a NUE faculty investigator. A project begins by an undergraduate student collecting one or two text books, two-three review articles, and 10-15 technical research papers published in peer-reviewed journals.

Table 2: Project Assignments for the Nanotechnology II Course

Spring 2011

- Fabrication of TiN Nanaowires for Applications in Nano- and Biological Science and Engineering
- Synthesis of Mg/MgO Nanoscale Multilayered Thin Films
- Leaning about Pulsed laser deposition method for the synthesis and engineering of nanomaterials and nanostructures

Fall 2012

- Role of pulsed laser deposition (PLD) method in the fabrication of advanced and emerging nanomaterials: Experiments and Theory
- Role of magnetron sputtering method in the fabrication of advanced and emerging nanomaterials: Experiments and Theory
- Operating principles of X-ray diffraction (XRD) and its application in the characterization of nanostructured materials
- Operating principles of scanning electron microscopy (SEM) and its application in the characterization of nanostructured materials
- Design, fabrication, and mechanical properties of Mg-based alloys

Each student enrolled in Nanotechnology-II course was required to make a mid-semester 15-minute PowerPoint presentation reporting his/her mid-term progress on an assigned project to a panel of 3-5 faculty members. At the end of the semester, each student was required to submit a written report (minimum 30 pages, double spaced), a poster documenting his/her work, and to make a 20-minute PowerPoint presentation to the same panel. The students enrolled in this course were also required to attend a weekly ERC seminar.

C. Nanotechnology Modules in Existing Undergraduate Courses: Our first educational activity as part of the NUE project was to introduce simple concepts of nanoscience and technology into existing required courses (Table 2) at undergraduate levels within the College of Engineering. As listed Table 3, these modules were covered using two lecture hours. These modules exposed the students to the core concepts of nanomaterials and unique phenomena at the nanoscale. Introducing the concepts of nanoscience and engineering at this early stage of undergraduate education was found to impact the students' interest in registering for the technical elective nanotechnology courses described in section II. All of these courses are offered during both Spring and Fall semesters and have enrollments in the range of 20-30. Thus, the modules developed to introduce the concepts of nanoscience and engineering in courses cumulatively benefit a large number of engineering undergraduate students. The students impacted by these courses are attracted to the new course that we have developed under the new NUE grant at our university.

Table 3: Courses in which modules introducing the concepts of nanotechnology were introduced

Course	Semester and Year	No. of students	Concepts Introduced Using two lectures
MEEN 260:Materials Science Major: Industrial and Chemical	Spring 2011	21	Nanoscale dimension and associated novel properties, Scaling law
	Fall 2011	18	
MEEN 360: Fundamentals of Materials Science Major: Mechanical	Spring 2011	33	Nanoscale dimension and associated novel properties, Nanotubes and nanowires
	Fall 2011	28	
MEEN 460: Modern Engineering Materials Major: Mechanical	Spring 2011	25	Artificial atoms, magic numbers, carbon nanotubes
	Fall 2011	22	
MEEN 446: Manufacturing Processes Major: Mechanical	Fall 2011	24	Nanomanufacturing, top-down and bottom-up methods

D. REU Activities: Under the REU activities sponsored through the NUE program, undergraduate students from the home institution as well external institutions were provided opportunities to work on nano-bio related projects during summer. The undergraduate students were paired to work with graduate student working under the supervision of NUE PI and CoPIs. There are presently three undergraduate students being supported by the NUE project. These students are working on a semester-long project related to nanofabrication and devices. Two of these students have taken Nanotechnology-I as well Nanotechnology-II course offered in 2011 under the NUE project. These two students have been given additional opportunities based on their performances in these courses and their interest in enhancing further their knowledge of nanoscience and nanoengineering. The outcome of summer research of an undergraduate student is shown in a poster form in Fig. 5.

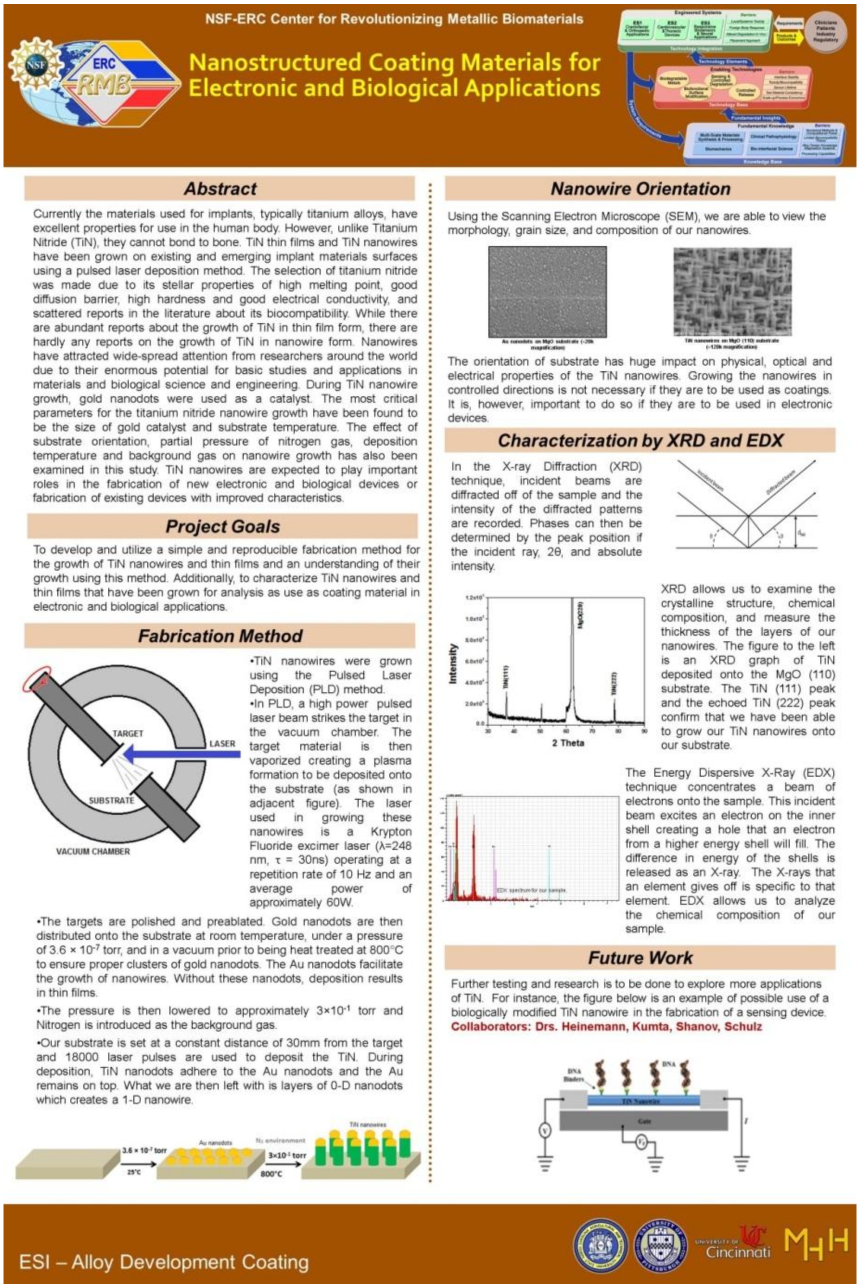


Fig. 5. A poster developed by an NUE supported undergradute student working on a nanoproject. The poster won the scond prize during the 2011 ERC-REU poster competition

E. Special Opportunity for NUE Students to visit an International Laboratory: One undergraduate student was given the opportunity to spend two weeks in the lab of Dr. Frank Witte at the Hannover Medical School, Germany. During the visit, the student was exposed to the theory and process behind cell adhesion. The student worked under Ms. Maike Haupt, a lab technician in Dr. Witte's lab at MHH. The first procedure she showed and worked through with was the MTT Assay. This procedure allows one to measure the activity of enzymes released from cells on sample surfaces. U2OS human osteosarcoma cells were used since these are the closest to real human cells. Everything was done under sterile conditions under a hood.

Conclusions

This paper reports our activities and findings toward enhancing undergraduate nanoscience and engineering education. We have used the practical approach of direct engagement of the students in ongoing research in our advanced materials laboratories. This was accomplished by providing students with classroom instruction heavily aided by hands-on laboratory learning. An interdisciplinary nanotechnology course (Nanotechnology I) with a significant hands-on laboratory component was developed as a preparatory course. Secondly, a few undergraduates well-imbued with this foundational perspective on nanotechnology were recruited to engage in a semester-long nanomaterials research project (Nanotechnology II).

References

1. D. Kumar, D. Pai, C. Lambeth, R. Liles, C. Waters, C.B. Lee, and S. Yarmolenko, "Nanotechnology Undergraduate Education (NUE) Project Report (EEC-0939344)" 2011.
2. D. Kumar, D. Pai, C. Lambeth, R. Liles, "Impacting Undergraduate Nanoscience And Nanoengineering Education," Engineering Education Awardee Conference, March 4-6, 2011, Arlington, VA.