

AC 2008-541: SUSTAINABLE NANOTECHNOLOGY EDUCATION FOR ENGINEERS

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Sustainable Nanotechnology Education for Engineers

Abstract

Nanotechnology is defined as the understanding and control of materials at dimensions of roughly 1 to 100 nanometers. Because of their unique size-tunable properties (e.g., the quantum size effects) and large surface areas, nanomaterials present vastly different properties from those of bulk materials. While nanotechnology has great potential for beneficial environmental uses, the explosion of nanotechnology-enhanced products raises concerns regarding the adverse effects of nanoparticles on human health and the environment.

The current engineering curriculum at the University of Missouri (MU), like the major of the 300 accredited engineering colleges in the U.S., lacks a sustainability component. The Accreditation Board for Engineering and Technology (ABET) 2000 criteria, however, requires that all engineering students develop an understanding of the impact of engineering solutions in a sustainable global context, as well as have “an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.” Undergraduate engineering students will face these significant challenges and their education and training must adapt in order to adequately prepare the next generation of engineers for these new realities.

Engineering faculty at MU started to develop an sustainable nanotechnology program for undergraduate students. We are developing a new course and laboratory modules through environmental nanotechnology research to integrate them into the existing engineering curriculum. Research activities related to sustainable nanotechnology and challenges in sustainable engineering education were discussed. By integrating the sustainable nanotechnology research into the undergraduate curriculum, students will develop an understanding of the impact of engineering solutions in a sustainable global context. The proposed activities will help achieve our long-term goals to for training new generation of engineers.

In modern society, sustainable development is a universal theme of humanity's future. Sustainable development encompasses three general areas: economic, environmental and social. In essence, we need to find the right balance between economic development, the benefit of society and concern for the environment, together with a notion of intergenerational equity.

The United Nations Commission on Sustainable Development promotes technical cooperation and capacity building to integrate the social, economic and environmental dimensions of sustainable development in policy-making. In the United States, the National Academies, which include the National Academy of Engineering, the National Academy of Sciences, the Institute of Medicine, and the National Research Council, have established a Science and Technology for Sustainability Program to encourage the use of science and technology to achieve long term sustainable development- increasing incomes, improving public health, and sustaining critical natural systems. The Accreditation Board for Engineering and Technology, one of the most respected accreditation organizations in the U.S., has provided leadership and quality assurance in engineering education for over 70 years. Its new criteria for the evaluation of engineering programs, *Engineering Criteria 2000*, require implementation of sustainability concepts in undergraduate education, as reflected in the following areas (criteria 3c and 3h) ⁽¹⁾:

- “Ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability;”
- “Broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context.”

Limited work has been conducted to address the need, effectiveness, and impact of incorporating sustainable engineering concepts in undergraduate engineering education. An integral model of education for “Peace, Democracy and Sustainable Development” was recently proposed to address the need as required by ABET ⁽²⁾. Peace was the key element of the model, where educators should promote the pursuit of peace in engineering education through being at peace with oneself, others, and the planet. Principles of green engineering are also important in engineering education ⁽³⁾, as engineers of future generations will use sustainable technology, benign manufacturing processes and an array of environmental assessment tools in their future professional careers. Because of interwoven relations of sustainable development and engineering ethics, some educators suggested to incorporate environmental ethics as part of sustainable education into the undergraduate engineering curriculum ⁽⁴⁾. Overall, educators believe that education for the engineer of the 21st century must include a critical component of sustainable development in modern engineering curriculum ⁽⁵⁾.

In response to the ABET 2000 criteria, several universities in the U. S. have launched programs to incorporate sustainable/green engineering principles into the engineering curriculum. For example, Carnegie Mellon University, the University of Texas at Austin, and Arizona State University established the NSF and USEPA sponsored Center for Sustainable Engineering in 2005 to enhance undergraduate education in sustainable engineering. This Center is developing peer-reviewed educational materials on sustainable engineering. The University of Texas at El Paso has developed a similar teaching and learning program by introducing sustainable engineering concepts in the teaching of specific existing courses ⁽⁶⁾. Their educators are also developing a sustainable engineering certification program. Michigan Technological University has issued an “International Sustainable Engineering Initiative” to promote international sustainable development engineering by nurturing and educating undergraduate students ⁽⁷⁾. Virginia Tech has also implemented a green engineering program to offer courses devoted to or

containing significant green engineering content, and the engineering students begin considering environmental impact from the very start in the mandatory engineering introduction courses.

Educators at MU also have a clear vision of sustainable engineering in undergraduate education. Our mission is to educate engineers, create leaders, and develop entrepreneurs in a research and interdisciplinary environment. The university has strong sustainable agriculture and sustainable/green building programs. As part of our continuous efforts in sustainable engineering, a symposium was held by the Multiscale Environmental Research Center for Sustainable Development at UMC in the summer of 2006, with keynote speakers including Professor Jerald L. Schnoor, Editor-in-Chief of *Environmental Science & Technology*, poster sessions and a panel discussion.

Engineers have a key role to play in the search for sustainable technologies that will solve the environmental woes plaguing today's society. Sustainable engineering programs ignite student imaginations while encouraging them to pursue innovation in their professional services; America's competitiveness in the global economy will heavily depend upon the innovation in the undergraduate engineering education to integrate global sustainability in engineering curriculum, which would likely to improve the quality of education in the following ways:

- It makes sustainable topics more real through a series of module presentations.
- Students make valid contributions to scientific research involving questions and data-driven hypotheses, and their notion of sustainable engineering expands via hands-on learning experiences.
- Students are able to function on multi-disciplinary teams (ABET criterion 3d) by using sustainable technologies across curriculum area, integrating many engineering subjects.
- It offers many opportunities for effective communication (ABET criterion 3g) among students and between instructors and students, as well as opportunities for assessing how well students understand the sustainable concepts.

Whereas sustainable engineering initiatives can provide an avenue for improving student learning and performance to meet ABET 2000 criteria, there are a few challenges for implementing sustainable engineering concepts in undergraduate education. One of the challenges is the strong resistance of change via engineering education reform to embedding additional requirements in the ABET criteria. The resistance comes without surprise as the development of new programs is often viewed as disruptive educational product innovation⁽³⁾. Lack of the learning materials including good textbooks, laboratory manuals, and qualified educators in sustainable engineering is another current and critical issue.

To address these challenges, we started to develop specific new learning materials to integrate sustainable engineering into the existing undergraduate engineering curriculum with minimum disruptive impact. Our strategies were to: (1) develop and sustain a research-supportive curriculum by introducing rigorous, hands-on lab sections of the courses, and (2) to integrate learning materials in current introductory courses.

To develop and sustain a research-supportive curriculum, emphasis was placed on team-based efforts and the integration of research and education. By collecting and disseminating multiple

examples of undergraduate research projects, we can promote learning through research and improve the quality of learning via training our students in more creative and meaningful ways. A few of the environmental nanotechnology research modules were developed for undergraduate education.

Module 1: Respirometric measurement of aerobic microbial growth

This laboratory module aims to measure aerobic microbial growth in the presence and absence of nanoparticles using well-developed extant respirometry⁽¹¹⁾. Maximum specific substrate

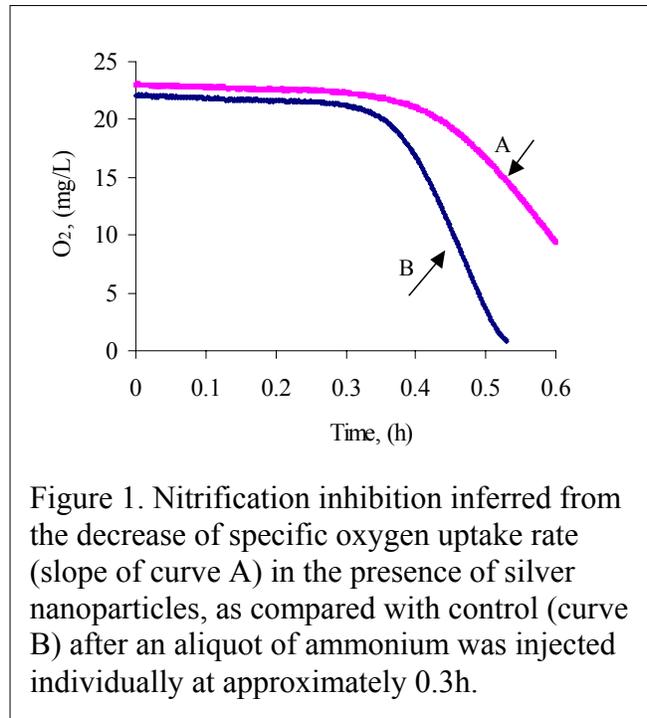


Figure 1. Nitrification inhibition inferred from the decrease of specific oxygen uptake rate (slope of curve A) in the presence of silver nanoparticles, as compared with control (curve B) after an aliquot of ammonium was injected individually at approximately 0.3h.

oxidation rates are measured to determine the microbial growth inhibition by nanoparticles. The assay is performed at a pH of 7.5 in replicate 50-mL respirometric glass vessels, maintained at 25°C. Biomass suspensions collected from wastewater treatment plants or laboratory nitrifying bioreactors are aerated with pure oxygen gas before aliquots of nanoparticles and substrate (e.g., glucose, NH₄⁺-N) are injected into the vessels. A decrease in the dissolved oxygen (DO) level in the vessel due to substrate oxidation will be recorded (Figure 1). Microbial kinetics (e.g., specific growth rate and half-saturation constant) can be determined through data fitting^(12, 13). At the completion of the laboratory work, students will understand how the organic matter or ammonia is stoichiometrically converted to biomass in the presence of

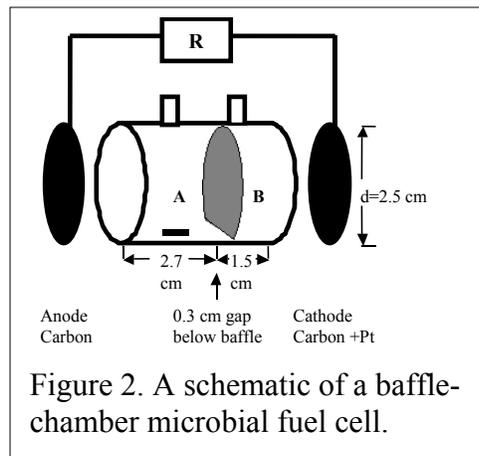
nanoparticles and the importance of aeration in wastewater treatment processes.

Module 2: Electrochemical monitoring of anaerobic microbial growth

This laboratory module aims to measure anaerobic microbial growth in the presence and absence of nanoparticles using baffle-chamber microbial fuel cells⁽¹⁴⁾. Microbial fuel cells (MFCs) for organic waste and wastewater treatment represent innovative and sustainable technologies by converting the chemical energy of organic wastes directly into electric energy⁽¹⁵⁻¹⁸⁾. In MFCs, bacteria oxidize organic contaminants in an anaerobic anode chamber, and transfer the electrons through an external circuit; the electrons are typically harvested in an aerobic cathode chamber, where electrons, oxygen and protons are combined to produce water. Wastewater containing a high amount of organic matter can be used for electricity production to compensate the operating costs.

Students will collect wastewater samples amended with selected nanoparticles (e.g., Ag). The microbial fuel cells are based on the prototype membrane-free, single chamber MFCs with an open air-cathode described by Liu and Logan⁽¹⁶⁾. We have modified the system by including a plastic baffle to allow fluid mixing in the anode chamber exclusively so that oxygen diffusion

adjacent to the cathode surface can be minimized and electron transfer efficiency improved (Figure 2) ⁽¹⁴⁾. Anaerobic digested sludge will be added to further improve the efficiency ⁽¹⁴⁾. The



The anode is made of carbon paper, while the cathode is similar to the anode in size but is a gas diffusion electrode containing 0.5 mg/cm² of Pt (E-TEK, NJ, USA). Room air in contact with the cathode provides the O₂ used as the electron acceptor. Sampling ports are provided at the top of each chamber and sealed with rubber stoppers during operation. Within a few weeks of inoculation, thick biofilms will form on both anode and cathode. Copper sheets and wires are used to connect the circuit (100 Ω resistor or less), and its voltage will be measured and recorded at 0.01 Hz using LabView™ V 8.2 (National Instruments, Texas). The effect of nanoparticles on electricity production can be determined

and evaluated. At the completion of this lab module, students will gain hands-on experience and knowledge of electrochemistry, microbiology, and process engineering to help apply the principles of sustainability in their professional careers.

Prior class surveys of engineering students about environmental sustainability indicate that most of the students (75%, n = 34) embrace the concept of sustainable development, which focuses on fulfilling present needs without compromising the opportunities available to future generations. When asked how to implement sustainable concepts into their professional services in the future, many students do not know the answers and would appreciate any meaningful and hands-on work in their undergraduate education and training.

One of the meaningful and sustainability-oriented work to be conducted by the students in the laboratory is through real-time data acquisition and process monitoring. For example, the author has introduced microbial growth and activity testing using extant respirometry (Figure 1) to determine the degree of nutrient removal from wastewater in undergraduate research training with great success. Students appreciated such type of real-time monitoring and quality learning. One of the students (Jocelyn Michelini, now stationed in North Dakota Air Base) joined the U.S. Air Force's Bioenvironmental Engineering program soon after her undergraduate engineering training with the author.

To integrate new learning materials such as developed laboratory models in curriculum, an introductory environmental and nanotechnology course *Introduction to Environmental Nanotechnology is being* developed for senior undergraduates and graduate students. The topics cover concepts of nano/bio technologies ⁽⁸⁻¹⁰⁾, their environmental applications and environmental risk assessment of nanomaterials.

The College of Engineering at MU is addressing ABET 2000 requirements and deficiencies in meeting the criteria of sustainability in undergraduate engineering education. At a time when undergraduate engineering enrollments were on the decline nationally, the College grew its undergraduate enrollment, with an increase of 39 percent over the past seven years. Undergraduate enrollment has been increasing concurrently in the Department of Civil and

Environmental Engineering, partially attributed to our continuous efforts in improving undergraduate curriculum and providing cutting-edge research opportunities for the students. With the cooperation of the engineering faculty and students, we believe our effort will attract engineering students including those who are not already highly motivated and skilled, to develop a meaningful understanding and appreciation of their field. This way, more students will be attracted to science and engineering careers, while no additional degree credit-hour requirements are necessary.

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