Nanotechnology Solutions to Engineering Grand Challenges

Dr. Edward W. Davis, Auburn University

Edward W. Davis received his PhD from the University of Akron in 1996. He worked in the commercial plastics industry for 11 years, including positions with Shell Chemicals in Louvain-la-Nueve Belgium and EVALCA in Houston TX. He joined the faculty at Auburn University in the fall of 2007. In 2014 he was promoted to Senior Lecturer. He has regularly taught courses in three different engineering departments. In 2015 he began his current position as an Assistant Professor in the Materials Engineering Program.

Dr. Joni M. Lakin, Auburn University

Joni M. Lakin, Ph.D. from The University of Iowa, is Assistant Professor of Educational Foundations, Leadership, and Technology at Auburn University. Her research interests include educational assessment, educational evaluation methods, and increasing diversity in STEM fields.

Prof. Virginia A. Davis, Auburn University

Dr.Virginia A. Davis' research is primarily focused on using fluid phase processing to assemble cylindrical nanomaterials into larger functional materials. Targeted applications include optical coatings, 3D printed structures, light-weight composites, and antimicrobial surfaces. Her national awards include selection for the Fulbright Specialist Roster (2015), the American Institute of Chemical Engineers Nanoscale Science and Engineering Forum's Young Investigator Award (2012), the Presidential Early Career Award for Scientists and Engineers (2010), and a National Science Foundation CAREER Award (2009). Her Auburn University awards include the Excellence in Faculty Outreach (2015), an Auburn University Alumni Professorship (2014), the Auburn Engineering Alumni Council Awards for Senior (2013) and Junior (2009) Faculty Research, the Faculty Women of Distinction Award (2012), and the Mark A. Spencer Creative Mentorship Award (2011). Dr. Davis is the past chair of Auburn's Women in Science and Engineering Steering Committee (WISE) and the faculty liaison to the College of Engineering's 100 Women Strong Alumnae organization which is focused on recruiting, retaining and rewarding women in engineering. 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.

Dr. P.K. Raju, Auburn University

Dr. P. K. Raju is the Thomas Walter Distinguished professor of Mechanical Engineering at Auburn University. He is the co-founder and director of the NSF-funded Laboratory for Innovative Technology and Engineering Education (LITEE). LITEE has been recently recognized by the National Academy of Engineering as one of the model programs in the country that has successfully infused real world experiences into engineering undergraduate education. He is also the founder and director of the Auburn Engineering Technical Assistance Program (AETAP). Prior to coming to Auburn in 1984, Dr. Raju held faculty positions in several universities in India and visiting positions at the Catholic University of America, Purdue University, and the Technical University of Berlin. Dr. Raju received his Ph.D. from the Indian institute of Technology, Madras, in 1977. He has made significant research contributions in engineering education and innovations, acoustics, noise control, nondestructive evaluation and technology transfer, resulting in award-winning and significant breakthroughs. He has received a total of $12 million in funding, including grants from industries, the United Nations, the National Science Foundation, NIST, NIH, EDA and other U.S. and international agencies. He has published 24 books, eight book chapters and 200 papers in journals and conference proceedings. He has received several awards for his teaching, research and outreach work from INEER, NASA, NSF, ASME, ASEE, Auburn University and others. He served as an United Nations and UNDP expert and as a World Bank lecturer. He has held Invited Professorships at

the Université Bordeaux I, Talence, and Université Du Havre, Le Harve, France. He has been an invited/ keynote speaker at several national and international conferences. He is a Fellow of the American Society for Engineering Education, a Fellow of the American Society of Mechanical Engineers, a Fellow of the Institution of Engineers (India), and a Fellow of the Acoustical Society of India. He is the editor-in-chief of the Journal of STEM Education: Innovations and Research

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Abstract

This research paper describes the implementation of educational modules that use the National Academy of Engineering's (NAE's) Grand Challenges as a framework for teaching engineering freshmen about nanotechnology and the societal importance of engineering. The introductory module includes multimedia presentations and activities to introduce students to Engineering Grand Challenges and nanotechnology. Modules on specific Grand Challenges include 1) a discussion of the 'current state of the art' for a specific Grand Challenge and needs for addressing the challenge, 2) a knowledge-centered introduction to potential nanotechnology enabled solutions, and 3) hands-on activities for use with the two previous sections. Knowledge and interest surveys at the beginning and end of the semester and before and after each module were used to assess changes in knowledge and attitudes. Two modules focusing on the Grand Challenges, "Make Solar Energy Economical" and "Reverse Engineer the Brain," were developed and used in one section of an introduction to engineering freshman course in Fall 2015. Other sections of the course did not utilize the modules and served as control groups. Demographic data and other identifiers enabled the matching of individual surveys, enabling a pairwise comparison of effects. These results indicate positive impacts on nanotechnology knowledge gains, broader engineering and Grand Challenges knowledge gains, and increased commitment to and engagement in engineering.

Introduction:

The first undergraduate engineering education issue this research addresses is that all engineers, not just a few specialists, will need to be nanotechnology literate [1] to perform their jobs. Over the last decade, there have been a plethora of initiatives focused on formal, and informal, K-12 nanotechnology education. A growing amount of high quality content is available through multiple online resources including NISEnet.org. However, there is often a large gap in nanotechnology education opportunities between high school and senior/graduate level electives. Engineering freshman, a growing number of whom have developed a high degree of interest in the potential of nanotechnology, must wait until graduate school or, if they are lucky, senior level elective classes to obtain any further nanotechnology education. At many schools (including Auburn University) much of the emphasis on nanotechnology has been in the form of academic research and electives for seniors and graduate students. A visual representation of courses available on NanoHub.org shows the vast majority are targeted at the junior level or above.[2] Some schools offer undergraduate nanotechnology degrees or specializations; however, even in these programs nanotechnology related content may not be formally introduced until junior year. For example, North Carolina State University's multidisciplinary minor in nanotechnology offers the first course, Introduction to Nanoscience and Technology," in the junior year.[3] The relatively few published examples of nanotechnology being introduced at the freshman level include, but are not limited to, Indiana University-Purdue University's nanotechnology themed learning community[3] and project to effectively communicate nano- size and scale,[4] Ohio State University's freshmen lab on a chip design project[5] and a Computer Numerical Control (CNC) milling course[6]. However, these specialized programs do not result in all students being exposed to nanotechnology as a pervasive part of science and engineering. The NNI website lists fourteen degree programs at US schools related to nanotechnology: four minor programs in nanotechnology, six degrees that include a specialization or concentration in nanotechnology, and four B.S. degree programs in nanoscience or nanoengineering.[7] A review of nanotechnology programs by Minaie et al. categorized current initiatives into nine models of integrating nanotechnology into engineering curricula.[8] Of the universities included in their review, Texas State was the only school categorized as integrating nanotechnology into existing courses. The majority of nanotechnology education efforts focusing on teaching nanotechnology as a separate subject or in addition to traditional topics in the curriculum is incongruous with the prediction that nanotechnology's impact will be pervasive and comparable to the invention of the automobile.[9] Nanotechnology is already a part of everyday life (*e.g.* sporting goods, deodorants, paints, and advanced electronics) with over 15% of total manufactured goods being somehow enabled by nanotechnology. For this reason, this effort is aiming to have all engineering freshman at Auburn University learn about nanotechnology and its importance to modern engineering.

The second issue this effort is addressing is attrition. Despite efforts to recruit more students to the engineering profession, most studies still show that attrition rates range from 40-60%.[10] While the engineering attrition rates are comparable to that for non-STEM majors,[11] the attrition rates for underrepresented students are particularly concerning. Based on current enrollment demographics these attrition rates translate to a workforce that is only 6% Hispanic, 0.3 % Native American, 4% African American, and 13% female.[12] Research indicates that a change in public perception of the role of engineers in society is required to facilitate the recruitment and retention of students, particularly those from underrepresented groups, to the profession.[13,14] In 2007, the NAE began working with a marketing company to rebrand engineering and better communicate the importance of engineering to the public and potential future engineers. The resulting messages are "1) Engineers are creative problem solvers, 2) Engineers make a world of difference, 3) Engineering is essential to our health, happiness, and safety, and 4) Engineers help shape the future."[15] As the implementation of Engineering Messages continues to grow, there is growing evidence of their effectiveness.[13,14] In 2008, the NAE launched the Engineering Grand Challenges website including fourteen Grand Challenges that highlight key issues facing modern society.[16] These Grand Challenges reinforce the engineering messages of how engineers and their creative problem solving skills are essential to improving our world and shaping the future. Connecting students' interests in nanotechnology to their first-year engineering courses and the Grand Challenges was therefore seen as an important strategy to promote nanoliteracy and engineering retention.

Modules that focus on the potential for nanotechnology to address the NAE Grand Challenges have been developed to address these two issues. The modules focus on nanotechnology as a science and broadening students' perceptions of engineering. Engineering Grand Challenges were selected to leverage the altruistic tendencies of today's students to motivate them to continue in the engineering program and increase their awareness of nanotechnology as a technology relevant to their future careers. While the modules are designed to be used in an introductory engineering course, the framework is suitable for more advanced courses in the curriculum as well as for outreach.

Ecosystem:

The work was conducted at a land grant institution with a large enrollment and multiple undergraduate programs. As in most engineering curricula freshman, and to a large degree sophomore, engineering student course work focuses on core math and science and not their intended engineering major. To address this gap, a required two-hour freshman-level introduction to engineering course was developed a decade ago. The goals of the course are to create enthusiasm for persisting in an engineering major and to "level the playing field" among freshmen by introducing basic engineering skills including design, unit conversions, systematic problem solving, teamwork, and communication. Each engineering department teaches at least one section of the course. All engineering students are required to complete the course prior to graduation. With the exception of transfer students from other universities or majors, students are expected to complete the course freshman year, and encouraged to enroll in a section offered by their intended department. A semester long team project is used as the focal point in many of the courses and the projects are broadly related to the department's focus of study. For example, the chemical engineering sections of the course often use the development of a fuel cell car as the project.[17] The course schedules vary but generally include one hour of lecture and two hours of "lab" time each week. The Grand Challenge modules were designed to be easily integrated into the existing course structure.

Description of the Modules:

The modules were developed with the intent that they could readily be used in their entirety, or an abbreviated form, by faculty teaching the freshman engineering courses at Auburn University or conducting outreach activities. Full details of the modules will be uploaded to internet resources including NanoHub in 2016 and can also be obtained from the authors. The initial module is an introduction to engineering and nanotechnology. To address the motivational goals of the course, a brief lecture that uses the Engineering Messages as a framework for why one might want to be and engineer is presented first. This module has also been used for both coed and all female engineering camps. The lecture starts with a discussion of the Engineering Messages" (Figure 1A). Through discussion, students are encouraged to describe why they selected engineering as a major and their long term goals. Common reasons that emerge from this dynamic discussion include working with talented people in a team environment, large variety of industries (film, industrial plants, food products, etc.), financial security, and engineering providing a gateway to a career in medicine, law, or business. This initial interactive lecture is also used to debunk myths about being an engineer such as "you have to be boring," "you can't have a life and get through engineering school," etc. The presentation concludes with motivational statements from recognized leaders in the profession (Figure 1B) and short motivational video such as the Exxon Mobil TV Spot "America's Future Engineers."[18] The motivational lecture is followed by an in class activity, "What's the challenge?" In this activity, teams of three to five students are asked to brainstorm "problems" that affect them, their families, or society as a whole. The teams report back to the class the top three to four "problems" identified. The class discussion (Figure 2) of the list focuses on relative importance of each "problem" to society as a whole and similarities between "problems." They then group individual problems together into broader issues and vote on two to three problems to be the class' grand challenges. At the conclusion of this activity a list of the NAE Grand Challenges

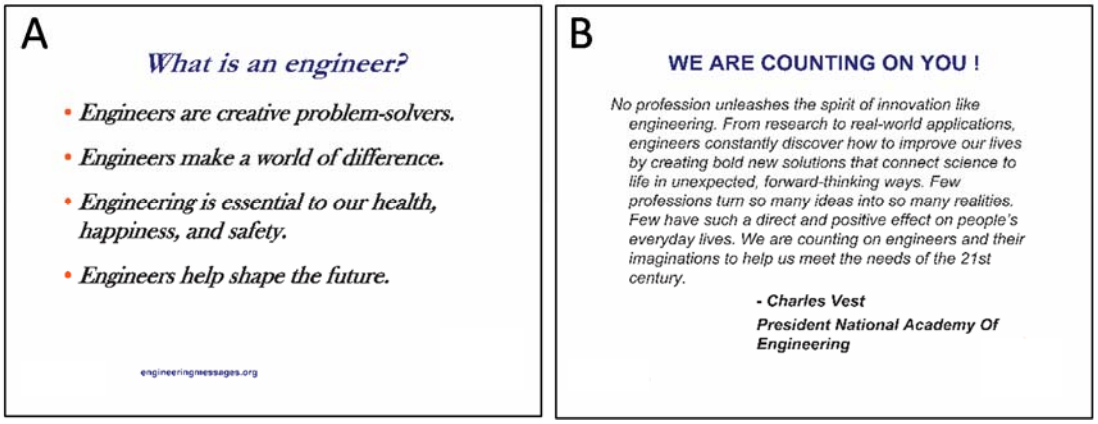

Figure 1. Example slides from the introductory module.

and a brief overview of how NAE arrived at this list is presented to the students. The class has the opportunity to discuss these challenges and how they relate to the list they had just developed. They are encouraged to think about how they, or their currently identified field might contribute to addressing these challenges. The students are then introduced to basic concepts in nanotechnology and how they generally might be applied to specific Grand Challenges.

The other modules are focused on specific Grand Challenges. Typically, short videos are used to introduce the topic such as those avaliable on the NAE Grand Challenges web site,[16] and the NAE E4U2 (Engineering for you too) video contest web site.[19] These videos are motivational and inspirational and are used to motivate students to learn more about the topic. Including videos submitted by more advanced students from Auburn University that made the E4U2 fnals increasing interest by showing identifiable landmarks and highlighting that more senior students are interested in grand challenges. After the videos the modules then proceed to a more in depth introduction to the specific Grand Challenge and the potential role of nanotechnology in overcoming the challenge. This is done through a combination of lecture and hands-on activities. Some of the content is introduced by the instructor, but presentations by guest speakers from industry and government agencies are preferred because it helps students understand the current state-of the art and real world issues. Presentations by alumni and co-operative education (co-op) students also help students envision themselves as engineers.

Figure 2. High school students attending engineering camp discussing importance of problems during the “What’s the Challenge?” activity.

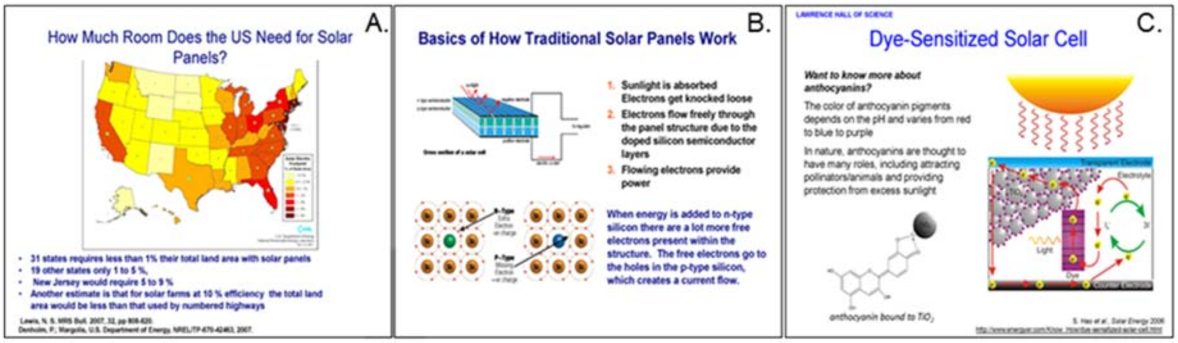

Figure 3. Example slides from the “Make Solar Energy Economical” module.

The “Make Solar Energy More Economical” module has been used in freshman engineering classes ranging in size from 20 to 120 students. The larger classes needed to be divided into sections of ~30 for the lab activities. Abbreviated versions of the module focused primarily on the activities and discussion have been performed with 8^{th} – 12^{th} grade students attending engineering summer camps. In the full version, details of the current state of solar technology, typical efficiency, percentage of power derived from solar energy, types, etc. were introduced by the instructor. Example slides are shown in Figure 3. In additional presentations, two industry speakers and a junior whose co-op assignment was at a company supplying materials for a solar farm provided their perspectives. The activities, Figure 4, included using an inexpensive solar panel, making a dye sensitized solar cell from nanoscale titanium dioxide and raspberry juice, and writing a lab report summarizing all of the lectures and activities and information from at least one additional source. Based on performing the activities with several group sizes teams of 2 – 4 students are preferred. The solar panel measurements used inexpensive panels from toy and hobby suppliers; students made voltage and current measurements when the panel was pointed at different angles in the shade and in the sun and calculated the power output. This activity teaches a number of basic skills (*e.g.* using a multi-meter, compiling data from multiple trials,

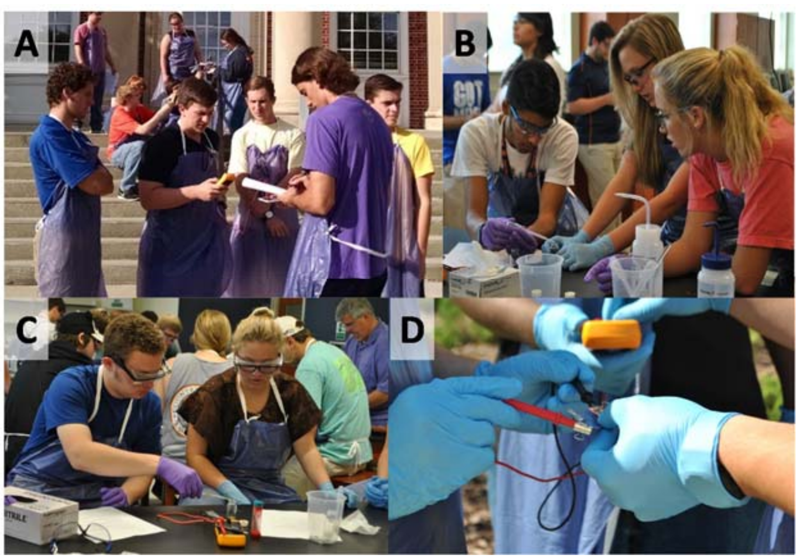

Figure 4. (A) Students testing a commercial solar cell, (B and C) Students constructing a dye sensitized solar cell, and (D) students testing their dye sensitized cells.

understanding sources of error, performing engineering calculations using the factor label method, and significant figures) while enabling students to move around outside. Students ae also shown the "A Delicious New Solar Technology" video in which a dye sensitized solar cell is made from powdered sugar doughnuts and Starbuck's Passion Fruit Tea.[20] Students then make own dye sensitized solar cells from nanoscale titanium dioxide and raspberry juice using a similar procedure. These cells have lower power output and more variability. Discussion of the activities focuses on the size and number of solar cells needed for certain applications (*e.g.* powering a lightbulb, a home, a city), differences between classroom and commercial manufacturing and their perception of the future of solar energy. At the conclusion of the module, students solidify their understanding and develop their written communication skills by writing a team lab report which includes:

- Introduction
  - Why is making solar energy more economical important?
  - Where are solar cells/panels used in Auburn?
  - How are solar cells/panels used other places?
  - What are some ongoing advances in solar?
  - How can nanotechnology affect this Grand Challenge (include 1 reference from outside of class)?
  - What are companies doing to advance solar energy?
- Lab results and discussion
  - Procedures
  - Tables showing current, voltage, and power data from individual trials and average values using the correct units and significant figures
  - Example calculations of power showing SI unit conversions
  - What did you like/dislike about these activities?
  - What did you learn from them?
- Conclusion
  - What have you learned about solar energy?
  - What do you think the future of solar energy is?

In the "Reverse Engineering the Brain Module," students were introduced to the challenge through videos on the NAE website and the White House and other government BRAIN Initiative webpages.[21] Technological issues that are limiting our ability to address "Reverse Engineering the Brain" are also reviewed, such as the vast amounts of data that need to be analyzed. Understanding how the brain works may lead to faster better computational systems but faster better computational systems may be needed to analyze the data required to fully reverse engineer the brain. This is a "chicken and the egg" question that can help students think more deeply about the way science advances. Nanotechnology concepts are incorporated by discussing how the size of the brain cells and axons are related to the nanometer scale to provide insight into how nanoscale sensors might be used to map the brains functions. Discussion of recent advances in neurological interfaces, imaging, and interfaces not only highlight the continuing evolution of science and engineering but also provide a framework for discussion of the difference between current science fiction and future science reality and the potential societal and ethical implications of "Reverse Engineering the Brain." In Fall 2015, much of the discussion focused on two themes: 1) the potential benefit of healing wounded veterans and others suffering from neurological impairments, and 2) the potential risks described in the recently released movie “Terminator Genisys.”

This module includes three short activities the students rotate through in approximately 15 minute increments. The first activity is functional mapping activity using two-point discrimination probes made from toothpicks and cardboard to gather data on the homunculus and quantify how much more sensitive the hands are than the arms. In the second activity, magnets immersed in Plaster of Paris and sandwiched between plastic dinner plates are used to simulate a slice of brain containing a tumor or other defect. Students use large magnets, iron filings, and ferrofluid to probe for the defects and draw the shapes they can see with each probe. The smaller the probe size the more clearly students can identify the exact location and number of objects. This reinforces why nanomaterials are being increasingly used for cancer detection. In the third activity, a Mindwave™ starter kit and associated phone and/or computer applications is used to enable students to visualize the instructor’s (or each other’s) brain wave changes in response to music, being startled or other stimuli. The students are also shown how blinking leads to small electrical signals that can be measured by an inexpensive EEG headset available on Amazon. This is used to discuss how measuring these electrical changes can be used for communication and other purposes.

Evaluation:

Effectiveness of the models was evaluated through pre- and post-semester surveys given to students. The surveys include questions relating to attitudes about engineering, interest in the Grand Challenges, and knowledge and perceptions about nanotechnology. Sources of the questions used to probe attitude are provided in Table 1. The level of nanotechnology knowledge was measured by both self –reported measures (How confident are you that you could name a nanoscale-sized object?) and objective measures (Which forces dominate interaction at the nanoscale?) Demographic information was also collected including gender, race/ethnicity, and

Table 1. Details about Attitude Measures.

Scale	Sub-Scale	Source	# items	Cronbach’s α
Beliefs about Engineering	Communal/Helping	Litzler & Lorah 2013[13]	7	0.73
	Status		7	0.64
	Interesting field		3	0.33
Occupational Values	Communal/Altruistic	Diekman et al. 2010[22]	4	0.78
	Status/Individualistic		5	0.68
	Creativity/Fun		2	0.53
Commitment to Engineering		Perez, Cromley, & Kaplan 2014[23]	4	0.66
Grand Challenges	How interesting are they?	New	17	0.85
	How important is nanotechnology to solving		16	0.91

enrollment status (1st year in college, transfer student, other). Importantly, while the individual survey results are kept confidential identifying information such as instructor name, initials (including middle initial) and month born were used to match surveys of respondents at the beginning and end of the semester or before or after the modules. This allowed for pairwise analysis of the changes in attitudes and knowledge of individuals. Post-module surveys were also developed to probe student's perceptions of the modules themselves. Each module activity was rated by the students for interest and contribution to learning. In addition, the survey asked open-ended question about how the modules could be improved. To obtain baseline comparison data, the pre/post-semester surveys were given to sections of the Introduction to Engineering course in the fall 2014 and spring 2015 prior to the development of the modules. In total, 663 students were surveyed in these two semesters, 443 in the fall and 220 in the spring. In fall 2015, one section of the Introduction to Engineering course utilized the modules while also completing these pre/post surveys. We included the course sections who engaged with the module as well as comparison classrooms who did not use modules.

Results:

Table 2 shows the results of pre- and post-semester attitudes surveys for different classrooms: classrooms not using any modules (comparing the professor who would later introduce modules to other faculty) and the focal professor when modules were implemented. Based on t-tests and Cohen's d effect sizes, we found that all students increased in their objective and self-reported knowledge about nanotechnology as a result of the class, but that students in Dr. Davis's class gained more (likely because nanotechnology already forms part of this professor's courses). The gains for Dr. Davis's were even larger when modules were used (a gain of 1.7 standard deviations [SD] in objective knowledge scores when modules used compared to 1.2 SD gains when they were not used with the same faculty member. Self-reported knowledge (assessed as confidence that the student could complete a series of nano-related tasks) also increased more for the class receiving the modules. Importantly, for the "no modules" sections, we saw small or no change in attitudes towards nano and career values related to engineering. For Dr. Davis's section

Table 2. Module effectiveness. Cohen's d-effect sizes are reported in SD units. *Significant effects based on paired t-test at the p<0.05 level indicated by * and at the p<0.01 level by **.*

	No modules						modules		
	Dr. Davis N=58			Others N=48			Dr. Davis N=66		
	Pre	Post	d effect	Pre	Post	d effect	Pre	Post	d effect
Nanotechnology									
Objective knowl.	1.17	2.00	1.25**	1.18	1.37	0.24*	0.89	2.02	1.70**
Self-reported knowl.	5.07	5.83	0.47**	3.98	4.96	0.60**	3.88	5.38	1.04**
Attitude	5.92	6.05	0.13	5.52	5.32	-0.17	5.26	6.01	0.84**
Value									
Status	1.81	1.81	0	1.83	1.78	-0.09	1.83	1.97	0.27*
Altruism	2.06	2.22	0.21*	2.26	2.23	-0.05	2.14	2.34	0.37**

that participated in the modules, attitudes towards nano and altruistic career values increased significantly with medium to large effect sizes. Status career values also increased somewhat, which was not expected and may or may not be a positive outcome. Students responded to surveys about interest in the NAE Grand Challenges and three additional topics, “preserve wildlife/environment,” “explore space through private organizations,” and “create new nano-technology/materials.” One interesting additional result that was apparent from the surveys was that there were clear gender differences in the level of interest students have for the various Grand Challenges. Some challenges were also more generally interesting to all students. In these surveys, the students were asked to rank their level of interest in each Challenge on a three-point scale: “not interesting” (0 points), “somewhat interesting” (1 point), “interesting” (2 points), and “extremely interesting” (3 points). As mentioned before, surveys of attitudes towards engineering were administered at the start and end of the semester. To allow students not to rate concepts they weren't familiar with, students had the option of indicating "I don't know what this is" for any of the challenges. This category of responses was tracked to assess the familiarity of the challenges.

Results from the start-of-semester surveys from Fall 2014 and Spring 2015 are shown in Figure 5. Overall, students clearly were more interested in Grand Challenges such as topics such as “make solar energy economical,” “create tools that advance scientific discovery,” “provide access to clean water,” and “reverse-engineer the brain.” For male and female students several significant differences in interest appeared using t-tests to compare average interest ratings, Table 3. Topics that were significantly more interesting for female students and that had the

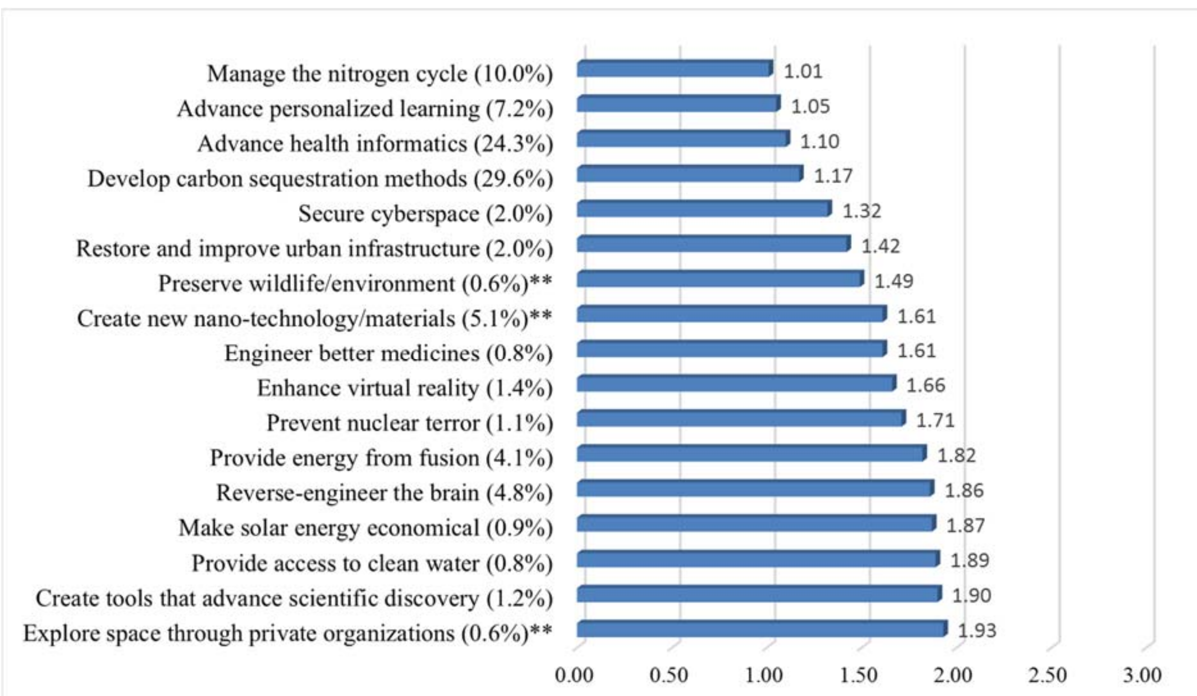

Figure 5. Average interest (scale of 0-3) in each of the engineering topics (14 Grand Challenges and 3 others [indicated with **]) from the pre-semester survey. In parentheses are the percent of students who did not answer that question or indicated they "don’t know what this is."

largest effect sizes (in terms of Cohen's d effect estimates) were “advancing health informatics,” “engineering better medicines,” and “advancing personalizes learning.” See Table 3. Topics that appealed more to male students included “exploring space …,” “providing energy from fusion,” and “secure cyberspace.” Comparing underrepresented minority (URM) racial/ethnic groups to non-URM students, just a few significant differences were found. URM students had significantly stronger interest in “create new nano-technology/materials” and “enhance virtual reality.”

Table 3. Comparisons of Gender and Race Groups

	Comparing Genders		Comparing Underrepresented and non-URM groups	
	t *	Cohen's *d*	t *	Cohen's *d*
Advance health informatics	8.02**	0.65	-1.01	-0.12
Advance personalized learning	6.81**	0.51	-2.43*	-0.27
Create new nanotechnology and nanomaterials	-1.94	-0.15	-3.66**	-0.42
Create tools that advance scientific discovery	-2.4	-0.18	0.09	0.01
Develop carbon sequestration methods	-0.77	-0.07	-1.3	-0.18
Engineer better medicines	6.43**	0.46	-0.78	-0.08
Enhance virtual reality	-3.39**	-0.25	-2.29*	-0.24
Make solar energy economical	-1.48	-0.11	-1.73	-0.19
Manage the nitrogen cycle	1.77	0.13	0.39	0.04
Prevent nuclear terror	-2.42*	-0.18	1.08	0.11
Provide access to clean water	3.63**	0.26	-0.54	-0.06
Provide energy from fusion	-5.47**	-0.41	0.83	0.09
Restore and improve urban infrastructure	-1.51	-0.11	-1.09	-0.12
Reverse-engineer the brain	2.5*	0.19	-0.37	-0.04
Secure cyberspace	-3.84**	-0.27	-1.88	-0.2

Conclusions and Future Plans:

Initial evaluation of the modules showed that they are effective at increasing the level of nanotechnology knowledge. In addition, they had a positive impact on students’ perceptions of engineering. Students also report enjoying the modules and learning important concepts from them. The developed modules are being incorporated in other sections of the Introduction to Engineering Course. In addition, new modules are being developed, some of which are being led by faculty teaching other sections which is aiding the institutionalization of the effort. Interest ratings from past semesters are informing the choice of topics. Over the next few years data will be collected to evaluate effects on retention in engineering and STEM fields in general. The modules are also being used as part of outreach efforts such as engineering summer camps for high school seniors and recent graduates.

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References:

(1) Yawson, R. M. An epistemological framework for nanoscience and nanotechnology literacy. *Int J Technol Des Educ* **2012**, *22*, 297-310.
(2) Resources: Courses Browse Visually. https://nanohub.org/resources/courses (accessed May 25, 2014.
(3) Veety, E. N.; Ozturk, M. C.; Escuti, M.; Muth, J.; Misra, V. In *Tilte*, Indianapolis, Indiana2014
(4) Rodgers, K. J.; Kong, Y.; Diefes-Dux, H. A.; Madhavan, K. In *Tilte*2014.
(5) Schlosser, P.; Trott, B.; Tomasko, D.; Clingan, P.; Allam, Y.; Merrill, J. In *Tilte*, Chicago, Illinois2006.
(6) Abernathy, S. M.; Carruthers, B. E.; Presley, K. F.; Clingan, P. A. In *Tilte*, San Antonio, Texas2012.
(7) College and Graduate Programs. http://www.nano.gov/education-training/university-college (accessed May 10, 2014.
(8) Minaie, A.; Sanati-Mehrizy, A.; Sanati-Mehrizy, P.; Sanati-Mehrizy, R. In *Tilte*, Seattle, Washington2015.
(9) Introduction to Nanotechnology. http://www.nanotechproject.org/topics/nano101/introduction_to_nanotechnology/ 2013).
(10) Lorimer, S.; Davis, J. A. In *Tilte*, Seattle2015.
(11) Chen, X. STEM Attrition: College Students' Paths into and out of STEM Fields. Statistical Analysis Report. NCES 2014-001. *National Center for Education Statistics* **2013**.
(12) Gray, M.; Lundy, L. In *Tilte*, Seattle, Washington2015.
(13) Litzler, E.: A Natural Experiment: NAE's Changing the Conversation Report and Students' Changing Perceptions of Engineering. In *120th ASEE Annual Conference and Exposition*; ASEE: Atlanta, GA, 2013; pp 1-17.
(14) Committee on Implementing Engineering Messages: Messaging for Engineering: From Research to Action. National Academy of Engineering, Ed.; National Academies Pres: Washington, DC, 2013.
(15) National Academy of Engineering: Changing the Conversation: Messages for Improving Public Understanding of Engineering The National Academies Press Washington D.C. , 2008.
(16) NAE Grand Challenges for Engineering. http://www.engineeringchallenges.org/.
(17) Davis, V. A.; Duke, S. Incorporating fuel cell car design into a freshman engineering class. *Chemical Engineering Education* **2014**, *48*, 157-164.
(18) America's Future Engineers. http://www.ispot.tv/ad/7Dwp/exxon-mobil-americas-future-engineers (accessed January 26, 2016 2016).
(19) E4U2 video contest. http://www.nae.edu/e4u2/ (accessed January 27, 2016 2016).
(20) A Delicious New Solar Technology. https://www.youtube.com/watch?v=bVwzJEhMmD8 (accessed July 7, 2015.
(21) THE BRAIN INITIATIVE Brain Research through Advancing Innovative Neurotechnologies. https://www.whitehouse.gov/BRAIN.
(22) Diekman, A. B.; Brown, E. R.; Johnston, A. M.; Clark, E. K. Seeking congruity between goals and roles: A new look at why women opt out of science, technology, engineering, and mathematics careers. *Psychological Science* **2010**, *21*, 1051-1057.
(23) Perez, T.; Cromley, J. G.; Kaplan, A. The role of identity development, values, and costs in college STEM retention. *Journal of Educational Psychology* **2014**, *106*, 315.