2006-1792: CURRICULUM DEVELOPMENT IN NANOTECHNOLOGY: TWO CASE STUDIES

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Abstract

Nanotechnology is at the cutting-edge of science and engineering disciplines and will have a broad impact on society. A sharp increase is predicted in the number of industries which will use different nanotechnology processes for developing their products in the near future. The extensive use of nanotechnology for product development will create a significant demand for equipment and to provide technical assistance in the development of products using nanotechnology concepts.

Academic programs in nanotechnology tend to be interdisciplinary in nature and require far larger resources than what is needed for traditional engineering technology programs. A curriculum in nanotechnology should be able to cut across the traditional boundaries of engineering technology education and must include academic disciplines such as biology, chemistry, materials, electronics, manufacturing systems, and mechanics.

This manuscript provides detailed information regarding two different nanotechnology curricula which effectively train the engineering technicians for nanotechnology implementation in industry. The manuscript focuses on the two different curriculum development approaches used by The Pennsylvania State University and The Portland Community College to train engineering technicians in the discipline of nanotechnology.

The manuscript describes the curricular elements of the nanotechnology programs at both the above mentioned educational institutions. The key issues related to the development and implementation of a nanotechnology curriculum are also discussed. Finally, the lessons learned from the implementation of nanotechnology curricula at the two above mentioned institutions.

Introduction

Nanotechnology is the creation of functional materials, devices, and systems through control of matter on the nanometer length scale and the exploitation of novel properties and phenomena developed at that scale [1]. Nanotechnology holds singular promise to revolutionize science, engineering, and technology, and in the process to transform our society [2]. The impact of nanotechnology on the health, wealth, and lives of people could be at least as significant as the combined influence of microelectronics, medical imaging, computer-aided design and manufacturing, and the man-made polymers developed in the 20th century. Some of the breakthroughs promised by nanotechnology include computers with 1000 times more information storage capacity and one million times faster processing speeds than today's devices, lighter and more fuel efficient vehicles, and dramatically more efficient genome sequencing processes [3].

The enormous potential of nanotechnology to transform our society demands that science and technology graduates understand this rapidly expanding technology. They should be able to integrate concepts and principles of nanotechnology into their knowledge bases. Nanotechnology has grown to an extent where the educational institutions need to move forward in order to develop and implement academic programs in this discipline. An academic curriculum in nanotechnology should be able to cross traditional boundries of various disciplines and must include topical **Curriculm Development in Nanotechnology**

Development of academic curricula in nanotechnology is described in several publications. Raju and Muthuswamy [1] provided a list of key issues to be addressed in developing and implementing a curriculum in nanotechnology. The list of issues is as follows:

- Preparing faculty to teach in a broad based technology that is still evolving.
- Industry involvement and practical experience for faculty.

1) The interdisciplinary nature of nanotechnology curriculum.
2) Arranging access to laboratory facilities.
3) Need to focus on a specific aspect of nanotechnology.
4) Outreach programs.
5) Co-op and internship arrangements aimed at real world experience for students.
6) Developing partnerships with education, industry, and government.
7) Securing resources to develop curriculum, faculty, laboratories, and appropriate technical support

Froyd, Creasy, Karaman, Teizer, and Caso [2] describe a project initiated by Texas A&M University to address issues in manufacturing at the nanoscale. The project will introduce nanotechnology concepts throughout the undergraduate engineering curriculum. The curricular change introduced by this project has four components corresponding to the four years of undergraduate engineering curricula. At each level, concepts related to manufacturing at the nanoscale are introduced at the appropriate technical level.

Alpert, Isaacs, Barry, Miller, and Busnaina [4] describe various nanotechnology education initiatives undertaken by University of Massachusetts, Lowell. One of the initiatives consists of starting a cross disciplinary graduate certificate in nanotechnology and nanoscience in Fall 2005. This certificate program is designed for industry workers as well as for traditional students. Another initiative involves designing curricula that use nanotechnology as a framework for examining the entire range of societal issues associated with emerging technologies.

Nanotechnology at The Pennsylvania State University

The Pennsylvania Nanofabrication Manufacturing Technology (NMT) Partnership is a higher education collaborative dedicated to creating and updating a workforce in Pennsylvania trained in the field of nanotechnology. The NMT educational partners include:

- The Pennsylvania State University
- Pennsylvania College of Technology
- The Pennsylvania State System of Higher Education
- Pennsylvania Commission for Community Colleges

All the activities and programs of the NMT partnership are coordinated by the Center for Nanotechnology Education and Utilization (CNEU) at The Pennsylvania State University. The key feature of the partnership is the sharing of nanofabrication facilities, staff, and faculty at The Pennsylvania State University with the above mentioned NMT educational partners.

The Penn State Nanofabrication Facility (Nanofab) is a professionally staffed Class 10 clean room facility providing a full range of processing capabilities for substrates as long as six inches in diameter. The facility is supported in part by the National Science Foundation (NSF) and is one of the NSF's National Nanotechnology Infrastructure sites. The Nanofab houses state-of-the-art equipment which provides extensive capabilities for wet chemical etching, lithography, film deposition/growth, dry etching, material modification, and characterization. The current research projects at the Penn State Nanofabrication Facility are in the following topical areas:

- Nano-structured films for Mass Spectroscopy
- Nano-channels
- Molecular pores
- Polymer filaments
- Development of Silicon Immersion Gratings
- Molecular Electronics
- Microcontact printing
- Nanostructured thin films
- Thin film transistors
- Novel materials
- Self assembling beads

- Development of new nanofabrication tools and methodologies
- Optoelectronics

The Nanofabrication Manufacturing Technology Degree

Reflecting industry priorities, the primary focus of the NMT Partnership is on meeting the need for associate degree level nanofabrication technicians [5]. To meet this need, the Pennsylvania State University offers an Associate in Engineering Technology Degree in Nanofabrication Manufacturing Technology (NMT). This degree prepares graduates for technical positions in the fields of nanofabrication technology, nanomanufacturing technology, or bionanofabrication.

There are two options available within the NMT program. The Nanomanufacturing Engineering Technology (2NMT/ET) option and the Nanomanufacturing Science (2NMT/SC) option. The 2NMT/ET option prepares graduates for technical positions in the field of nanofabrication technology. The primary objective is to provide a broad foundation of theoretical and practical knowledge in the areas of nanofabrication manufacturing, electrical and electronic circuits, digital circuits, nanofabrication manufacturing equipment, processing, and testing. The 2NMT/SC option is designed to meet the basic educational needs of students who want to pursue professional programs in nanomanufacturing technology fields primarily in the biotech and biomedical companies. The program provides a fundamental sequence of science courses and a comprehensive group of nanomanufacturing technology courses to those who wish to pursue employment opportunities which demand such knowledge. Graduates of this program may qualify for admission to the baccalaureate degrees in science.

For the 2NMT/ET degree, 72 credits are required. The program will be submitted for accreditation to the appropriate commission of the Accreditation Board for Engineering and Technology (ABET) at each Penn State campuses where the full two years of the program are offered [6]. A typical course sequence for the 2NMT/ET degree is shown below:

Table 1

Associate Degree in Nanofabrication Manufacturing Technology
Engineering Technology Option

First Semester		Second Semester	
Engineering Design & Graphics	3	Technical Physics	3
Electrical Circuits I (DC circuits)	3	Electrical Circuits II (AC Circuits)	4
Electrical Circuits Laboratory I	1	Electrical Circuits Laboratory II	1
English Composition	3	Digital Electronics	3
Technical Mathematics I	4	Digital Electronics Laboratory	1
Humanities Elective	3	Technical Mathematics II	3
Credits this Semester:	17	Humanities Elective	3
		Credits this Semester:	18

Third Semester		Fourth Semester Capstone Semester at the Nanomanufacturing Facility located at University Park	
Chemical Principles with Laboratory	4	Materials, Safety and Equipment Overview for Nanofabrication	3
Quality Control for Nanotechnology	1		
Speech Communication	3	Basic Nanofabrication Process	3
Introduction to Nanotechnology	3	Thin Films in Naniofabrication	3
Elementary Statistics	4	Advanced Lithography and Dielectrics for Nanofabrication	3
Humanities Elective	3	Materials Modification in Nanofabrication	3
Credits this Semester:	18	Characterization, Packaging, and Testing of Nanofabricated Structures	3
		Credits this Semester:	18

NMT Capstone Semester

For both the 2NMT/ET and 2NMT/SC options, students must spend one semester at the University Park Campus of The Pennsylvania State University where they are required to take the following 6 courses (18 credit hours). The NMT Capstone Semester exposes students to state-of-the-art equipment and clean room facilities at The Pennsylvania State University. The course descriptions are summarized in Table 2 as follows:

Table 2

The Six Capstone Semester Courses
of the Pennsylvania NMT Partnership

Penn State Course Number and Name	Summary of Course Content
ESCI 211: Materials, Safety, Health Issues, and Equipment Basic to Nanofabrication	Provides an overview of basic nanofabrication processing equipment and materials handling procedures with a focus on safety, environment, and health issues.
ESCI 212: Basic Nanofabrication Processes	Provides an overview of the equipment and processes used to fabricate devices and structures such as complementary metal oxide semiconductor (CMOS) transistor and power devices, micro-electromechanical (MEM) devices, and biomedical devices including “lab-on-a-chip” structures.
ESCI 213: Thin Film Utilization in Nanofabrication	Addresses thin film deposition and etching practices, including atmospheric, low pressure, and plasma enhanced chemical vapor deposition and sputtering, thermal evaporation, beam evaporation, physical vapor deposition, reactive ion etching, high-density plasma reactors, ion beam etching, and wet chemical etching.
ESCI 214: Lithography for Nanofabrication	Covers all aspects of lithography from mask design and fabrication to pattern transfer and inspection. This course addresses photo-resist materials, optical masks, aligners, steppers, scanners, and advanced optical lithographic techniques.
ESCI 215: Materials Modification in Nanofabrication	Covers materials modification and addresses material growth and annealing, including rapid thermal annealing, and the impacts of thermal processing on defects, gettering, impurities, and overall electrical, mechanical, optical, and chemical properties.
ESCI 216: Characterization, Packaging, and Testing in Nanofabrication	Addresses nanofabrication characterization, packaging, and testing, emphasizing basic measurements for yield analysis and process control.

Future Directions

The NMT Partnership is enabling a wide range of initiatives in nanotechnology education. These initiatives include continuous improvement and expansion of associate degree programs in nanofabrication, development of baccalaureate degree programs addressing nanofabrication, expanded student recruitment, and industrial outreach. Baccalaureate degree programs addressing nanofabrication are needed if the nation is to successfully exploit the nanotechnology opportunity. Efforts are underway within several colleges and departments of The Pennsylvania State University to develop options, minors, or concentrations within existing baccalaureate degrees. A key factor driving these efforts, in addition to nanotechnology career opportunities, is the need for students to be prepared during their undergraduate studies to support new nanotechnology research programs as graduate students.

Nanotechnology at Portland Community College

Fifteen years ago in January of 1990, Intel Corporation's Oregon Site asked Portland Community College (PCC) to develop a new associate of applied science degree program to prepare technicians for their new wafer fabs in Oregon. At that time, college administrators were less than enthusiastic about committing college resources to resurrecting a degree that they had discontinued several years earlier. Nevertheless, under the leadership of Daniel Sempert, Director of PCC's Workforce Training Department, PCC and Intel Corporation entered into an agreement to create a new associate degree program to produce Intel's workforce of the future.

At this time, Intel Corporation was still operating Fab 4, their original, four-inch wafer fab in Oregon. However, Fab 4 was was slated for closure in the early 90's as Intel moved to larger wafer sizes. Next to Fab 4, Intel's first research and development fab, named D1A, was being built, and Fab 5, Intel's former DRAM fab, was being re-tooled to produce Pentium processors.

Intel's motivation for creating a new associate degree program was economic. That is, they wanted to move their workforce from an operator/equipment technician/process technician workforce model to a new "self-sustaining technician" workforce model in order to achieve greater efficiency and flexibility in their manufacturing operations. In their original workforce model, different individuals filled the roles of operator, equipment technician, and process technician. This staffing paradigm was viewed to be an expensive mode of staffing factory. In their new workforce model, one individual would fill the role of "self-sustaining technician." This new technician would perform the combined roles of operator and technician, thereby, reducing the head count in the factory.

In terms of educational qualifications, individuals filling operator and technician positions in the existing workforce in Fab 4 typically had high school diplomas or military training. Few had earned college degrees. The educational requirement for the self-sustaining technician model would raise the minimum educational requirement to an associate of applied science degree or equivalent. PCC's new associate of applied science degree would provide a bridge for Intel's existing workforce to meet the higher educational requirements for technician positions in their new factories.

To fund the program, Intel Corporation agreed to fund all program development and operation. As a consequence, the program would serve only Intel employees and be offered only at Intel's Aloha, Oregon, site located west of Portland.

Program Development

Once a contract was signed between Intel Corporation and PCC, program development began. Dan Sempert asked David Hata, Department Chair of the Electronic Engineering Technology Program, to lead the development effort. The first meeting was held in January of 1990. In attendance were fab managers from Intel's Oregon site. The start date for the new program was September, 1990.

Developing a new degree program in nine months is difficult, if not impossible, in an academic environment. Fortunately, we didn't have to start from the beginning. PCC's original Microelectronics Technology program had not been eliminated, but only "moth-balled" during the economic recession of the late '80s. Re-activating the original program only required notifying the Oregon State Department of Education of PCC intent and submitting the new curriculum to be implemented.

Intel's managers described the new workforce that they envisioned for their new factories. They described a new staffing paradigm that would require a workforce that needed to be very agile, being able to adapt to rapidly changing technologies and manufacturing practices, and able to effectively function in teams in the factory. Self-sustaining technicians, as Intel called them, would function in multiple roles, performing the duties of operator, equipment technician, or process technician, depending on the need at the time. Being able to handle multiple tasks would increase the productivity of each technician and ultimately reduce head-count for the factory. Furthermore, life in the fab is a fast-paced with technology advancing constantly, requiring everyone to continually assimilate new processes, tools, and procedures into their work.

Approximately 160 Intel employees enrolled in classes in September, 1990. Unfortunately, most of these individuals did not meet the math and/or English entry requirements for the program. As a result, enrollment was concentrated in developmental math and English classes during the first year of the program.

One dedicated classroom was assigned to the program. Classes were also scheduled in available conference rooms at the Aloha, OR, Intel campus. No laboratory space was created at Intel, requiring students to travel to one of PCC's campuses for their science and electronics lab sessions.

Classes were scheduled around Intel's compressed-workweek schedule. That is, classes were scheduled to meet on Monday and Tuesday, or Thursday and Friday. This allowed students to take classes on their own time.

The program used the "fab as the lab" for advanced technical courses, e.g. MT 230 Vacuum Systems. The assumption was that most of the students would be working in the fab, and hence, they would have some exposure to the equipment and practices used in the factory.

In 1995, the Microelectronics Technology Program moved from Intel's campus to Portland Community College. Lack of adequate space on PCC's comprehensive campuses, the program moved into temporary quarters in PCC's Washington County Workforce Training Center located northwest of Beaverton, OR, and in close proximity to both Intel's Aloha and Ronler Acres campuses. Intel directly and indirectly subsidized the program for the next five years.

In 2000, the Microelectronics Technology Program received funding from PCC's General Fund and in 2004, the program moved to permanent facilities at PCC's Rock Creek Campus.

PCC's Microelectronics Technology Degree

From discussions with fab managers and experience in placing EET students in cooperative education positions in the fab at the Aloha campus, several conclusions about the new curriculum were obvious. First, the wafer fab was a unique manufacturing environment requiring skills different that those provided by existing professional/technical programs at PCC, e.g. PCC's Electronic Engineering Technology Program. Second, the wafer fab was a complex chemical factory that manufactured electronic components. Third, workers in the factory would need a multi-disciplinary background that would not only enable them to adapt to a rapidly changing technology, but would provide the technical literacy to work in functional teams. And finally, the associate degree program should not focus solely on entry-level skills, but provide the foundation for learning through the individual's career, whether at Intel or another company or industry.

PCC's Microelectronics Technology Program requires 101 quarter-credits for the associate of applied science degree. The two-year curriculum is listed in Table 3. Anchoring the curriculum is a solid math/science core that includes 13 credits in mathematics, 10 credits in general chemistry, and 12 credits in general physics. Statistics was chosen over calculus since statistical process control is an important part of the functioning of the fab.

Fifteen percent of the credits are allocated to the development of oral and written communication skills. An additional nine credits fulfills the general education component of the AAS degree.

The remaining 42 credits are devoted to the technical component of the AAS degree. Eighteen credits are allocated to electronics topics, eight to semiconductor manufacturing processes, ten to semiconductor processing equipment, and six to supporting technologies (i.e. vacuum and plasma technology). A comparison of the credit allocations by subject area for the PSU and PCC programs is provided in Table 4.

Table 3.

Associate of Applied Science Degree in Microelectronics Technology

First Term	**Second Term**
MT 110 Intro to Microelectronics 3 MT 111 Electronic Circuits/Dev. I 4 CH 221 General Chemistry 5 MTH 95 Intermediate Algebra 4 WR 121 English Composition 3	MT 112 Electronic Circuits/Dev. II 4 MT 121 Digital Systems I 3 CH 222 General Chemistry 5 MTH 111C College Algebra for Math Science and Engineering 4 WR 122 English Composition 3
Third Term	**Fourth Term**
MT 113 Electronic Circuits/Dev. III 4 MT 122 Digital Systems II 3 MTH 243 Statistics I 4 WR 227 Technical Writing 3	MT 223 Vacuum Technology 3 MT 224 Process Equipment I 3 PHY 201 General Physics 4 SP 130 Business & Professional Speech Communication 3 General Education 3
Fifth Term	**Sixth Term**
MT 240 RF Plasma Systems 3 MT 227 Process Equipment II 3 PHY 202 General Physics 4 SP 215 Small Group Communication: Process & Theory 3 General Education 3	MT 200 Semiconductor Processing 3 MT 222 Quality Control in SMT 2 MT 228 Process Equipment III 4 PHY 203 General Physics 4 General Education 6

Table 4.

A Comparison of Credit Allocations by Subject Area for the PSU and PCC Programs. May total more than 100% due to rounding.

Subject Area	PSU	PCC
Mathematics	16%	13%
Science	10%	22%
English & Speech	9%	15%
General Education	13%	9%
Electronics Technology	18%	18%
Nanotechnology	31%	24%
Other:	4%	

Unlike Penn State University, PCC does not have a National Science Infrastructure site in the geographic area, but PCC does have Intel Corporation's R&D fabs close by in Hillsboro, OR. The R&D fabs are not affected by economic fluctuations as production fabs are. Hence, Intel could provide consistent support for PCC's AAS program over the long term.

Early in program development, the decision was made to focus on process equipment and supporting technologies rather than building a functioning cleanroom to provide a process focus in the curriculum. A major deterrent was the high operational and maintenance cost of a teaching cleanroom facility. Five courses in the second year of the program provide this process equipment focus. The following is a brief summary of the content of these five courses:

MT 223 Vacuum Technology – 3 credits (2 lecture hours/week, 3 lab hours/week, 11 weeks). Covers the theory and practice of vacuum technology as used in semiconductor manufacturing. Includes vacuum principles, gas loads, pumping techniques, pressure measurement, RGAs, and leak detection.

MT 240 RF Plasma Systems – 3 credits (2 lecture hours/week, 3 lab hours/week, 11 weeks). Covers the theory and practice of RF plasma systems used in semiconductor manufacturing. Includes plasma physics, RF power subsystems, gas delivery, and plasma-aided manufacturing processes.

MT 224 Process Equipment I – 3 credits (2 lecture hours/week, 3 lab hours/week, 11 weeks). First course in semiconductor process equipment. Covers microcontrollers, DC and stepper motors, and mechanical systems.

MT 227 Process Equipment II – 3 credits (2 lecture hours/week, 3 lab hours/week, 11 weeks). Second course in semiconductor process equipment. Covers pneumatic and robotic systems.

MT 228 Process Equipment III – 4 credits (2 lecture hours/week, 6 lab hours/week, 11 weeks). Covers a semiconductor processing tool, e.g. oxide etcher. Includes power, vacuum, gas delivery, robotic and control systems. Focuses on systems maintenance and troubleshooting.

Two laboratories support these five lecture/lab courses. The Vacuum/Plasma Systems Laboratory is configured around six high-vacuum training systems and six RF plasma training systems. Supporting equipment includes leak detectors, gas plasma demonstrations, and equipment to support fundamental experiments in vacuum and plasma technology. The Process Systems Laboratory is configured around two oxide etchers donated by Intel Corporation and robots donated by Brooks Automation. It is the Process Systems Laboratory that provides the "capstone" laboratory experience for our students. Development of these teaching laboratories has been supported by two National Science Foundation grants and contributions by Intel Corporation and Brooks Automation.

The Intel Academics & Industry Program

Providing students with an on-campus, cleanroom experience is very costly. Prior attempts to provide this experience required annual budgets of $70,000 or more for materials and supplies on top of installation and infrastructure costs for equipment. Local support for creating a teaching cleanroom was lacking, even from Intel Corporation who had created a teaching cleanroom at Albuquerque TVI in New Mexico. A creative alternative to providing an on-campus, cleanroom experience is to partner with local companies to provide this experience in their wafer fabs.

To provide a cleanroom experience for our students, PCC and Intel Corporation have developed an "Academics & Industry" Program that has the attributes of a work-study or internship program. Students enrolled in PCC's Microelectronics Technology Program and have accrued a minimum of 15 credits towards the AAS degree are eligible to apply for an A&I program position at Intel. Applicants submit an application and are interviewed by Intel. Those students selected must enroll in a minimum of 12 academic credits applicable toward the AAS degree during each term and work a minimum of 20 hours per week at Intel. Intel pays an hourly wage provides a benefit package that includes tuition reimbursement, among other benefits. In order to participate in the A&I Program, students must receive acceptable work reviews and earn a "C" or better in all of their classes.

Participation in the Intel A&I Program is not required for the AAS degree, nor are all students who apply accepted into the program. Students accepted into the A&I Program work at Intel until they graduate with the AAS degree. Upon graduation, Intel can exercise their option to offer the graduate a full-time position, and the graduate can choose to accept, or not accept, their offer.

Conclusion

Even though PSU and PCC have taken different approaches to implementing model nanotechnology programs, there are some important lessons that have been reinforced.

- ✓ The importance of partnerships. For Penn State University, a strong partnership between different campuses and the Penn State Nanofabrication Facility is crucial to their program. Similarly, PCC's partnership with Intel Corporation is essential to achieving program goals.

- ✓ Curricular innovation leading to multi-disciplinary curricula with a strong math/science foundation. The shift away from single-discipline, technician education programs is needed in order to provide the scientific literacy for technicians in a rapidly-changing, team-structured industry.

- ✓ Faculty who are willing to embrace change in order to prepare students for careers in nanotechnology. This change will changes in credit allocations within a degree program, teaching methodology, subject matter taught, and a greater focus on outcomes-based education.

- ✓ Replication of the PSU and PCC programs will be a challenge. Many colleges will not have the same type of partnership opportunities that PSU and PCC have. Colleges will have to be creative in developing their own partnerships. Faculty will also have to make sacrifices, both individually and as a group, to implement new initiatives.

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