Multidisciplinary Undergraduate Minor Program in Nano-Science and Technology at North Carolina State University

Dr. Elena Nicolescu Veety, North Carolina State University

Elena Veety received the Ph.D. degree in electrical engineering from North Carolina State University, Raleigh, NC, in 2011. Her research focused on liquid crystal polarization gratings for tunable optical filters and telecommunications applications. Since 2011, she has been a Teaching Assistant Professor of Electrical and Computer Engineering at North Carolina State University. Currently, she is the Assistant Education Director for the NSF Nanosystems Engineering Research Center for Advanced Self-Powered Systems of Integrated Sensors and Technologies (ASSIST).

Prof. Mehmet C. Ozturk, North Carolina State University

Mehmet C. Ozturk received his BS degree in Electrical Engineering from Bogazici University in Istanbul, Turkey in 1980. He received his MS degree from Michigan Tech in 1983 and his PhD degree from NC State University in 1988. Immediately after graduation, he joined the faculty in the Department of Electrical and Computer Engineering.

Since 2008, Dr. Ozturk has been serving as the director of the NCSU Nanofabrication Facility, which operates as the central laboratory for the entire University. In 2012, he became the education and diversity director of the NSF sponsored ASSIST Nanosystems Engineering Research Center.

Dr. Ozturk's research interests center around innovations in engineering education, nano-materials/processes and flexible energy harvesting technologies. In the ASSIST center, he is leading a research group working on thermoelectric energy harvesting for self-powered body wearable sensors for health and environmental monitoring. He was named a fellow of IEEE for his contributions in Si and SiGe Epitaxy and their applications in advanced MOS field effect transistors.

Dr. Michael Escuti
Dr. John Muth
Prof. Veena Misra, North Carolina State University

A Multidisciplinary Undergraduate Minor in Nanoscience and Technology at North Carolina State University

Introduction

Nanotechnology has come a long way since Richard Feynman gave his visionary talk "There is plenty of room at the bottom" at the 1959 meeting of the American Physical Society[1]. Nanotechnology has already impacted the marketplace with estimated values of nanotechnology-enabled products of $91 billion in the United States and $254 billion worldwide in 2009[2]. It is estimated that the number of nanotechnology products and workers will double every 3 years, and by 2020, there will be a $3 trillion market with six million workers[2]. At the same time, it is recognized that nanotechnology is still a developing field and nanotechnology R&D is expected to accelerate throughout the decade[3]. Patents and scientific papers on nanotechnology topics quadrupled in the last decade, and this growth has accelerated in the past couple of years[4]. All of these trends point to a need to train nanoscience researchers and scientists to continue the growth in this field and meet the nanotechnology vision for 2020 set forth by NSF[3].

Along with continuous advances in nanoscience and technology, educators have developed different courses and programs at both undergraduate and graduate levels to attract the best and brightest students to the field and help creation of a new work-force. Wansom et al.[5] succinctly summarized the outcomes of three important studies on the topic of nanotechnology education, and synthesized a rubric for nanoscience and technology degree programs. That rubric consists of: balanced content in the areas of Processing, Nanostructure, Properties, and Applications (P-N-P-A), interdisciplinary exposure, experience with advanced nano-instrumentation, and exposure to nano-related societal issues. The importance of hands on experience, and societal aspects of nanotechnology are also commonly mentioned[6,7,8].

The center for Advanced Self-Powered Systems of Integrated Sensors and Technologies (ASSIST) was established in September 2012 as a Nanosystems Engineering Research Center (NERC) with funding from the National Science Foundation (NSF). ASSIST employs nanotechnology to develop wearable, energy-autonomous, health and environment monitoring systems. One of the key missions of ASSIST's education program was to establish a multi-disciplinary minor in nanoscience and technology to educate our engineering undergraduates about the field and prepare them to join the work-force as successful scientists and engineers. The program was approved for the Fall 2013 semester and the first group of students was admitted to the program's required junior-level introductory course. The highly multi-disciplinary nature of ASSIST was key to developing a program that relied on a multitude of courses taught by a diverse group of faculty representing a variety of engineering departments. This paper provides an overview of the new program's key components as well as the lessons learned in the program development process.

Program Development

Development of the minor program began in September 2012 immediately after the ASSIST center was officially established. A multi-disciplinary committee led by the education director of ASSIST and including faculty representatives from each engineering department at North Carolina State University was formed for this purpose. The faculty members participating in this effort either received research funds directly from ASSIST or they were active in the field of nanotechnology through funds from other sources. Every member of the committee also taught a relevant class either at the undergraduate or graduate level in his/her department. As such, all committee members had a vested interest in contributing to the development of the program by sharing ideas as well as current and new nano-related courses. The ASSIST center provided a great infrastructure of nanoscience and technology faculty representing different disciplines, which enabled the selection of a comprehensive list of technical courses.

The undergraduate advisors or undergraduate program directors of the various engineering departments were also included in many of the discussions. This collaboration was essential to developing a structure that could be seamlessly integrated into the existing curricula in different engineering departments.

The committee identified the objectives of the minor program as follows:

- To train undergraduate students in the fundamentals of nano-scale materials, devices, and systems for a broad variety of applications.
- To create a multidisciplinary program that combines courses from a variety of engineering disciplines, and is accessible to students from all engineering backgrounds.
- To encourage students and prepare them to pursue graduate degrees in nanoscience and technology.
- To prepare undergraduate students for the global workforce by combining technical training with diversity awareness, engineering ethics, and an understanding of global issues in science and technology.

By the end of the Fall 2012 semester, the committee had reached a consensus on the structure of the program shown in Figure 1. This 18 credit hour program included a required introductory course, three technical elective courses, and two general education elective courses.

Minor Program Requirements	
Required Course 3 credit hours Junior Year	• Introduction to Nanoscience and Technology (3cr)
General Education Electives 6 credit hours Junior or Senior Year	• Engineering Ethics Elective (3 cr) • Diversity and Global Issues in Science and Technology Elective (3 cr)
Technical electives 9 credit hours Senior Year	• Approved Technical Elective (3 cr) • Approved Technical Elective (3 cr) • Out-of-Department Elective (3 cr)
Total Requirement	• 18 credit hours (6 courses)

Figure 1: Structure of the 18 credit hour minor program in Nanoscience and Technology

Establishing this multi-disciplinary structure required consent of individual course instructors as well as administrative approval from departmental course and curriculum committees and administrators at different levels. Anyone who has previously attempted to develop a multi-disciplinary program of this magnitude will be familiar with these challenges. For example, one of the key difficulties in establishing a multidisciplinary program is to match the prerequisites of senior level courses from various departments. A good working relationship among departments is necessary to ensure students can earn credit for equivalent courses in various departments, and are able to meet their prerequisites.

Our experience has been very positive in terms of these cross-disciplinary relationships and we have felt the full support of the college of engineering as well as the individual departments throughout the process. While we undoubtedly enjoy a very collegial environment at NC State, it is obvious that the strong influence of the ASSIST center on campus paved the way for the success of this program. The center provides a great deal of momentum within the university through newsletters, Internet and television publicity, and even visits from our congressman. We believe this momentum translates to an increased willingness by the faculty and departments to contribute and become part of the center's success. Therefore, many of the common obstacles that often plague multidisciplinary efforts are more easily overcome. We believe that NSF engineering research centers and other centers of this magnitude carry tremendous power to achieve major programmatic changes and new centers should be encouraged to take advantage of their strong influence within their institutions.

Program Description

By design, the minor in Nanoscience and Technology is a multidisciplinary program open to all engineering students. The minor is administered by the ASSIST Nanosystems Engineering

Research Center. The education director of the center, who reports to the center director, serves as the program administrator as well as the main point of contact for all students enrolled in the minor. In the following sections, we provide an overview of the program and describe its critical components.

Introductory Course

Introduction to Nanoscience and Technology (E 304) has been specifically designed to serve as a foundational course for the minor program. The course provides an introduction to the physical principles of materials and structures at the nano-scale and how these principles are connected to exciting applications in different fields such as nanoelectronics in electrical engineering, nanofluidics in mechanical engineering, or nano-biotechnology in biomedical engineering. The course textbook, titled *Nanotechnology: Understanding Small Systems*[9], highlights these various applications effectively for a multidisciplinary classroom. To underscore the multidisciplinary nature of the minor, the course is listed as a general engineering (E) course under the college of engineering as opposed to cross-listing the course among multiple departments. It is important to note that our students at NC State are familiar with this practice due to a required first year course entitled E101 *Introduction to Engineering and Problem Solving*. The course prerequisites are satisfied by all engineering disciplines through completion of the physics and the calculus sequence during the second year. The instructional objectives of the course are:

- Explain the fundamental properties of materials at nano-scale, especially as distinguished from their properties at the micro-scale.
- Critically analyze nano-scale systems and distinguish their unique properties that are solely based on nano-scale features.
- Discuss the current and potential impact of nanoscience in applications, including mechanics, electronics, photonics, and biotechnology
- Perform calculations and estimates of the electronic, optical, mechanical properties of materials at nano-scale.
- Describe operational principles of devices based on nano-scale patterning or nano-structured materials and calculate their properties.
- Articulate the early milestones, key personalities, and current challenges of nanotechnology.

The course provides a broad introduction to fundamental concepts of nanoscience and technology while emphasizing the multi-disciplinary nature of the field. The impact of scaling on fundamental properties of matter is reviewed emphasizing unique properties that emerge as a result of scaling. This is followed by examples to showcase how different nano-concepts merge to create systems with unique functions and characteristics. Applications in different engineering disciplines including mechanics, electronics, heat transfer, fluidics, photonics, and biotechnology are covered, making the course relevant to students coming from a variety of backgrounds.

Technical Electives

After completing the introductory course, the students must take three technical electives. Upon entering the program, students meet with the program administrator and prepare a plan of work.

During this meeting, the students are advised on the electives based on their backgrounds and interests. In some cases, elective courses can double count for requirements in the student's degree program as well. The 12 technical electives currently available to students enrolled in the minor are listed in Figure 2. To emphasize the multi-disciplinary nature of the program, students are required to choose at least one elective outside of their home department.

Chemical and Biomolecular Engineering	
CHE 465	Colloidal and Nanoscale Engineering
CHE 460	Nano-Electronic Materials
CHE 462	Fundamentals of Bio-Nanotechnology
Biomedical Engineering	
BME 422	Fundamentals of Biomedical Instrumentation
BME 422	Bioelectricity
Textiles Engineering	
TE 466	Polymeric Biomaterials Engineering (cross-listed as BME 466)
Mechanical and Aerospace Engineering	
MAE 495	Introduction to Multidisciplinary Nanotechnology Laboratory
Materials Science and Engineering	
MSE 460	Microelectronics Materials
MSE 465	Introduction to Nanomaterials
Electrical and Computer Engineering	
ECE 404	Introduction to Solid-State Devices
ECE 442	Integrated Circuit Technology and Fabrication
ECE 468	Conventional and Emerging Nanomanufacturing Techniques and Their Applications in Nanosystems (cross-listed as CHE 468)

Figure 2: Technical Electives

It may be noted that not all of these courses are strictly "nano" courses yet they are included in the list because they provide the background for applications where nanotechnology can have an impact. A good example for courses in this category is *BME 425 Bioelectricity* in which the emphasis is on electrical signals in the human body. While this course is not often considered a nanoscience course, it provides students the critical biomedical background needed to understand the design of nano-enabled health monitoring systems which are a key research area in ASSIST.

The more fundamental nanoscience and technology courses are considered core *nano* electives and students are encouraged to take at least one of these courses. The following courses from three different departments are representative of this category:

- Colloidal and Nanoscale Engineering - The first part of this course presents the fundamentals of nanoscale colloidal processes, including interactions and self-assembly

of particles, surfactants and biomolecules. The applications of these fundamentals to the nanotechnology and engineering on the nanoscale are discussed. The nanoscience has led to the development of many new technologies with relevance to chemical engineering, including microfluidics, lab-on-a-chip, bioarrays and bioassays. These emerging technologies are presented and discussed in the second half of this course.

- Conventional and Emerging Nanomanufacturing Techniques and their Applications in Nanosystems - Review of techniques for patterning, deposition, and etching of thin films including emerging techniques such as an imprint and soft lithography and other unconventional techniques. Electronic and mechanical properties of 0 to 3-D nanostructures and their applications in nano-electronics, MEMS/NEMS devices, sensing, energy harvesting, storage, flexible electronics and nano-medicine.
- Introduction to Nanomaterials - Introduction to nanoparticles, nanotubes, nanowires, and nanostructured films, emphasizing their synthesis, structural and property characterization, novel physical and chemical properties, applications and contemporary literature.

The elective courses are periodically evaluated by a committee of faculty within the center to ensure that a core collection of high quality, relevant, and multidisciplinary courses are available to students.

The ASSIST Center's focus on innovation and close relationships with industrial and international academic partners creates opportunities for undergraduates to interact within an ecosystem that promotes entrepreneurship. Many of the technical electives within the minor are developed by ASSIST faculty, and are therefore informed by current research within the center. As such, students are in close contact with ASSIST research, and they are encouraged to engage in undergraduate research within the center.

General Education Electives

The past decade has seen a proliferation of nanotechnology across almost every science and engineering discipline, but also worldwide and even in many developing countries[10]. Many view nanotechnology to be the "next big thing" that will fundamentally change our world, improve global health, clean the environment, and change society as a whole. At the same time we recognize that due to its deeply transformative potential as well as its cross-disciplinary and global impact, nanotechnology carries with it many complex societal and ethical implications. We propose that a nanotechnology technical education cannot be complete without a foundational understanding of these issues.

For example, the issue of equity is at the forefront of the nanotechnology conversation. While it is easy to claim that nanotechnology is expected to improve health for instance, the reality is much more complicated. Cozzens et al.[11] approaches this topic with questions such as: Will nanotechnologies be designed for and accessible to all populations, or will they only benefit the

wealthy? Will the benefits of nanotechnologies be distributed worldwide, or will they be focused in certain countries? Our students must be prepared to contend with these and other ethical questions in their future nanotechnology careers.

Equitable distribution of employment in nano-fields is another important issue. The disproportionately large percentage of white and Asian men in the science and engineering education pipeline is likely to lead to a non-equitable distribution of workers in the nano field. This trend is particularly alarming when considering the recent findings by Savath et al.[12] showing that women and men nano scientists view the social and ethical implications of their work in very different ways. The study concluded that women nano scientists are more likely to recognize the unique risks and potential impacts of their research. Examples like this illustrate the importance of incorporating many diverse perspectives in order to solve a problem, and we feel it essential for our students to appreciate these benefits of diversity.

The global nature of nanotechnology brings up issues of cultural diversity. The ethical and social issues related to nanotechnology are viewed differently by various cultures. While broadly there is agreement on the goal of improving the world, a deeper understanding shows us that various stakeholders have very complex and diverse definitions of what exactly constitutes an 'improvement' and how we define the 'world'[10]. In fact, promoting global coordination is one of the strategic priorities for nanotechnology looking towards the year 2020[3]. Future leaders in the field will need to work together to develop and maintain standards, explore international co-funding mechanisms, and seek international coordination for Environmental Health and Safety (EHS) and Environmental Legal and Societal Implications (ELSI).

In addition to the societal and ethical implications that are specific to nanotechnology, it is generally accepted that technical training is not enough for students to become competitive and successful engineers in the global economy. Recent literature shows an increased acknowledgement of the need to provide engineering students with a range of skills and attributes. Perhaps the most well-known of these is the National Academy of Engineering publication, The Engineer of 2020[13] which outlines the following desirable attributes: strong analytical skills, practical ingenuity, creativity, communication, business and management, leadership, ethics and professionalism, flexibility, and lifelong learning. Others point to the desired attributes of a global engineer, showing a general consensus that students ought to:(i) appreciate other cultures, (ii) understand the bigger picture context of engineering work cross-disciplinary aspects, business, ethical, and social implications, and (iii) communicate, work with, and direct teams of ethnic and cultural diversity.

In order to prepare students to navigate the various risks and implications of nanotechnology as well as train them in the global competencies essential to success, we have incorporated diversity, ethics, and global issues as requirements of the minor program. Students are required to complete three credit hours in Diversity and Global Issues in Science and Technology and three credit hours in Ethics. Students have a choice of courses including: Women and Gender in

Science and Technology, Science Technology and Public Policy, Introduction to Science Technology and Society, Ethical Dimensions of Progress, and Ethics. These courses are offered by the Science, Technology, and Society, Political Science, and Philosophy departments at North Carolina State University. It should be noted that all undergraduates at NC State are required to take six credit hours each of humanities and social sciences courses as part of the General Education requirement and the above courses come from the approved list of General Education electives. Therefore the minor program guides students toward courses that we believe are essential for nanoscience, but allows them to meet their other university requirements at the same time.

Although we believe it is very valuable for our students to take these classes outside of the engineering departments, we do recognize that this type of program places an additional burden on the humanities departments that teach the ethics, diversity, and global issues in science and technology courses. Coordinating with the humanities and social sciences to accommodate an influx of students in these general education courses is essential.

Preliminary Results

The program is still in its first year and currently enrolling students. Based on the positive reception of the introductory course, we do expect the program to grow quickly and graduate its first students starting in the spring 2015 semester. Our foremost indicator of enrollment comes from the success of the Introduction to Nanoscience and Technology course, which has enrolled approximately 80 students in the first two semesters. As expected, the students registering for this course represent many engineering departments. Of the 80 students, 27.5% are Chemical Engineers, 38.75% are Electrical and/or Computer engineers, 6.25% are Materials Engineers, and 27.5% represent other engineering departments including Biomedical, Mechanical and Aerospace, Industrial, Computer Science and Nuclear Engineering departments.

In order to evaluate the minor program and its impact on students, we will gather data related to student self-reported skill gain, attitudes, perceptions, and dispositions towards nanoscience and nano-related careers. This data will be collected in the form of anonymous and confidential surveys throughout students' participation in the minor program. In addition, we will track students' educational experience throughout the program and after graduation, to assess the impact of the program on their involvement with undergraduate research, industry internships, and career path decisions.

Preliminary evaluation results from the introductory course show positive trends in students' attitudes toward nanoscience and technology. In surveys conducted at the start and end of the course, students were asked a range of questions including how likely they were to do the following: take another course, conduct research, pursue a graduate degree, or pursue a career in nanoscience and technology. Figure 3 shows responses at the start and end of the semester respectively.

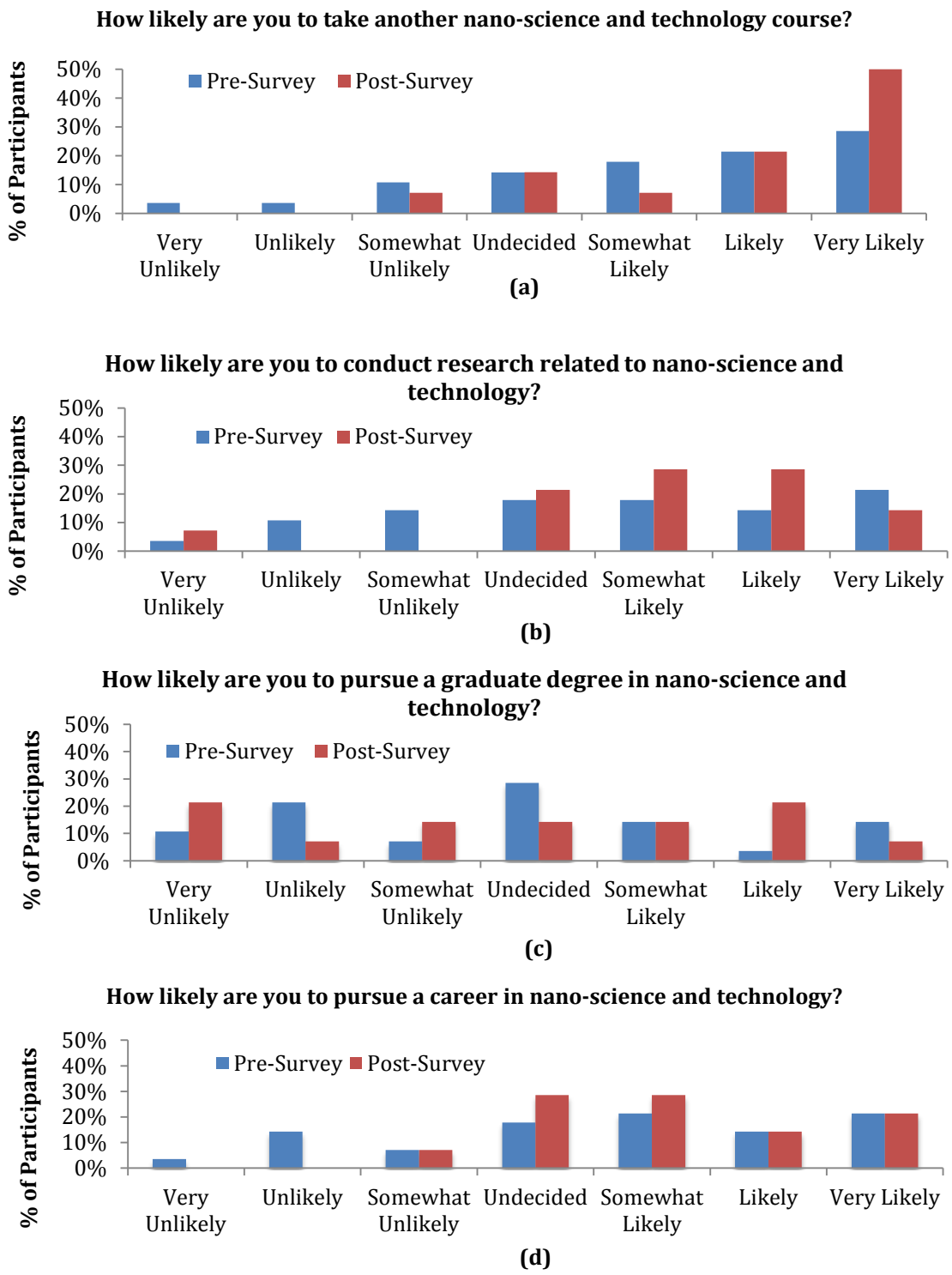

Figure 3: Pre-survey and post-survey responses showing how likely a student is to: (a) take another course, (b) conduct research, (c) pursue a graduate degree, or (d) pursue a career in nanoscience and technology

Summary

An 18 credit-hour, multidisciplinary undergraduate minor program in Nanoscience and Technology was developed at North Carolina State University under the leadership of the NSF sponsored ASSIST Nanosystems Engineering Research Center. The program was approved by the University in Spring 2013 and the first students were admitted to the program in Fall 2013. The minor includes a junior level required introductory course, three technical electives and two general education electives emphasizing diversity, ethics and global issues. The technical electives come from a variety of engineering departments and taught by faculty performing research in nanoscience and technology.

Perhaps not surprisingly, one key lesson learned through the development process was the importance of strong interdisciplinary relationships among engineering departments. Developing a technically well-rounded program and seamlessly integrating it with curricula from a variety of departments takes a great deal of coordination among faculty and administrators. However we found that being part of a large engineering research center with NSF funding, carries a great deal of power to promote collaboration and effect meaningful programmatic change.

The program's evaluation plan consists of individual course evaluations, periodic assessment of students' attitudes and dispositions towards specific courses as well as the overall program, quantitative measures of enrollment and retention within the program, participation in undergraduate research and/or internships, and longitudinal studies of career choices made by graduated students. Preliminary data from the first semester of the introductory course already indicates a positive shift in students' attitudes towards nanotechnology courses, research, and careers. We are confident that these trends will continue as enrollment in the program increases.

Acknowledgements

This work was supported by the National Science Foundation through the Nanosystems Engineering Research Center for Advanced Self-Powered Systems of Integrated Sensors and Technologies (EEC 1160483). The authors would like to thank Dr. Jerome Lavelle, associate dean of academic affairs, Dr. David Parish, assistant dean of academic affairs, the undergraduate advisors of the engineering departments participating in the minor: Cecilia Townsend, Lianne Carty, Larry Silverberg , Cheryl Cass and Lisa Bullard, and the instructors of the minor courses.

References

[1] R. Feynman. There's plenty of room at the bottom. Engineering and Science, 23(5):22–36, 1960.

[2] MC Roco, CA Mirkin, and MC Hersam. Nanotechnology research directions for societal needs in 2020: Retrospective and outlook. January 2011.

[3] Mihail C. Roco, Chad A. Mirkin, and Mark C. Hersam. Nanotechnology research directions for societal needs in 2020: summary of international study. Journal of Nanoparticle Research, 13(3):897–919, March 2011.

[4] Hsinchun Chen, Mihail C. Roco, Jaebong Son, Shan Jiang, Catherine A. Larson, and Qiang Gao. Global nanotechnology development from 1991 to 2012: patents, scientific publications, and effect of NSF funding. Journal of Nanoparticle Research, 15(9), September 2013.

[5] S Wansom, TO Mason, and MC Hersam. A rubric for post-secondary degree programs in nanoscience and nanotechnology. International Journal, January 2009.

[6] N Chopra and RG Reddy. Undergraduate Education in Nanotechnology and Nanoscience. JOM Journal of the Minerals, January 2012.

[7] Roberto Cingolani. The road ahead. Nature Nanotechnology, 8(11):792–793, November 2013.

[8] KS Martirosyan and D Litvinov. NanoScience Concentration Program for science, engineering and technology curricula. (IEEE-NANO), January 2012.

[9] B Rogers, J Adams, and S Pennathur. Nanotechnology: Understanding Small Systems. Crc Press, 2011.

[10] Joachim Schummer. Cultural diversity in nanotechnology ethics. Interdisciplinary Science Reviews, 31(3), 2006.

[11] Susan E Cozzens and Jameson M Wetmore, editors. Nanotechnology and the Challenges of Equity, Equality and Development. Springer, 2011.

[12] Vivien Savath and Suzanne Gage Brainard. Managing nanotechnology risks in vulnerable populations: A case for gender diversity. Review of Policy Research, 30(5), 2013.

[13] National Research Council. The engineer of 2020: Visions of engineering in the new century. The National Academies Press, 2004.