Incorporation of Nanotechnology into the ChE Curriculum at Oregon State University

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Introduction

With the substantial investment into the development of nanotechnology infrastructure for the 21st century and beyond, there is a need to adapt engineering and science curricula to equip students with the skills and attributes needed to contribute effectively in manufacturing based processes that rely on nanotechnology.[1-3] The incorporation of nanotechnology into the undergraduate engineering curriculum represents both an opportunity and a challenge. On the one hand, nanotechnology can revitalize undergraduate programs by engaging students with interesting nanotechnology related concepts, examples, and experiments. On the other hand, due to its inherent interdisciplinary nature, programs will need to accommodate greater degrees of interdisciplinary teaching and research. Chemical and biological processes will play a significant role in the manufacturing operations. Chemical and biological engineers have the advantage of a solid background in chemical kinetics, reactor design, transport phenomena, thermodynamics and process control to undertake the challenges in the high volume manufacturing of nanotechnology-based products. Thus, these processes fall well within the purview of chemical and biological engineering undergraduate programs. However, at the same time, the products rely on principles based on other disciplines such as physics, mechanical engineering and electrical engineering. Thus research and development of new processes based on new products is inherently interdisciplinary in nature. The curricular challenge that needs to be addressed is how to design a program that reinforces the ChE undergraduate's core skills (Depth) in a way that can be applied towards manufacturing nanotechnology-based products while simultaneously providing the Breadth to interact effectively on the multidisciplinary teams which span the wide range of opportunities enabled by this emerging area.

It has been proposed that as the chemical engineering profession takes its next evolutionary step towards applying molecular scale engineering to a set of new and emerging technologies, the core undergraduate curriculum needs associated reform.[4] However, as topics from these emerging molecular-based technologies are incorporated, there is a legitimate concern of dilution of the core content due to staffing issues.[5] At OSU, the Chemical, Biological and Environmental Engineering programs have recently joined into a single administrative structure. This structure alleviates the staffing issue in two ways. First, a significant portion of the courses for all three programs are jointly taught. This set of eleven core courses covers fundamentals germane to all three disciplines (e.g., material and energy balances, transport processes, thermodynamics and process data analysis) while reducing the number of instructors needed. Second, the Option areas in chemical engineering are taken from topics that have core research faculty. In two of the Options, biological processes and environmental processes, students take elective classes from amongst those offered by the other programs. In this way, some of the key elements identified in the "New Frontiers in Chemical Engineering Education" workshops are integrated into the undergraduate curriculum while, simultaneously, holding students accountable for the same depth of learning which has served OSU ChE graduates for many years. Moreover, this integration is accomplished in a reasonable scope commensurate with the resources of the program.

This paper presents the curriculum developed to incorporate nanotechnology education in the College of Engineering (CoE) at Oregon State University OSU. The approach is twofold: (1) to develop a Nanotechnology Processes Option in the Chemical Engineering (ChE) Program and (2) to develop a survey course within the CoE that is broadly available to all engineering undergraduates. The curricular development fits in well with the growing research and commercialization activity of the Oregon Nanoscience and Microtechnologies Institute (ONAMI), and is consistent with the evolutionary vision developed by leading chemical engineering educators in the three-workshop series "New Frontiers in Chemical Engineering Education."[4]

Nanotechnology Processes Option in Chemical Engineering

To meet all the ABET engineering topics and advanced science requirements, ChE students are required to take five to six technical elective classes outside the ChE core. These courses may be taken in any area as long as they have the appropriate engineering or science content as prescribed by ABET and AIChE. However, taken in an *ad hoc* manner, students were getting little satisfaction or career enhancement. The ChE Department has established Options to aid students in selection of elective courses. This also helps to broaden and strengthen the undergraduate ChE curriculum, potentially attracting more students to the department. To be eligible for an Option, the student must fill out and present a Student Petition for Option Program in Chemical Engineering to the faculty "champion" for the desired area. The champion is a faculty member with expertise in the area of the Option. Additionally an Option must contain at least 21 credits. Three options have been available at OSU: (1) Biochemical Processes; (2) Environmental Processes and (3) Microelectronics Processes and Materials Science. These areas correspond to strengths in the OSU ChE program. A fourth option, the Nanotechnology Processes Option, has been developed. An outline of the curricular requirements is listed in Table 1. It contains six courses, five required courses and an elective, including two sophomore level courses. Four of the five required classes are laboratory-based and emphasize hands-on experience. The Nanotechnology Processes Option was approved at the university level in Fall 2006. In Fall 2008, there were 10 seniors and 12 juniors who have selected this option.

The Science, Engineering and Social Impact of Nanotechnology (ENGR 221) is a general engineering survey course that provides students from Chemical, Biological, Electrical, Environmental, Industrial, Manufacturing and Mechanical Engineering exposure to the field of nanotechnology; therefore, there is inherently a multidisciplinary approach. On the other hand, Material and Energy Balances in Nanotechnology (ChE 214) is a ChE specific laboratory-based course, emphasizing how the fundamental skills students have learned couple to nanotechnology. For ChE students, the approach is to provide students both a breadth of multidisciplinary experiences and a depth of specific technical applications within the discipline. Thus,

TABLE 1. Nanotechnology Processes Option

Class#	Credits	Title
ENGR 221	3	The Science, Engineering and Social Impact of Nanotechnology (lec)
ChE 214	4	Material and Energy Balances in Nanotechnology (lec/lab)
ChE 416	3	Chemical Engineering Lab III (lab)*
ChE 417	4	Analytical Instrumentation in Chemical, Environmental and Biological Engineering (lec/lab)
ChE 444	4	Thin Film Materials Processing (lec/lab)
	3	Elective

* The capstone laboratory project will be in the area of nanotechnology

they are exposed to these complementary experiences early in their undergraduate studies. These sophomore level courses lead into three upper division courses already in place. This duality (Breadth plus Depth Pedagogy) is reinforced in senior laboratory (ChE 416), through which students synthesize both aspects in their capstone project, and potentially through their Honors College thesis.

ENGR 221 - The Science, Engineering and Social Impact of Nanotechnology

ENGR 221 is a general engineering survey course with the objective of ensuring all engineering students have access to a course offering basic understanding of the engineering field of nanotechnology. The course learning outcomes are presented in Figure 1 below. The concepts of nanotechnology have been divided in several sections, with each one spanning roughly one to two weeks. The course includes several features intended to promote active learning including hands-on activities and demonstrations and a capstone ethics project where students complete a risk assessment of the impact of nanotechnology on society. In addition to introducing technical knowledge surrounding the field of nanotechnology, this course focuses on synthesizing fundamental concepts in science and engineering within the context of nanotechnology.

ENGR 221 was delivered for the first time in winter 2007 with an enrollment of 31, and again in winter 2008 with an enrollment of 45. The success of the course was assessed in terms of the achievement of these learning objectives and the effectiveness of the different modes of delivery used during the course. Assessment methods for this course primarily relied on pre and post assessments of one kind or another. Overall course pre and post concept inventory assessments were administered, in addition to pre and post worksheets for two class activities. The other major methods of assessment of student learning were an end of term survey and an analysis of critical thinking of the final ethics paper.

The course was assessed in terms of both achievement of learning objectives and modes of delivery such as lecture, lab, or projects. The following assessment methods were used:

- Overall course pre and post concept inventory assessments
- End of the term survey
- Pre and post worksheets for a lecture
- Wise learning tool
- Pre and post worksheets for a hands-on laboratory activity
- Final ethics project analysis

The detailed assessment will be presented elsewhere.[6] One of the interesting results is from analysis of an end-of-term survey that asked students to discuss in more detail one concept that they applied, and how it related to nanotechnology. These responses were then rated as declarative, procedural, or schematic (conceptual) knowledge.[7] In their responses, 21 out of 36 students showed a conceptual understanding of the material they discussed. Students were able to take concepts introduced in other classes, build on them in the context of nanotechnology, and develop that knowledge into a strong, conceptual understanding of both the basic material and its relation to nanotechnology. Schematic learning is valuable due to its transferability. That so many students are displaying this type of learning is a great success for the course.

After successful completion of this course, students become able to:

1. Define nanotechnology.
2. Discuss how nanotechnology may impact society.
3. Identify products based on nanostructured materials.
4. Explain how the properties of nanostructured materials differ from their non-nanostructured (conventional) material counterparts.
5. Explain how these unique properties may adversely impact human health and the environment; define the concerns with nanotoxicity research and summarize the status in this area.
6. Explain the difference in approach of top-down and bottom-up manufacturing methods.
7. Describe major manufacturing methods used to produce nanostructured materials and devices and discuss issues in this area.
8. Identify some common methods used for nanomaterials characterization; describe the principles by which each method works and the type of information obtained.
9. Compare two prevalent ethical theories, utilitarianism and absolutism
10. Perform a risk assessment to determine the best direction for nanotechnology development.

FIGURE 1. Course Learning Objectives for ENGR 221

ChE 214 – Material and Energy Balances in Nanotechnology

ChE 214 is a chemical engineering lab course intended to give students an immediate way to apply what they learned in Material and Energy Balances (the first strongly technical chemical engineering course students take) in a nanotechnology setting. The course learning objectives are presented in Figure 2. For most students, this course will directly follow ENGR 221, and students will already have a solid background in nanotechnology.

CHE 214 is a lab course, consisting of a two hour lecture period and a four hour lab period each week. Each lab is not an isolated occurrence, but instead builds on all previous labs. For example, the catalyst the students create in the first lab is used throughout the course to grow nanotubes. The lecture periods consist of one hour of new material followed by an hour-long quiz. Students are given weekly homework assignments intended to prepare them for lab.

After successful completion of this course, students become able to:

1. Quantitatively describe the rate of reaction through real-time measurements of changes in the mass of product carbon nanotubes.
2. Calculate molar and mass concentrations based on flow rates of mixture-gas components and correlate them to GC based concentrations.
3. Calculate the fractional conversion of limiting reactant based on the reactant inlet and outlet flow rates.
4. Calculate product yields based on the gas-flow rates and correlate them to mass-based product yields.
5. Use temperature measurements at the reactor inlet and outlet to explain heats of reaction in conjunction with endothermic and exothermic reaction concept.
6. Predict reactor outlet temperature and compare it to actual temperature measurements.

FIGURE 2. Course Learning Objectives for ChE 214

As a course specific to chemical engineering, the students in CHE 214 have exclusively been chemical engineering majors. There were 15 students enrolled in the course during spring 2007 and 12 in spring 2008. In 2008, the enrollment was evenly divided between sophomore and seniors. Again the success of the course was assessed in terms of the achievement of the learning objectives. Since the course consisted primarily of laboratory sessions, observations and survey of these sessions were the primary tools of assessment. In addition, a pre and post test was administered, an end of term survey and analysis of the final project (which covered most material introduced in the course).

The survey was intended to reveal the student's perception of what they were expected to learn and the concepts they employed in each lab. Again the responses to each question of each survey were categorized in terms of declarative, procedural, or schematic knowledge. The first conclusion from this analysis is that seniors are better able to think about the lab material schematically than sophomores. A second conclusion is that students are more able to respond schematically when asked directly about a concept than they are when asked about what they were intended to learn in the laboratory. In fact, when asked about what they learned in lab, students are much more likely to describe the physical system and its operation than the concepts behind why the system behaves as it does. This is especially true for sophomore students.

An unsolicited comment from a senior read as follows:

> Throughout my career as a chemical engineering student, I was always curious about the research and experimentation process of creating and testing a new product. It may not be a primary goal, however, CHE 214 does a great job of taking students through the entire laboratory process of research experimentation. I really appreciated starting from making a catalyst and following through to product characterization using scanning electron microscopy. I found this to be very beneficial since many of the techniques taught in CHE 214 can be applied to testing much more than carbon nanotube production.
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> One of the most exciting aspects of this class was the opportunity to work on creating a product which is very close to the cutting edge of new technologies. It was exciting to be the only undergraduate students in the country to be creating carbon nanotubes as an instructional lesson on chemical engineering principles. It was very helpful to having a significant amount of time in which questions could be answered on the barriers in carbon nanotube and nanotechnology in general.

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