Introduction to Nanotechnology Design
Course for Freshmen and Sophomores

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1.0 Introduction

Revolutionary, nanoscience-based technologies are reshaping the future of humankind and are emerging at a breathtaking rate. Many of these developments require a confluence of disciplinary skills and include nanoscale science and engineering (NSE) concepts that are missing from traditional compartmentalized undergraduate educational programs in science, technology, engineering, and mathematics (STEM). An interdisciplinary environment is needed to train engineers and scientists effectively in the skills and knowledge required to make valuable contributions in the nanoscale revolution.

A new course called Introduction to Nanotechnology Design has been developed and, during spring 2007, is being offered on a pilot basis to freshman and sophomore WVU students as the first of many steps to be taken to establish an interdisciplinary nanoscale science and engineering curriculum designed to train a nano-literate workforce. This paper describes the goals and objectives for, the implementation of, and the historical need and generous support for the course.

2.0 Need for an Introductory Nanotechnology Course

NSE training is an essential component of the mission of the WVNano Initiative, West Virginia’s initiative to improve the infrastructure for nanoscale science, engineering, and education at West Virginia University and at Marshall University. In July 2006, this initiative received an historic $9 million NSF EPSCoR research infrastructure improvement grant and matching funds of $4.5 million through WV EPSCoR. These funds are being used to acquire equipment, to hire new faculty, and to support the establishment of facilities needed to support world-class research in nanoscale science and engineering.

Curriculum development is needed to pass along these research infrastructure improvements to the next generation of nanoscale scientists and engineers. Dr. Gerald E. Lang, WVU Provost, said; “This curriculum development will facilitate the transfer of WVNano research expertise into the classroom, integrating faculty research and teaching in a way that will help to prepare a workforce that is qualified to make significant contributions in nanoscale science and technology.”

Training a nano-literate workforce is important to economic development in West Virginia because of the enormous economic potential of nanotechnology. The National Science Foundation predicts that nano-related goods and services could grow into a $1 trillion market by 2015. Nanotechnology may literally transform our everyday lives, including innovations in transportation, information technology, and disease prevention, treatment, and cure.

2.1 Nanoscale deficiencies in STEM education models

Traditional STEM educational models virtually ignore the nanoscale physics and chemistry that are essential to the understanding of nanoscale devices and systems. At WVU, majors in engineering and in most of the science disciplines are not required to take physics beyond introductory general physics. Accordingly, most students lack fundamental understanding of the
quantum mechanics and mesoscopic physics associated with the operation of many nanoscale devices and systems such as quantum dots and spintronic systems. Chemistry students might learn that surfaces can be locations of high reactivity and can be modified with specific chemical functionalities, but from this they can gain little insight into the design of nanoparticle systems with specific traits, such as catalysis or bioactivity. Courses taught from a purely classical perspective leave students with little sense of the nanoscale, little understanding of how size matters in device design, little understanding of bio-nano devices, and little comprehension of how one might use nanoscale phenomena to solve a particular problem. Students with these deficiencies cannot be expected to gravitate to NSE studies or to assume leadership roles in the NSE workforce.

2.2 Development of an NSE curriculum at WVU

2.2.1 NSE Minor

Establishing an NSE curriculum at WVU will help to address these deficiencies. Recognizing that training in a particular discipline is as important as training in interdisciplinary collaboration, this NSE curriculum was developed as an interdisciplinary minor area of study for students majoring in STEM disciplines. The minor is expected to attract a campus-wide spectrum of STEM students including science, engineering, pre-pharmacy, and pre-medical majors. After taking the freshman introductory course, students seeking the NSE minor will then choose from among several higher level courses with nanoscale content offered by departments across campus in order to complete the requirements of the minor and to prepare themselves for a senior capstone research experience, which will bring students together again in a multidisciplinary research experience. To promote a sense of community, students will receive credit toward the minor for attending a weekly NSE seminar during their undergraduate years.

The goal of this minor is to equip STEM students to enter the workforce with the skills and understanding needed to contribute to and to shape an NSE-based economy. This proposed minor will include (a) courses inside and outside the student’s major, (b) a continuous thread of seminar classes of increasing depth of inquiry that maintains student cohorts, and (c) an authentic capstone research experience bringing students back together as young scientists and engineers that are formed in their disciplines and are trained in interdisciplinary collaboration.

As part of the WVU curriculum development process, curriculum development efforts at Oregon State University, Pennsylvania State University, Texas A&M University, University of Cincinnati, University of Maryland, University of North Carolina at Chapel Hill, University of Northern Colorado, and University of Virginia at Charlottesville have been investigated. NSE minors have been established at the University of Maryland¹ and Pennsylvania State University.²

Like many of these efforts, the WVU collaborative approach to undergraduate NSE education includes perspectives from physical science, engineering, biomedical sciences as well as perspectives from education, philosophy, and women’s studies through strong intra-institutional research collaborations through WVNano. A multidisciplinary team of WVU faculty from WVNano, Chemistry, Physics, Biomedical Science/Basic Pharmaceutical Sciences, Engineering, Electrical Engineering, Philosophy, and Women’s Studies has been assembled to develop the
freshman introductory course and the subsequent nanoscale curriculum. The biomedical science perspective is valuable because of the nearly limitless promise of nanotechnology for human health and drug development, and because of the importance for physical scientists, biomedical scientists, and engineers to work together to solve biomedical problems that require a confluence of expertise. The education perspective is valuable because scientists and engineers often ignore proven pedagogies that would improve recruitment and retention in STEM disciplines. The philosophy perspective is valuable because of the need for engineers to clearly understand the potential social and ethical implications of the new technologies with which they design, enabling them to “design for acceptance.” The women’s studies perspective is valuable because of the desire and need to recruit and retain women and minorities to nanoscience and STEM careers.

2.2.2 Freshman NSE Course

At WVU, the freshman course is intended to serve as the portal to the interdisciplinary NSE minor. Rather than delaying nanoscale training until after students have begun a program of study within a particular discipline, one objective in developing a freshman NSE course is to pique interest in interdisciplinary nanoscale STEM careers by building in the students a genuine understanding of their potential as young professionals to contribute to finding design solutions of societal import through application of NSE. It is important to instill this understanding before students, especially women and underrepresented minorities, are steeped in a particular STEM discipline or choose not to pursue a STEM career. The intent is to recruit them while they’re young and malleable and to provide a positive interdisciplinary experience to which they may refer back during their undergraduate years. This will help students to develop an understanding and respect of the necessary role of other disciplines in collaboration with their own in advancing NSE discovery and innovation.

Specific objectives for the development of the freshman NSE course are:

1. To implement engaging inquiry-based pedagogies and hands-on laboratory explorations of nanoscale devices and systems.
2. To involve experts on campus, including award-winning teachers, to facilitate discussions and need-based design problems in their areas of expertise while maintaining continuity of presentation and assessment techniques.
3. To integrate social and ethical implications of nanotechnology into the pedagogy and to organize group activities proactively to engage women and underrepresented minorities.
4. To develop student skills in programming, technical writing, and oral presentation through meaningful term projects.

3.0 What is Nanotechnology?

A nanometer is one billionth of a meter, a measure so small that a human hair is 100,000 nanometers wide. Nanoscience is the study of the fundamental principles of molecules and structures with at least one dimension between 1 and 100 nanometers. Nanotechnology is the implementation of such nanostructures in useful devices.
Nanostructures are at the confluence of the smallest of human-made devices and the largest molecules of living things, and thus represent a magical point in the dimension scale, a point where many well-established laws of physics and chemistry break down. This breakdown supplies both the fascination and the challenge of nanotechnology, and motivates cutting-edge research efforts at WVU, Marshall University, and elsewhere.

Nanotechnology is one of the hottest topics of the new millennium; a quick Internet search identifies 15 million web pages containing this word. One reason is the enormous economic potential of nanotechnology (Sec. 2.0). A second reason is that nanotechnology poses tough social and ethical quandaries. For example, nanotechnology may offer the capability to sequence human DNA, thus exposing personality traits, disease susceptibilities, and tendencies to violence and chemical addictions. But, under what conditions should such information be made available to insurance companies, to potential employers, or to government agencies?

4.0 The Introduction to Nanotechnology Design Course

The Introduction to Nanotechnology Design course includes discussions of such economic, social and ethical issues. The course objectives are to enable students (a) to discuss the role of nanotechnology in current and emerging devices and systems, (b) to consider social implications for engineering design and critically discuss ethical issues related to nanotechnology, and (c) to appreciate the roles of scientists, engineers, and humanists in the process.

Specific course content begins with a basic introduction to nanoscale and some of the basic physics principles pre-requisite to understanding nanoscience. That introduction is followed by modules on devices, materials, and biomacromolecules.

Throughout the course, students work in teams for design projects, classroom discussions and laboratories. Teams involve students from different disciplines so students can learn to draw on diverse talents, skills and approaches to solve challenging problems. Each team will complete three design projects during the semester. Each team will prepare a Power Point presentation for one of the projects, a poster presentation for another, and a physical scale model plus a five-page paper for the remaining project. For each project, the societal need upon which the project is based must be stated, a nanoscale design solution must be described clearly, and the societal and ethical concerns that might affect design acceptance must be discussed.

After successfully completing this course, students will be able to (a) define nanoscale science and engineering, (b) discuss its enabling role in current and emerging devices and systems, (c) consider social implications for engineering design and critically discuss ethical issues related to nanotechnology, (d) appreciate the roles of scientists, engineers, and humanists in the process, (e) contribute to group problem solving efforts, (f) present results orally and in writing, (g) and use a computer as a tool for analysis, modeling, design, and communication.

A critical component of the success of the course is the ability for students to “see” at the nanoscale in hands-on laboratory experiments. Nanoscale and microscale experiments will be undertaken using state-of-the-art imaging equipment, including an atomic force microscope, due to generous support from the WVU Provost’s Office, the Eberly College of Arts and Sciences,

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the College of Engineering and Mineral Resources, the Departments of Physics and Chemistry, and benefactors Russell and Ruth Bolton.

For the pilot offering of the course in Spring 2007, ten students were selected based on their interest and previous academic success. Interested and highly qualified freshmen and sophomore students of science, engineering and mathematics were invited to apply to enroll in this pilot interdisciplinary introductory course. While the only pre-requisite is basic calculus (Math 150 or Math 155), students applied for the course by submitting a transcript copy and a short letter of interest including their academic major. Their transcripts and letters were reviewed carefully and the first class cohort was selected based on academic excellence with an emphasis on balancing majors and encouraging participation of women and minorities.

5.0 Relevance of the course to engineering education

Engineering majors at WVU generally have full course schedules. One way to fit the NSE minor in their schedules is to offer courses with nanoscale content as alternatives to required engineering courses. Engineering students are required to take two courses during their freshman year to introduce them to engineering as a discipline as well as to teach them essential problem solving, communication, and professional skills, ENGR 101 and ENGR 102. Recently, discipline-specific alternatives to ENGR 102 have been approved for advanced, highly motivated, and successful chemical, electrical and computer engineering students who meet the College requirements for early advancement into their discipline majors. By incorporating the required elements of problem solving, programming, technical writing, and oral presentation into the freshman NSE course, this pilot course was approved as an alternative to ENGR 102 for engineering students who meet certain academic criteria and have not yet declared a discipline major. While ENGR 102 gives students a taste for what it’s like to be an engineer, this course will give students a taste for what it’s like to be a nanoscale engineer or scientist working in an interdisciplinary environment. Also highly relevant to engineering education is the course’s emphasis on working in interdisciplinary teams, focus on societal need, and the completion of engineering design projects calculated to fill this need.

6.0 Encouraging Participation of Women and Underrepresented Minorities

A concerted effort is needed at WVU to recruit and retain women and underrepresented minorities in STEM disciplines, especially in engineering. Whereas WVU’s overall undergraduate enrollment is 46% female and 7% minorities (black, Asian, Hispanic, and Native American), its STEM and engineering enrollments include much smaller fractions of women, and the WVU enrollments of women and minorities fall short of national averages (NSF 04-317, WVU Division of Planning, see Table 3):

<table>
<thead>
<tr>
<th></th>
<th>Women STEM</th>
<th>Minority STEM</th>
<th>Women Engineers</th>
<th>Minority Engineers</th>
</tr>
</thead>
<tbody>
<tr>
<td>WVU</td>
<td>29%</td>
<td>6%</td>
<td>10%</td>
<td>6%</td>
</tr>
<tr>
<td>National</td>
<td>51%*</td>
<td>26%*</td>
<td>19%</td>
<td>27%</td>
</tr>
</tbody>
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*Bachelor’s degrees awarded

A first step to increase the underrepresented minority enrollment any STEM course is to actively
recruit students from a variety of backgrounds to the pilot freshman NSE course. Assistance in recruiting women and minorities was solicited from the WVU Department of Women’s Studies as well as from the WVU Center for Black Culture and the Health Sciences and Technology Academy (HSTA) program. In future recruiting efforts, additional assistance may be solicited from student chapters of professional engineering organizations, such as the Society for Women in Engineering (SWE) and the National Society of Black Engineers (NSBE), as well as from the WVU Native American Studies program and the WVU Center for Excellence in Disabilities.

Within the freshman NSE course, a two-fold plan is implemented to encourage participation of women and minorities. The first element is to proactively rotate the responsibility to represent each group among the members of the group in order to maximize participation by all group members and to avoid domination by a single member of the group. When a single student dominates group activities, others experience minimal growth and may lose confidence and interest.

The second element in this plan is to use pedagogies that link science content to social context, especially focusing on how the science can be applied to societal needs and can improve human lives. Pedagogies that focus on the social, ethical and economic implications of STEM concepts have been found to help women gain confidence in their scientific abilities and to gain interest in science overall. Jessup, Sumner, & Barker designed a computer science course that used design-based learning to provide an authentic learning context, to allow for collaborative assessment, to encourage knowledge sharing among students, and to humanize technology; their course attracted higher numbers of women students from outside the College of Engineering and Applied Science than computer science and engineering courses lacking this social context.

Smith College’s Picker Engineering Program, the first engineering program at an all-women’s college, links engineering with the humanities and social sciences.

The approach of integrating scientific content with its societal context by including social, ethical and economic implications of nanoscience and nanotechnology is believed to be particularly engaging for groups that are traditionally underrepresented in the STEM workforce. In addition to attracting members of underrepresented groups, this approach will improve science education for all students, by building on the 1996 National Science Education Standards in which “…science education is to give students a means to understand and act on personal and social issues…[and] give students a foundation on which to base decisions they will face as citizens.”

Figure 1 shows the members, both students and instructors, of the pilot offering of the Introduction to Nanotechnology Design course.
Figure 1: Students and faculty participating in the Spring 2007 pilot offering of *Introduction to Nanotechnology Design*, from left (photo taken on the first day of class, January 9, 2007): Greg McKelvey, Andrew Cullison, Cassie Cunningham, Robin Hensel, Phyllis Barnhart, Kyle Potts, Austin Anuta-Darling, Victoria Wheaton, Larry Horak, Mark Dodson, Jacob Fennick, Boyd Edwards, Doug Bowman, Joseph Duperre, Peter Gannett, Kasi Jackson, Josh Fernandez, Mikala Shremshock, and Lloyd Carroll.

Bibliographic Information


