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NUE: The Freshman Experience and Nanotechnology Solutions to Engineering Grand Challenges

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She was also the founding advisor for Auburn's SHPE chapter. Dr. Davis earned her Ph.D. from Rice University in 2006 under the guidance of Professor Matteo Pasquali and the late Nobel Laureate Richard E. Smalley. Prior to attending Rice, Dr. Davis worked for eleven years in Shell Chemicals' polymer businesses in the US and Europe. Her industrial assignments included manufacturing, technical service, research, and global marketing management; all of these assignments were focused on enabling new polymer formulations to become useful consumer products.

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Introduction:

The objective of this work is to develop introductory engineering education modules that utilize Engineering Grand Challenges as a framework for teaching nanotechnology at the freshman level, and to evaluate the impact of these modules on student learning. The self-contained multimedia modules, designed for use in freshmen level engineering courses, focus on the potential nanotechnology-based solutions to the Engineering Grand Challenges identified by the National Academy of Engineers (NAE). The authors' ultimate vision is that nanotechnology education will become integrated into throughout engineering curricula by including relevant examples in courses on traditional engineering subjects. This work is motivated by the importance of creating a well-trained, diverse pool of professional engineers who will contribute to societal advancement. Altruism has been shown to have a significant influence on the career motivations for Millennial and GenZ students.[1-4]

The NAE Engineering Grand Challenges highlight the significant positive impact engineers can have on solving global problems. Many of these solutions will involve nanotechnology. In fact there are striking similarities between the NAE Grand Challenges and the White House's Grand Challenges for Nanotechnology. Nanotechnology is also an increasing part of numerous engineering job markets including biomedical engineering, personal care products, electronics, energy, defense, communications, entertainment, and infrastructure. Therefore, it is important that undergraduate engineers attain nanotechnology knowledge.

While the importance of nanotechnology education has been recognized since the inception of the National Technology Initiative,[5] much of the emphasis has been on K-12 and graduate education. While some universities have nanotechnology undergraduate programs, at many universities nanotechnology is limited to senior electives and graduate courses. In fact, a visual representation of courses available on NanoHub.org shows the vast majority are targeted at the junior level or above.[6] Although there are exceptions, most engineering freshman, many of whom have developed a high degree of interest in the potential of nanotechnology as a result of K-12 initiatives, must wait until upper level electives or even graduate school to obtain formal nanotechnology education. The relative paucity of undergraduate nanotechnology education is incongruous with the approximate two trillion dollar economic impact of nanotechnology and the fact that approximately 15% of total global manufactured goods including some form of nanotechnology.[7,8]

Building engineering freshmen's nanotechnology knowledge and showing its importance to engineering grand challenges provides continuity from K-12 nanotechnology outreach, shows its importance to students' intended major, and provides a foundation for weaving nanotechnology throughout the curriculum and preparing them for the workforce. *A keylong term goal of this NSF research is to enable nanotechnology to be viewed as a core part of the engineering curriculum, and not a research specialty.* This mirrors the way that the growth of "biotech" resulted in the biological sciences being incorporated throughout the undergraduate engineering curriculum. For example, in chemical engineering courses, the stoichiometry of bioreactions is now included alongside key petrochemical reactions; reactor design now includes the design of fermenters and other bioreactors. In electrical engineering and computer science, students learn about medical devices, diagnostic instruments, and cutting edge research in neural interfaces. Similarly, nanotechnology and related concepts could be broadly incorporated.

Approach:

In order to provide a foundation for nanotechnology education throughout the curriculum we have focused on developing content for the ENGR 1110 Introduction to Engineering course taken by all freshmen and transfer students in Auburn's Samuel Ginn College of Engineering. The learning objectives for ENGR 1110 serve the dual purpose of ensuring that all students have 1) basic knowledge in calculations, units, and notation, and 2) a design experience that requires teaming, creative problem solving, ethics, and written and oral communication. All of the ENGR 1110 sections place significant emphasis on providing students a positive engineering design experience and cultivating an awareness of the engineering profession. Each department teaches one or more sections of ENGR 1110 and students are encouraged to take the section offered by the program they believe they want to major in. Total semester enrollments approximate 500 students, but individual sections vary from 20 to 130 students depending on the semester and discipline. An overarching aim of ENGR 1110 is to increase the likelihood students will remain interested in engineering while taking predominantly math, science, and general curriculum courses. Research has shown that found that Millennial and GenZ students are particularly motivated when course content is put in a real world context and related to engineers' societal impact.[1-4] Therefore, the National Academy of Engineering's (NAE's) Engineering Grand Challenges[9] was chosen as a framework for introducing nanotechnology to freshmen. Examples of the potential nanotechnology solutions to each of the grand challenges are shown in **Table 1**. Over the term of this grant, modules will be developed to address six of the fourteen grand challenges. The modules are being designed to be consistent with ABET Criterion and to address three primary learning environments identified in the NRC framework:[10]

- **Knowledge centered.** Nanotechnology literacy and familiarity with Grand Challenges are important knowledge bases for students. Further, these topics are expected to make general learning objectives (*e.g.,* measurement units and conversion) more interesting and help students master this material and transfer that knowledge to future coursework.
- **Learner-centered.** The combination of Grand Challenges and nanotechnology are expected to support/change students' perceptions of "engineering as a helping profession," which is believed to motivate students.[1,11] This content is also likely to motivate students by increasing interest and personal relevance (and thereby motivation).[12] We expect that making the modules personally relevant to students will also enhance student learning of fundamental engineering concepts (including the general ENGR1110 objectives) and promote transfer of those concepts to future classes.
- **Assessment-centered.** The use of formative assessments (*e.g.,* in-class quizzes and lab reports) will provide greater feedback opportunities to students and opportunities to learn through assessment. For example, in-class "clicker" quizzes help students immediately recognize gaps in their learning and can tap a range of learning objectives.[10]

Table 1: National Academy of Engineering Grand Challenges and Nanotechnology

Challenge	How nanotechnology may help address challenge
Make solar energy economical	Reduced manufacturing cost and flexible forms, improved efficiency through self-cleaning surfaces and more efficient light to energy conversion
Provide energy from fusion	Improved materials for reactor walls, smaller more durable robots for maintenance and repair.
Develop carbon sequestration methods	Nanostructured CO_2 sorbants, analysis of geological structures, Ni catalyst for CO_2 conversion to $CaCO_3$
Manage the nitrogen cycle	Better methods for fertilizer application, controlled release materials, sensors
Provide access to clean water	Nanostructured membranes for desalination and decontamination, nanoparticles for contaminant absorption, and sensors
Restore and improve urban infrastructure	New load bearing materials that are cheaper and easier to install, protective coatings to increase life span and improve aesthetics of structures, sensors
Advance health informatics	Nanoinformatics, modification of bioinformatics approaches to advance nanomedicine, advances in computer technology
Engineer better medicines	Faster systems to assess patient genetic profile, nanoparticles as a mode of drug delivery, nanostructured scaffolds
Reverse-engineer the brain	Better medical imaging, neural implants
Prevent nuclear terror	Nanophotonic radiation detectors
Secure cyberspace	Better authentication methods, advances in computing capability
Enhance virtual reality	Better resolution displays, responsive materials to replicate the sensations of sound, touch, and motion.
Advance personalized learning	Nanoenabled advances in neural science aspects of learning
Engineer the tools of scientific discovery	Quantum computing, further advances in characterization instrumentation

The intent is for all modules to be adaptable to a wide range of freshman class sizes, outreach activities, upper level courses, and internet dissemination. The first module is an interactive module introducing the NAE's Engineering Messages, Engineering Grand Challenges, and nanotechnology was developed. Prior to being introduced to the NAE Grand Challenges students brainstorm and select what they think the most important grand challenges are. They then learn about the NAE process for selecting the Grand Challenges and watch videos from the NAE website and videos submitted to the NAE E24U video contest. The videos submitted by upperclassmen at Auburn, several of which made the 2015 finals, are particularly engaging for Auburn students because they feature familiar landmarks and help freshmen envision themselves as engineers. In general, each Grand Challenge specific module contains the following:

- An overview of the targeted grand challenge. A learner-centered approach will be taken to support/change students' perceptions of "engineering as a helping profession".
- Interviews with, or presentations by, industrial stakeholders. This reinforces the commercial benefits of providing solutions, and develops students' vision of engineering as a teamwork-based profession.
- Introduction to relevant advances in nanotechnology. A knowledge-centered approach will be taken focusing on the development of a knowledge base for the students this will include

basic engineering skills such as measurement, estimation, unit conversion, and basic engineering problem solving.
- Suggestions for formative assessments. Assessment material will be included as an aid to educators using the modules in their courses.

To date, modules on “Make Solar Energy More Economical,” and “Reverse Engineering the Brain” have been developed. A module on “Access to Clean Water” is under development.

Results:

Beginning in Fall 2014, students were given knowledge and attitude surveys at the beginning and end of their ENGR 1110 course. In Fall 2014 and Spring 2015, 663 undergraduate pre-engineering majors completed the baseline survey assessments that are being used to compare knowledge and attitude gains in future cohorts that receive the Nano/Grand Challenges modules. This baseline data provided important information about which Grand Challenges were most interesting to the freshmen. Overall, the Grand Challenges that students found the most interesting were the following: creating the tools that advance scientific discovery, providing access to clean water, making solar energy more economical, and reverse engineering the brain. There were several differences between male and female students. Females were more interested in advancing health informatics, engineering better medicines, and advancing personalized learning. Males were more interested in providing energy from fusion, and securing cyberspace. Underrepresented minority students (primarily African American and Hispanic) had significantly stronger interest in nanotechnology and enhancing virtual reality.

The first modules developed focused reverse engineering the brain and more economical solar energy. Initially, an abbreviated version of the solar energy module was tested in Summer 2015 with a total of 61 high school students attending two different engineering camps at Auburn **(Figure 1).** Evaluations showed that the Grand Challenges brainstorming activity and hands-on portions of the solar module were highly engaging. Students made significant and substantial gains in their objective and self-reported knowledge of nanotechnology from pre- to post-test. Based on these results the modules were refined and incorporated into the chemical engineering sections of ENGR 1110 in Fall 2015. This course is taught as a 50 minute Monday lecture for all 120 students; with students also meeting on Tuesdays and Thursdays in 75 min lab sections of 60 students each. For each module, introductory material and guest presentations were given in the large section while the hands on activities were conducted in the smaller lab sections The importance of the “Make Solar Energy More Economical Challenge” was conveyed using a video made by upper level Auburn students for the NAE E4U2 video contest.[13] In additional lectures, industrial speakers from Southern Company and Eastman Chemical spoke about their companies’ solar energy related work. The lab sections were further subdivided to thirty students each for the hands on activity; this subdivision was necessary due to space availability. In the lab section, students used solar panels from the Horizon Solar Energy Hydrogen Generation set[14] to measure current and voltage as a function of solar panel angle in both the shade and the sun and had to calculate the power. Students also had to estimate the number and/or area of these inexpensive panels that would be needed to power a lightbulb or a home. This activity was one of the first times many students had used a multimeter, and provided significant opportunities to reinforce students’ understanding of unit conversion, understanding significant figures, experimental variability, and estimation.

Students also made their own solar cells from nanoscale titanium dioxide, ITO glass, raspberries, and iodide/iodine solution. This activity was based on the ACS Nanotation contest video "A Delicious New Solar Technology;"[15] and the video was used to introduce the activity. Students repeated the voltage and current measurements using the solar cells they built. They discussed why there was so much variation between groups and how making the cells in an industrial process would be different. In the final part of the module, students wrote a group memo describing the following: 1) why making solar energy more economical is important, 2) where solar cells/panels are used in Auburn, 3) how solar cells/panels are used other places, 4) ongoing advances in solar, 5) how nanotechnology can help make solar energy more economical, 6) what companies doing to advance solar energy, 7) laboratory results, 8) what they learned about solar energy, and 9) what they think the future of solar energy is. Assessment of the module showed that students found all of the segments of the class to be interesting, but building solar panels and the lecture on nanotechnology and solar panels were rated the most interesting. Students also reported that they learned new things from all four segments, but especially learned from the two lectures (although they were rated as less interesting than the hands-on activities).

Figure 1. Pilot testing of the Grand Challenges activity and solar module during the June 2015 coed Senior Teams and Individuals Guided by Engineering Resources (TIGERS) and Women in Engineering camps. **A.** and **D**. Students prepare dye-sensitized solar cells from raspberry juice and nanoscale titanium dioxide guided by E. W. Davis. **B.** Students brainstorm on what they think grand challenges are **C.** Students learn how shade and solar panel angle affect voltage and current and learn how to calculate power.

A preliminary version of a module on the grand challenge of reverse engineering the brain module was tested Fall 2015. It included a lecture by Mr. Walt Woltosz, an Auburn engineering alumni, on the evolution of science and technology and assistive communication. Mr. Woltosz developed the interface used by Stephen Hawking to speak as well as many other technologies. Another lecture highlighted research by Auburn's MRI research center and nanoparticle MRI contrast agents. During the laboratory session, students rotated between three activities. In one activity, the importance of probe size was highlighted by comparing the ability of large magnets, iron filings, and ferro fluid to detect magnets encased in plaster of Paris molds. The mold represented a brain slice and the magnets represented tumors. In the second activity, students learned about the cortical homunculus by gently using two point discrimination probes made of toothpicks and notecards on each others' hands and arms. In the third activity, a MindWave Mobile Brainwave Starter Kit and associated software observe changes in the instructor's brain waves when blinking or startled. Evaluation of these activities indicated more time and background information was needed; this will be incorporated into future semesters.

Conclusions and Forward Plan:

There are significant opportunities for synergy between nanotechnology education, the NAE's Engineering Messages and Grand Challenges, and ABET outcomes. Initial data shows that students have both enjoyed and learned from the modules developed to date. However, time and physical space have shown to be a challenge to implementation. Initially, it was envisioned that each ENGR 1110 section would eventually teach two Grand Challenges a semester. In order to retain other important class features such as the design project, one grand challenge per semester is more realistic. Now that initial module development and testing has been performed by the PIs and evaluator, the goal is to engage more faculty in implementation and evaluation. This will facilitate institutionalization and provide more information on the effect of the modules on nanotechnology knowledge, perceptions of engineering as an altruistic profession, and intent to persist in major. The existing modules will be incorporated into other sections of ENGR 1110. In addition, a new module on providing access to clean water will also be developed in the coming year. This module is particularly relevant to current events and is seen as very interesting in past surveys. It will include nanofiltration and the use of nanosilver in filters to kill bacteria. Ongoing assessment will measure module specific knowledge gains and the impact of this initiative on nanotechnology and engineering attitudes and persistence in major.

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