AC 2011-591: NANOTECHNOLOGY UNDERGRADUATE EDUCATION INITIATIVE

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Nanotechnology Undergraduate Education Initiative

The emerging field of nanoscience has experienced explosive growth in the last decade, particularly in the field of biomedical engineering, making it crucial to provide advanced training to America's future workforce [1-3]. In keeping with industry demands and the Wentworth tradition, hands-on nanotechnology laboratory experience is a central component of Wentworth's emerging nanotechnology and engineering course offerings. The impact on undergraduate science and technology education is significant, and the project is generating new research opportunities for undergraduate students. The nanotechnology laboratory allows students to develop nanotechnology-related knowledge and skills through their coursework that can later be applied to further research, improve design projects, and create solutions to improve the overall quality of life. The laboratory is used not only by undergraduate students, but also by high school students through Wentworth's outreach programs. The outreach program for high school students has been designed to teach students nanotechnology along with other STEM subjects at the Summer STEM Discovery Program. The principle aim of this project is to give students, at undergraduate level, a fundamental understanding of nanoscale science. Wentworth Institute of Technology has received multiple government and private funding to initiate an undergraduate nanotechnology education and the establishment of a nanotechnology laboratory. The laboratory is used to supplement the nanotechnology courses, undergraduate research at senior levels through senior design offerings, and for teaching across engineering disciplines. This initiative has had a positive impact on Wentworth's ability to offer undergraduate research opportunities. Several workshops have been developed for high school science teachers by introducing them to fundamental concepts of nanotechnology and other STEM subjects. This initiative has integrated nanotechnology into the curriculum and consequently promoted cross-disciplinary teamwork. The findings of this study will include the challenges of introducing undergraduate nanotechnology into different engineering curricula.

Nanostructure materials possess unique chemical, magnetic and optical properties [4-5]. These properties have opened a new third dimension to the periodic table involving the relationship between the number of atoms and the properties of materials [6]. This phenomenon opens of a new frontier in science and engineering. America has always been at the forefront of new technologies and scientific innovations and nanotechnology is not an exception [7]. The National Science Foundation has predicted that the sale of Nanoscience goods would reach one trillion dollars by 2015 and will create two million new jobs [8]. Forty percent of these jobs will be in the United States. Therefore, training students to fulfill these jobs in a considerably short period of time is a very important undertaking. Traditionally, nanotechnology has been associated with graduate research activities in academia [9]. However, due to the exponential growth in the field of nanotechnology particularly in the last decade, universities have started to train students at undergraduate levels and some universities such as University of California at San Diego, The State University of New York at Albany, Rice University, University of Washington, University of North Carolina at Charlotte and University of Wisconsin have gone further by offering nanotechnology related degrees. In this project, we discuss how nanotechnology can be integrated into undergraduate curricula to train the next generation of workforce.

One of obstacles in achieving a goal of educating American workforce at undergraduate level in an emerging field such as nanotechnology is the lack of funding. It is difficult to have any nanotechnology fabrications without access to expensive fabrication and analytical equipment. Although some institutions have integrated nanotechnology undergraduate education with their intensive research graduate programs, nevertheless this usually is overlooked by graduate students who are busy preparing to defend their thesis or dissertations and present and publish their work. Having an exclusive undergraduate laboratory is important because the instruction can adjusted to their level of understandings without any comparison with their graduate counterpart. In the year 2000, President Clinton unveiled the creation of the National Nanotechnology Initiatives with an initial budget of \$464 million for Fiscal Year 2001 which grew rapidly to \$1.76 billion in Fiscal Year 2011(Figure 1). Close to ninety percent of this budget has gone to Department of Defense (DOD), National Science Foundation (NSF), Department of Energy (DOE) and National Institutes of Health (NIH).

Figure 1: The National Nanotechnology Initiatives' Budget

In support of nanotechnology undergraduate education, National Science Foundation has initiated a new funding program exclusively for Nanotechnology Undergraduate Education (NUE) in Engineering which aims at introducing nanoscale science, engineering, and technology through a variety of interdisciplinary approaches into undergraduate engineering education [9]. National Science Foundation (NSF) has allocated \$25 million to nanotechnology education-related activities in Fiscal Year 2010. These funding opportunities enable intuitions to build a solid foundation for nanotechnology education.

The most important reason for the exponential growth of nanotechnology and nanoscience in the last few decades is the inventions of analytical equipment. The analytical equipment enables scientists and engineers to analyze and manipulate nanostructures into useful devices.

Traditionally, people with terminal degrees were working on the analytical equipment such as Scanning Electron Microscope (SEM). Now, the industry is looking for talented workforce to operate these machines with a crisp understanding of the outcomes and the type of analytical equipment should be used for each specimen under study as the need to operate these complicated microscopes continues to grow. These types of training can be easily done at the undergraduate level without offering a formal degree in the field or completing a graduate degree.

To begin with, the engineering and science curricula should be adaptive enough to adjust themselves to new and emerging technologies to cover basics and fundamentals of new emerging sciences. Wentworth Institute of Technology has been able to introduce nanotechnology through engineering elective courses in different engineering disciplines. Nanotechnology demands an integration of different science and engineering disciplines, and this will be a great venue to have such diversity in one place. Students from different engineering and science disciplines can take an introductory nanotechnology course to fulfill their curriculum elective requirements. In order to achieve these objectives the followings two undergraduate courses are offered. In the first introductory course (Introduction to Nanotechnology), students learn about basic fundamentals of nanotechnology (Table 1) and use the laboratory to learn about nanoparticle nucleation through particle condensation and how to use analytical equipment such as Atomic Force Microscope. In the second nanotechnology course (Advances of Nanotechnology), students learn about recent advances and issues in molecular nanotechnology which includes sensors, nano optics, nanoscale materials and their unique properties (Table 2). The newly built nanotechnology laboratory is used to supplement the nanotechnology courses (Table 3), undergraduate research in senior levels through senior design offerings, and for teaching across engineering disciplines, particularly in the area of Electrical, Mechanical, Biomedical and Electromechanical Engineering. The nanotechnology laboratory is also used to outreach to high school students by teaching them nanotechnology along with other STEM (Science, Technology, Engineering and Mathematics) subjects at the Wentworth Summer STEM Discovery Program. Moreover, the laboratory is used for professional development of high school teachers by introducing them to fundamental concepts of nanotechnology. These activities will inspire high school students to consider nanotechnology related fields when they embark on their college studies.

Although presently undergraduate students who are exposed to nanotechnology are in their sophomore and junior years, but the aim of this project is to give students a fundamental understanding of nanoscale science beginning with first year students. That can be done by adding a two-week nanotechnology module in the Introduction to Engineering course in the freshman year. The project integrates nanotechnology into the different technical curricula and consequently promotes cross-disciplinary teamwork. Moreover, this has a positive impact on Wentworth's ability to offer undergraduate research opportunities.

The followings are the course descriptions of the nanotechnology courses mentioned above. The first course does not have a prerequisite and covers basic fundamentals of nanotechnology, but the prerequisite for the second course is junior status.

Course Title: Introduction to Nanotechnology

Course Description: The ongoing impact of nanotechnology on the current state of science and engineering will be explored here. Various deposition techniques and applications are also studied.

Prerequisite: None

Course Title: Advances of Nanotechnology

Course Description: The fabrication of nanostructured materials, nanoscale films, compositions, devices, their unique properties and recent advances and issues in molecular nanotechnology are studied.

Prerequisite: Junior Status

	Introduction to Nanotechnology
1	What are Nanoscience and Nanotechnology?
2	Chemical synthesis and processing of nanostructured powders and films
3	Nanostructured materials for gas reactive applications
4	Magnetic properties of nanocrystalline materials
5	Nanostructured electronics and optoelectronics
6	Nanofabrication: top-down and bottom-up methods
7	Nanotechnology Tools:
	Scanning Electron Microscopy (SEM)
	Atomic Force Microscopy (AFM)
	Transmission Electron Microscopy (TEM)
	X-Ray Diffraction (XRD)
	Ellipsometry
	Time of Flight (TOF)
8	Nanostructured film formation: Atomic nucleation process, grain structures of films
9	Various 1-D nanostructures: nanowire, nanotube and atomic lines
10	Quantum phenomena of low-dimensional systems
11	New advances in nanotechnology: students' research projects and presentations

Table 1: Nanotechnology Lecture Topics for the First Nanotechnology Course (Introduction to Nanotechnology)

	Advances of Nanotechnology
1	Nanoscale Materials
2	Nanotechnology enabled Sensors
3	Microelectronics
4	Drug Delivery
5	Information Technology – Quantum Computing
6	Nano Architecture
7	Nano Optics
8	Students’ research projects and presentations

Table 2: Nanotechnology Lecture Topics for the Second Nanotechnology Course (Advances of Nanotechnology)

	<i>Laboratory Experiments</i>
1	Nanoparticles and Magnetic Data-Storage - Isolating bits on a Magnetic Drive
2	Atomic Packing of Nanoparticles
3	Nanoparticle nucleation and Deposition
4	Properties of Nanostructured Films
5	Ellipsometric Study of Nanostructured Thin Film
6	Atomic Force Microscopy in Contact and Tapping Modes
7	Nanolithography
8	Sensors and Nanostructured Materials
9	Time-of-Flight Spectroscopy

Table 3: The Laboratory Experiments Conducted in Nanotechnology Courses

After taking nanotechnology courses, students are expected to accomplish the following outcomes.

- A clear understanding of basic fundamentals of nanotechnology
- A good preparation to conduct basic research in the area of nanoscience and/or nanotechnology
- An ability to work in nanotechnology related industries
- An adequate groundwork to complete an advanced degree in the field of nanotechnology

The above mentioned outcomes are assessed by examinations, students’ course evaluations and students’ exit surveys to find the areas of improvement and how we can better prepare students to attain the outcomes. Since some of our engineering programs such as Electrical Engineering and Electromechanical Engineering have three elective courses in their curricula, we are planning to have a third course at senior level in the areas of nanomechanics and nanoelectromagnetics to augment the other two nanotechnology courses. That will create a new concentration within the engineering programs.

Students start thinking about nanotechnology related junior and senior design projects when they are exposed to nanotechnology in their freshman or sophomore year. Students are welcomed and encouraged to use the nanotechnology lab for different junior and senior projects. Students are also encouraged to present their work at local and regional conferences. This has a positive impact on Wentworth's ability to offer undergraduate research opportunities. Since the class is open to all technical majors, students from different disciplines work together on their laboratory projects and class presentations. The project certainly integrates nanotechnology into the curriculum and consequently promotes cross-disciplinary teamwork at Wentworth which involves knowledge from diverse disciplines. Furthermore, students are exposed and to some extent trained with tools of nanotechnology, different fabrication methods and certainly vacuum technology. The combinations of these skills are enough for an entry level position in the area of nanotechnology and nanoscience.

In summary, Nanotechnology education at undergraduate level equips graduates with the flexibility to adapt to emerging technologies. Nanoscience and Nanotechnology are inherently interdisciplinary, and all approaches in educating students need to have some interdisciplinary elements. In order to foster interdisciplinary education in nanotechnology, courses in nanotechnology are offered through technical elective offerings. The impact on undergraduate science and technology education will be significant, and it generates new research opportunities for undergraduate students. An exclusive nanotechnology laboratory allows students to develop nanotechnology-related knowledge and skills through their coursework that can later be applied to further research, improve design projects, and create solutions to improve the overall quality of life.

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