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NUE: NanoCORE II (Nanotechnology Concepts, Opportunities, Research and Education) at the FAMU-FSU College of Engineering

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NUE: NanoCORE (Nanotechnology Concepts, Opportunities, Research and Education) at the FAMU-FSU College of Engineering

The research and development in nanoscale science and engineering have grown rapidly in the past decade. Many nanotechnology breakthroughs have begun to impact the marketplace. The current values for nanotechnology-enabled products are estimated at about $91 billion in the United States and $254 billion worldwide. Current developments presage a burgeoning economic impact: trends suggest that the number of nanotechnology products and workers worldwide will double every three years, achieving a $3 trillion market and 6 million workers by 2020.[1] Thus it is important for college students to be familiar with nanotechnology concepts and for these students to develop positive attitudes towards nanotechnology. The Nanotechnology Concepts, Opportunities, Research and Education (NanoCORE) program at the Florida A&M University - Florida State University (FAMU-FSU) College of Engineering has been supported by the Nanotechnology in Undergraduate Education (NUE) program at the National Science Foundation. The first NanoCORE program was successfully completed during January 2009 through December 2010, and the NanoCORE II program extended the project efforts during January 2011 through December 2012.

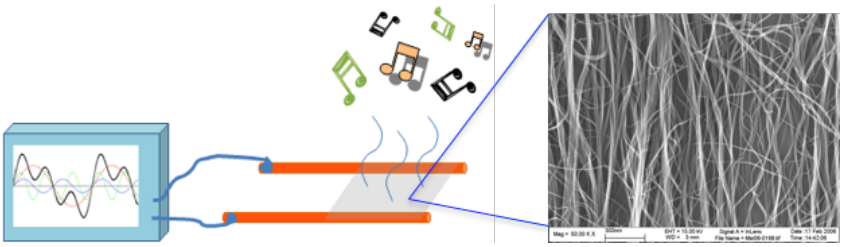
The FAMU-FSU College of Engineering is home to a diverse student body where 42% of the undergraduate student population belongs to traditionally under-represented groups. The NanoCORE program introduces and integrates nanoscale science and engineering (NSE) as permanent components of the core undergraduate engineering curricula, presents multiple opportunities for undergraduate learning of concepts in nanoscale science and engineering, and creates opportunities for undergraduates to pursue nanotechnology related research activities. In the first NanoCORE project, we focused on introducing nanoscale science and engineering into the undergraduate curriculum through short teaching units, which we refer to as "nanomodules," within existing courses. Students also had opportunities for more in-depth nanotechnology training by enrolling in technical electives and participating in undergraduate research. The program has made a noteworthy impact on our undergraduate educational content and experience.[2] With the NanoCORE II project, we have extended the program by expanding student-learning opportunities to include additional hands-on and laboratory activities. The NanoCORE II topic areas and activities are designed to promote student interest and generate excitement about NSE and thus improve student retention. The project team also coordinates undergraduate research opportunities in nanoscale science and engineering across the College. Additionally, this program is designed to attract students into graduate studies in the field.

During the project period, we incorporated six nanomodules in eight engineering courses across all engineering disciplines. We have implemented these nanomodules in core courses, along with an introductory nanomodule presented to incoming freshman. We have made a special effort to relate nanotechnology topics to existing course content. We also have implemented and added two nanolabs into two existing junior level courses. A total of 862 students were impacted in these courses that included the nanomodules and nanolabs.[3] The extensive assessment instruments were used to gauge students' awareness of, attitude toward, and interest in nanotechnology.[2] In the NanoCORE II project, the assessment used shorter assessment

instruments and student work to measure students' attitude and knowledge of nanotechnology. The NanoCORE II program also brings together faculty from across the College of Engineering and thus fosters an interdisciplinary and collaborative research setting. Course materials developed through this project have be made widely available through web resources and presented to the local community through outreach activities.

To provide students with the opportunity to participate in a more in-depth and hands-on nanotechnology learning experience, we had a pilot effort to sponsor senior design during the NanoCORE II project phase. This capstone project was consistent with ABET requirements and was implemented in conjunction with the yearlong Capstone Senior Design course in the related departments. This senior design team is a multidisciplinary team with three students from Industrial and Manufacturing Engineering (IME) and two students from Electrical and Computer Engineering (ECE). The team was co-mentored by faculty from these two departments, who also are principal investigators in the NanoCORE program. This two-semester senior design project was initiated during the Fall 2011 and Spring 2012 semesters. The topic was "Carbon Nanotube Speakers". Speaker is a device used in our daily life. Most of the speakers consist of a cone, a voice coil attached to the apex of the cone, a permanent magnet fixed to the loudspeaker's frame, and an enclosure. When an audio current waveform is applied to the voice coil, an audio frequency movement of the cone is produced due to the magnetic interaction between the voice coil and the magnet, thus reproducing the sound pressure waves. It was found that the carbon nanotube (CNT) sheet, a very thin CNT film, could emit loud sounds once fed by sound frequency electric currents.[4,5] Different from the traditional speakers, carbon nanotube speaker has a very simple structure and works without magnets and moving parts. Figure 1a shows the schematic illustration of the device of carbon nanotube speaker and a scanning electron microscope image shows the structure of the speaker formed by CNTs. The CNT sheet can work as a speaker because it has a special three-dimensional aerogel like structure. The sheet has the ability to heat up and cool off very quickly when an audio current waveform is applied to the CNT sheet. The quick heating and cooling of the sheet cause thermal expansion and contraction of the air around it. This air fluctuation creates a sound wave that is dependent on the frequency and amplitude of the audio current flowing through the sheet. Namely, the sound is produced thermoacoustically rather than through the classic means of vibration. It might open up new applications of speakers and other acoustic devices. It is found that the sounds making efficiency strongly depends on the structure of the CNT assembly and the speaker needs a special signal amplifier. As a senior design team, the ECE students designed and made electric circuit for speaker and IME students investigated the effects of CNT sheet structures on the sound making efficiency of the CNT speakers. The faculty mentors conducted weekly meetings with the students. The students have made good progress on the project during the Fall 2011 semester and continued during the Spring 2012 semester, culminating in the final project presentation at the end of the semester at the departments' senior design showcase. The students presented and demonstrated their project in an open house event (Fig. 1b). They learned about nanomaterials (with a focus on CNTs) and demonstrated that nanomaterials and nanotechnology can provide new functions and new practical applications.

We established the NanoCORE Undergraduate Research Program at the FAMU-FSU College of Engineering during the first NanoCORE project. This successful program has been continued in the NanoCORE II project and continues to receive interest from the students. The program has



(a)

(b)

Fig. 1. (a) Schematic illustration of the device of carbon nanotube speaker and a scanning electron microscope image shows the structure of the speaker formed by carbon nanotubes. (b) Photo images show that the students present and demonstrate their senior design project to audiences in the open house event.

been advertised throughout the College and during nanomodules presented in courses. Application materials are available on the NanoCORE project website. The research program is open to all majors and all levels. The application requires students to complete an application form and submit an essay about their research interests and goals, along with transcript and resume. Any faculty member who conducts research in areas relevant to nanoscale science and engineering may review these applications and serve as mentors. In some cases, faculty who did not have active nanotechnology research but interests in NSE related to their research fields served as mentors, resulting in positive impacts in their research and allowing them to expand their research field. Faculty from all engineering departments – Mechanical Engineering, Electrical and Computer Engineering, Civil and Environmental Engineering, Chemical and Biomedical Engineering, and Industrial and Manufacturing Engineering – have participated as mentors. We also have made an effort to showcase the interdisciplinary nature of nanoscale science and engineering by matching up engineering students with faculty mentors from engineering disciplines different from their majors. A total of 37 undergraduate students participated in nanotechnology research through the NanoCORE program. Most of the research fellows were juniors, while we received applications from sophomores through seniors. During Summer 2012, a more structured and formal undergraduate research program was implemented. In addition to working with faculty mentors on NSE-related research topics, students also participated in additional activities aimed to enhance their research experience. The student research topics included applications of nanotechnology and nanomaterials to electrical applications, concrete, wastewater, as well as nanoscale science in nanomaterials, polymer, and bioenergy applications (Table 1). Students were required to prepare, in consultation with their research mentor, a research abstract at the beginning of the summer. Students also had the

opportunity to participate in research and professional development seminars. In addition, students had the opportunity to tour labs and watched a demonstration of nanofabrication with the chemical vapor deposition process. At the end of the summer, NanoCORE fellows prepared and presented posters summarizing their research activities and findings. The poster presentations were held in conjunction with the FSU MASS (Multi-physics of Active Systems and Structures) REU research symposium. Figure 2 shows the undergraduate research fellows presenting their posters at the joint poster symposium.

Table 1. NanoCORE undergraduate research program in Summer 2012

Student Major	Mentor's Department	Topic
Environmental Engineering; Chemistry	Civil and Environmental Engineering	Using HPLC-ECD to Detect Pharmaceuticals in Wastewater
Electrical Engineering	Electrical and Computer Engineering	Using LEDs to Stimulate Conformational Change in Azobenzene Molecules
Civil Engineering	Industrial and Manufacturing Engineering	Performance Optimization of Carbon Nanotubes in Electron Field Emission and Other Electrical Applications
Electrical Engineering	Mechanical Engineering	10 nm MOSFET's Operation at over 1 THz
Civil Engineering	Civil and Environmental Engineering	Nanotechnology and the Application of Nanoscience in Concrete
Chemical Engineering	Chemical and Biomedical Engineering	Effects of Blending on the Crystallinity and Morphology of random Propylene 1-Hexene Copolymers
Chemical Engineering	Chemical and Biomedical Engineering	Effects of Different Pretreatment Methods on Bagasse Crystallinity and Subsequent Enzymatic Hydrolysis

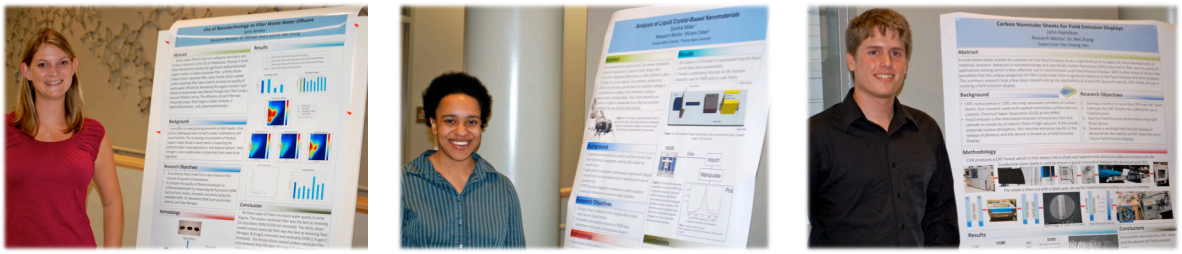


Fig. 2. NanoCORE undergraduate research fellows presenting their posters at the joint poster symposium (August 2012).

Outcomes of the NanoCORE II program include piquing students' interest and curiosity about nanotechnology, instilling positive attitudes toward nanotechnology, increasing NSE literacy and promoting lifelong learning, and equipping students with the tools necessary to function effectively in a nanotechnology driven environment. At the same time, the NanoCORE II program modernizes our undergraduate curriculum and fosters interdisciplinary education and research activities. In addition, several 2012 NanoCORE fellows made presentations at professional and technical conferences (and won awards) and co-authored in publications. Also, three of the NanoCORE research students participated in FSU's Honors in the Major program (Fall 2011-Spring 2012). The students are extending their NanoCORE research into senior theses.

NanoCORE research fellows completed an anonymous survey at the end of their project, responding to questions about their experience in the NanoCORE research program, opinions about graduate school and research, and future plans. All the responses to the NanoCORE research program were positive, with 91% responding "very satisfied." Example comments included:

- "Absolutely amazing, I hope this opportunity continues to be offered. I feel it is so important that students are able to be a part of research, and know that it is an option for them if they are interested even as undergraduates. Only so much can be learned within a classroom, and pursuing research allows us to grow so much as academics and shape us into more viable grad studies candidates. More than that it makes Florida State University a stronger university by creating a stronger engineering program, producing students with capabilities above and beyond their peers domestically and internationally."
- "The NanoCORE program has been highly valuable in the enhancement of my research and analytical skills as well as relating current and/or future work to previous literature studies. I have found the experience highly enjoyable and would certainly recommend the program to other undergraduates interested in research related to nanoscale science and engineering as well as students interested in the pursuit of an advanced graduate degree in STEM fields of study."
- "I feel very fortunate for having the opportunity to gain over two years of research of experience before graduating with a Bachelors degree. I wish to send my thanks to Dr. xx for giving me the opportunity to prove myself in the advanced materials lab prior to my junior year. I would also like to thank my adviser Dr. xx for his continued support and guidance. This experience was hugely important in starting my career and I would highly recommend any undergraduates to take advantage of research opportunities such as this."
- "A good opportunity to pursue research at the College of Engineering; facilitates communication between students and professors they would likely not meet otherwise."

The NanoCORE program has been successful in introducing undergraduate students to nanotechnology. Through the multiple exposure approach, students increased their nanotechnology awareness and literacy through the nanomodules and nanolabs incorporated into multiple courses at different levels. Students also had opportunities for in-depth nanotechnology training through the technical electives, the multidisciplinary capstone senior design project, and the undergraduate research program. Students are curious about nanotechnology and its potential applications.

1. "Nanotechnology Research Directions for Societal Needs in 2020," Mihail C. Roco, Chad A. Mirkin, and Mark C. Hersam, Eds., *NSF/WTEC report*, Springer (2010).
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3. A. Chan Hilton, M. Zhang, R. Alamo, and P. Andrei, "Highlights and Updates of the NUE Nanotechnology Concepts, Opportunities, Research and Education (NanoCORE) Program," submitted to *Journal of Nano Education.*
4. M. Zhang et al., "Strong, Transparent, Multifunctional Carbon Nanotube Sheets," *Science*, **309**, 1215-1219 (2005).
5. L. Xiao et al., "Flexible, Stretchable, Transparent Carbon Nanotube Thin Film Loudspeakers," *Nano Lett*. **8**, 4539 (2008).