Nanotechnology Undergraduate Certificate: A Novel Approach

Mansour Taherenzhadi[1], Penny Billman[2], Michael HajiSheikh[3], Promod Vohra[4]

[1] College of Engineering and Engineering Technology, NIU, USA
[2] Outreach, NIU, USA
[3] Department of Electrical Engineering, NIU, USA
[4] College of Engineering and Engineering Technology, NIU, USA

tahernez@ceet.niu.edu[1]

Abstract

This paper advances a new curriculum for establishing nanotechnology undergraduate certificate program. Utilizing an interdisciplinary team of faculty members from engineering, sciences, and business, the proposed curriculum demonstrates a problem based pedagogical approach to increase content retention for undergraduate students in STEM areas. The certificate program features a total of 5 courses for a total of 9 credit hours. Special emphasis is placed on device aspects of nanotechnology with focus on biological nano-self assembly, nano-sensors, marketing, health and ethics aspects of nanoscale engineering.

Introduction

According to the Woodrow Wilson Center [2], more than 200 nano products are on the market, with the U.S. taking the lead in 126 products, followed by East Asia and Europe having 42 and 35 nano products, respectively. As a result, it is becoming increasingly clear that nanotechnology will continue to revolutionize manufacturing industries and contribute enormously to the dynamic, competitive global economy.

To prepare undergraduate students for this nano-driven, global competition, universities must offer their students a curriculum that builds an interdisciplinary understanding of engineering and science, including the first-hand view of the collaboration among engineers and scientists in disciplines such as biology, chemistry, and physics [1].

In addition, the role of business cannot be ignored. Emerging technology is effective only if it can find a willing market. Businesses that can bridge the gap between the creation of a new product and the sale of that product will be competitive. The university graduates entering the workplace need to understand patenting and the business/societal aspects of their work.

This project answers the calls to overhaul engineering education [3]-[5]. Consequently, in recent years, emphasis on team-based, problem-based projects has increased substantially. This is best evidenced from the Engineering Criteria 2000 (EC2000) of the Accreditation Board for Engineering and Engineering Technology (ABET) [5], which places special significance on (i) insightful team design projects and (ii) experiences in learning and practicing project proposing, planning, and control.

The capstone modules in this project will provide students with interdisciplinary experiences on projects using nanotechnology in applied, hands-on projects. The four capstone modules, though independent, complement each other and build the skills of the students. It is envisioned that as students progress through the courses, they will feel part of a community of learning with their fellow students and professors.

Engineering By Design

An Understanding by Design [6] approach is being used to coordinate the four courses and to infuse strands from the various discipline content areas. For each course, the desired student learning outcomes were identified in relation to the knowledge and skills students could demonstrate at the completion of the course. From this, the curriculum was designed and connected in a cohesive manner. Throughout the design phase, the focus was on getting students to

learn through higher levels of thinking.

The capstone modules will present students with problem-based projects—ones that are complex and ill-formed, like authentic problems faced by an engineer or scientist. As students work towards the solutions, a team-based, collaborative approach will be used [7].

A review of the research on the effectiveness of problem-based learning [7] concluded that students improve their research capabilities and that retention and transfer of content to new situations is enhanced as students learn to work collaboratively and communicate clearly—all skills needed by the engineer. Perhaps the most critical finding on the research on problem-based learning is that students learn that arriving at solutions require crossing the discipline boundaries: "problem-based instruction highlights interconnections between disciplines and the integration of concepts" [7, p. 7].

In addition to being problem-based, the modules will combine collaborative learning and team-building models of instruction. Collaborative learning is most effective when planned and used strategically to engage students in their learning [8]. As students engage in these interactions, faculty members can help them develop the team skills needed in the workplace.

In summary, the modules will use a hands-on, problem-based approach in which students work collaboratively on authentic projects that require the integration of various discipline areas.

Recruitment and Retention of Students

A major focus of this project is to increase the numbers of students, especially from under-represented groups, who elect to take the nanotechnology certificate and pursue engineering.
The capstone modules and the videos of their implementation will be used to help retain students in the program. The high-interest projects will engage students in authentic learning situations during their first two years of college and should help them better understand the multi-faceted role of the engineer. As a recruiting tool, clips of the videos showing students engaged in the projects will help high school students envision themselves in such projects, too. Combined with the retention activities, the project could be effective in recruiting and retaining students, especially the female, African American, and Hispanic students [9, 10, 11].

Proposed Courses and Nanotechnology Modules

This section provides a brief background on the certificate that builds on three current courses and includes one new course. Each of the courses will end with a capstone module. Even though the courses are designated as engineering, they are applicable to all science majors, thus strengthening the connection among the sciences and engineering. The content presented below was identified in previous meetings among the engineering, science, and business faculty members.

The first three courses (UEET 101, 102, and 103) are one-credit hour courses at the freshman level (UEET 101 and 102) and sophomore level (UEET 103). The new 3-credit hour course is at the sophomore level. The capstone project builds on the integration of the content in the course.

Course 1: UEET-101- Freshman Level

This course lays the foundation for the certificate and is at an introductory level.

First Course: UEET 101				
	Chemistry	**Physics**	**Mechanical Engineering**	**Marketing & Society**
Focus and Content	A concept development approach is used. Content covers atoms, the building blocks; size of atoms and why "nano"; bonds between atoms; and diversity of materials.	Content includes origins of quantum mechanics and quantum physics and their interaction with the modern world.	Content includes nano-materials, nano-mechanics, nano-heat transfer, nano-fluids, and simple test systems to measure the effect of nanoparticles on the thermal conductivity of suspended nanoparticles.	Content covers the understanding of marketing's role in organizations, including the creation of value in the marketplace and the realization that product, price, place of distribution and promotional strategies must all be in accord with the corporate mission.

Possible Capstone Project for UEET 101

The capstone project for the first class could investigate the effects of carbon nanotubes on the strength of sporting equipment and the importance of carbon nanotubes in the future of sporting equipment. For example, students would look at the strength of materials, mechanics of motion, and the chemistry of the connecting fibers. For the marketing component, students would explore whether the nano-features help in the marketing strategies; e.g., does "nano" help sell the product.

Course 2: UEET 102 – Freshman Level

The topics covered in the second course were chosen to complement the more basic topics in the first freshman class. The geology and biology strands are integrated. Biological structures have been called the ultimate nanomachines [12] because they have very similar analogs in the macro-machine world. These structures are motors, valves, pumps, and medicine delivery devices. The advent of transgenic crops [13] put the concept of nano-manipulation of biologic specimens front and center in the popular press.

Students will understand the potential health implications of nanotechnology. When any material/product has health implications, there will be ethical issues that arise relative to disclosure, marketing, and consumer safety. While benefits of nanotechnology are widely publicized, the discussions of the potential health effects are just beginning. Particles in the nano-size range can enter the human body via the lungs and the intestines. Some can enter through the skin and even penetrate deep into the dermis or further. An increased risk of cardiopulmonary diseases has been implicated with exposure to nanoparticles. After nanoparticles enter the body, the distribution of the particles in the body and potential health effects appear to be a function of the surface characteristics of the particles. The presence of the contaminants, such as metal catalysts present in nanotubes, and their role in the observed health effects will be considered along with the health effects of the nanomaterials. Nanoparticles designed for drug delivery or food components are also addressed. Rice University's ICON EHS database (International Council on Nanotechnology Environmental Health and Safety) will be used in this course.

Finally, the ethics and social responsibility of a business is addressed along with marketing strategy (including new product development), how consumers formulate buying decisions, how businesses sell to businesses, and global marketing trends that make up the marketing environment.

Second Course – UEET 102				
	Geology	**Biology**	**Engineering**	**Marketing & Society**
Focus and Content	Introduces students to the concept of biological specimens as nanostructures. Discusses the tools and materials used to produce and manipulate biological nanostructures.		Discuss potential health issues, types of exposures, how to monitor exposures, medical surveillance, exposure control methods, and nano-ethics.	Discuss how a firm formulates ethically responsible decisions given all of the micro and macro forces that influence an organization.

The capstone project for the second course involves the disinfecting properties of nano-particles. Nanoparticles have been used as a way to kill bacteria and molds for odor control. This module will require students to compare and contrast the disinfecting properties of various materials. Various organisms will be grown in Petri dishes and the students will test the various nano-particles. The marketing aspect involves the use of nano-particles in clothing to prevent odors and related safety and ethical concerns.

Course 3: UEET 103 Sophomore Level

Building on the previous courses, the chemistry section has students conduct a lab study on the synthesized sol-gel block. First, UV-Vis spectrum of the material will be taken and changes of the spectrum, as function of acidity, will be followed to help students learn how their synthesized material was useful as an acidity - pH - sensor. Follow-up instruction will address the principles of UV-Vis spectroscopy and principles of the instrumentation. Tearing down of a laboratory spectrometer will be the final step. To remove any mystery about these turn-key instruments, a simple laboratory spectrometer will be used and then disassembled and reassembled.

In the physics section, students learn how the materials have important implications with respect to memory devices and magnetic field sensors. Crystalline magnetic structures have preferred growth domains and can be investigated using x-ray analysis and SQUID (superconducting quantum interference device) measurements. Students will get direct exposure to modern measurement techniques.
The electrical engineering section will explore how nano-materials can be used to sense chemical and biological hazards and to create passive electrical components that have been tailored for specific properties.

Third Course – UEET 103				
	Chemistry	**Physics**	**Electrical Engineering**	**Marketing & Society**
Focus and Content	Focus is on synthesis of a sample of a nano-structured material: sol-gel polymer doped with metal.	Introduction of basic concepts of materials science and solid state physics, including the magnetic behavior of multilayer films and patterned magnetic nanostructures.	Explore concepts of nanoscale electronics and the use of nano-materials as sensing elements.	Look at how firms create value through new product evelopment and use service-blueprinting - a process of setting technological requirements for a service setting.

Possible Capstone Project for UEET 103
The capstone module for the third course leverages the expertise NIU faculty members have gained through a project with Argonne National Labs. Students will explore the effects of nano-fluids by comparing the effects of nano-fluids with coolants and nano-fluids without coolants. Can you improve the lubricant and thermo-conduction properties of the fluid? What would a service blueprint be for such a product?

Course 4: New Sophomore-Level Course

The 3-credit hour course will be a series of experiments building on the previous courses but concentrating on nano-sensors. The first experiment is the construction and measurement of an anodic nanoporous alumina (AAO) based capacitive humidity sensor [14]. This basic sensor has been demonstrated by Dr. Haji-Sheikh [14] and is relatively simple to set up as an experiment.

The second experiment is focused on the effect of nano-particles. The largest volume of nanoparticles used presently is the ZnO particles, used primarily as a sun-blocking additive. Students will compare the micro-particle ZnO versus the nano-particle ZnO. This will allow the students to explore the physics that causes the microparticles to be opaque and the nano-particles to be transparent to visible light. The discussion of nanoparticles will allow for the introduction the health and safety components with special consideration towards homeland security issues.

The third experiment will demonstrate the concept of self assembly by presenting biological self assembly in the shape of diatoms. As an example, the structural elements of diatoms have long provided engineers and architects inspiration for innovative design for strength/weight ratios, as well as aesthetics, but the recognition that natural nanomaterials can be used in nanotechnology is a new but rapidly growing concept [15]-[17]. Current applications and an exploration of the potential of diatoms in diverse branches of nanoscience research were the subject of a special issue of the Journal of Nanoscience and Nanotechnology (Volume 5, Number 1, January 2005). New venues, however, are needed to explore non-conventional interdisciplinary synergies between the fields of diatom biology and nanotechnology. The laboratory will consist of the exploration of the structures of diatoms using scanning electron microscopy and the characterizations of these structures. This will allow for students to investigate the properties of self assembling biological structures.

The fourth experiment will study the effects of the nanomaterials in the local environment. Clay is a rock term indicating typically a fine-grained mineral which is relatively plastic at high-water contents and hardens when dried. The clay mineral subgroup within James D. Dana's phyllosilicate classification of minerals is defined structurally by the presence of water trapped between silicate sheets. These minerals possess numerous physical and chemical characteristics, such as sub-microscopic crystals, expansion with increasing water content, plasticity at high-water contents and remarkable adsorption ability, which delineate the group relative to other silicate minerals. Whereas the absorptivity of clay minerals is known generally, the mechanism, variability, and extent of adsorption within the clay mineral group has not been well documented. This material exhibits natural self assembly as it aligns during its drying.

Advances in nanotechnology, such as those in high-resolution transmission electron microscopy, extended X-ray absorption fine structure, and AFM, over the last two decades have made possible analyses of the local atomic structure of submicroscopic minerals [18]-[19]. These advances have also provided much needed data for models detailing clay adsorption [20]-[21].

Students will look at how marketers conduct exploratory, experimental, and descriptive research initiatives for new product, service creation and modification, and obtain a secondary data analysis regarding a new product or service that encompasses nanotechnology. Students will review marketing plans that assess current marketing situation; strength, weakness, opportunity, threat situations; target market analysis; pricing; distribution strategy; promotion strategy; and five year financial budget and controls.

Possible Capstone Project for Fourth Course

The final capstone project will explore the concept of nanomaterials used as a sensing media. The class will build a nanoporous humidity sensor and then use the sensor in a basic circuit to measure the drying effect of nanoparticulate clay materials. The patent process will be outlined and a marketing plan designed for the commercialization of the sensor and/or clay materials.

References

01. Rocco, M.C. & Bainbridge, W.S. (Eds), 2002, "Converging Technology for Improving Human Performance: Nanotechnology, Biotechnology, Information Technology and Cognitive Science, Arlington, VA: NSF/DOC. http://www.grenoble.inra.fr/site/Nano/document/report/convergingNSF.pdf
02. Woodrow Wilson International Center for Scholars (2008). New Nanotechnology Consumer Products Inventory. http://www.wilsoncenter.org/index.cfm?topic_id=166192&fuseaction=topics.item&news_id=173868
03. Coward, H.R., Ailes,C.P. & Bardon, R. (2000). Progress of the Engineering Education Coalitions, Arlington VA: SRI, Int., Engineering Education Centers Division, NSF.
04. Meyers, C.W. (1995). Restructuring Engineering Education: A Focus on Change, Arlington, VA: NSF Workshop Engineering Education.
05. ABET (2000). Criterion for Accrediting Engineering Programs, Baltimore, MD: ABET.
06. Wiggins, G., & McTighe, J. (1998). Understanding by Design. Alexandria, VA: Association for Supervision and Curriculum Development.
07. Duch,B.J., Groh, S.E., & Allen, D.E. (2001). The Power of Problem-Based Learning. Sterling, VA: Stylus Publishing.
08. Barkley, K., Cross, P., & Major, C.H. (2004). Collaborative Learning Techniques: A Handbook for College Faculty, San Francisco, CA: Jossey-Bass.
09. National Academy of Sciences (2006). Beyond bias and Barriers: Fulfilling the Potential of Women in Academic Science and Engineering. Washington, DC: Author.
10. National Research Council (2006). Multiple Origins, Uncertain Destinies: Hispanics and the American Future. Panel on Hispanics in the United States. M. Tienda and F. Mitchell, eds. Washington, DC: The National Academies Press.
11. Kao,G. & Tienda, M. (1998). Educational Aspirations of Minority Youth. American Journal of Education, 106, 349-384.
12. Goodsell, D. "Biomolecules and Nanotechnology," American Scientist, 88:3, p. 230.
13. Marvier,M. "Ecology of Transgenic Crops," American Scientist, 89: 2, p.160.
14. Haji-Sheikh, M.J, Ervin,J. & Andersen,M (2004). "Anodic Nano-Porous Humidity Sensing Thin Films for Commercial and Industrial Applications", IEEE IAS Meeting, October 4-7, 2004.
15. Gordon,R.,Sterrenburg, F. and Sandhage, K. Special Issue on Diatom Nanotechnology. Journal of Nanoscience and Nanotechnology, 5:1, 2005, pp. 1-4.
16. Scherer,R., Sjunneskog, C., Iverson, N., Hooyer, T. (2005). "Frustules to Fragments, Diatoms to Dust: How Degradation of Microfossil Shape and Microstructures Can Teach Us How Ice Sheets Work," Journal of Nanoscience and Nanotechnology, 5:1, pp. 96-99.
17. Scherer,R., Sjunneskog, C., Iverson, N., Hooyer, T. (2004), "An index of diatom fragmentation from sub-glacial compaction and shearing," Geology, 32, pp. 557-560.
18. Cruz-Guzman, M., Celis,R., Hermosin,M.C., Koskinen,W.C., Nater, E.A., Cornejo,J. (2006). "Heavy metal adsorption by montmorillonites modified with natural organic cations," Soil Science Society of America Journal, 70:1,pp. 215-221.
19. Kogure, T. (2004). "Nano-scale structure analysis of phyllosilicates by electron microscopy. Translated: Spatial distribution of claysphere and analysis methods," Journal of the Clay Science Society of Japan, 43:3, pp. 129-136.
20. Peacock,C.L. & Sherman,D.M. (2005). "Surface complexation model for multisite adsorption of copper(II) onto kaolinite," Geochimica et Cosmochimica Acta, 69:15, pp. 3733-3745.
21. Pieper,H., Bosbach,D., Panak,P.J., Rabung,T., Fanghaenel,T. (2006). "Eu(III) coprecipitation with the trioctahedral clay mineral, hectorite," Clays and Clay Minerals, 54:1, pp. 45-53.