PATHWAYS FROM COMMUNITY COLLEGE TO BACHELORS OF SCIENCE IN ENGINEERING WITH A NANOTECHNOLOGY MINOR

Paul M. Hallacher, Douglas E. Fenwick, and Stephen J. Fonash

The Penn State Nanofabrication Facility

The impact of nanotechnology on the health, wealth, and lives of people could be at least as significant as the combined influences of microelectronics, medical imaging, computer-aided engineering, and the man-made polymers developed in the 20th Century (National Science and Technology Council, July 2000). Some of the breakthroughs promised by nanotechnology include computers with 1,000 times more information storage capacity and one million times faster processing speeds than today's equipment, lighter and more fuel efficient land, sea, air, and space vehicles, ability to remove contaminants from water and air, and dramatically more efficient genome sequencing processes (National Science and Technology Council, February 2000).

It is estimated that the United States will need between 800,000 and 1 million nanofabrication workers in the next 10 years (Breslau, 2002). Several industry sectors are driving this workforce need. First are the established industries that traditionally use micro- and nanotechnology, such as microelectronics, information storage, optoelectronics, and others. Expanded employment opportunities are also anticipated in industries that are just beginning to use nanotechnology (Siegel, 1999). These include industries that have been newly created by this technology, such the micro- and nano-electromechanical systems (MEMs and NEMs) industries, and the emerging nanobiotechnology and nanoelectronics start-ups.

A third driving sector is composed of the major industries that previously have never used micro- and nanotechnology but are now actively embracing it. Among these are giants such as the pharmaceutical and chemical industries, and even more traditional industries like clay and glass. In addition to these product-producing industry sectors, there is a growing workforce demand coming from micro- and nanotechnology research centers housed in industry, universities, and national laboratories that are advancing understanding of this new field of science and engineering.

The Pennsylvania NMT (Nanofabrication Manufacturing Technology) partnership was established in 1998 as a state government response to the nanotechnology workforce and research needs of industry. Its guiding principle, since its inception has been the sharing of the Penn State Nanofabrication Facility, a NSF National Nanofabrication Users Network (NNUN) site, with educational institutions across Pennsylvania. The NMT Partnership has grown into a unique team effort involving over 30 institutions of higher education, secondary schools including vocational-technical schools, and private industry. The NMT Partnership has firmly established Pennsylvania as the national leader in nanotechnology education and training. (See: Hallacher et al, 2002; Hallacher et al, July 2002; Fonash, 2001).

Based on industry advice and concerns, the initial thrust of the NMT Partnership was on research support and on meeting the need for associate degree level

nanofabrication technicians. Through the NMT Partnership, the nation's first associate degree programs in nanofabrication have been established at community colleges across Pennsylvania. The key feature of the NMT Partnership that enables the community colleges to offer associate degree programs in nanofabrication is a suite of six nanofabrication courses taught three times per year (fall and spring semesters and summer session) at the Penn State Nanofabrication Facility. The Nanofabrication Facility staff teaches these six nanofabrication courses, called the "capstone semester," for the community colleges and other partner institutions. To date, 173 students from 16 different institutions have completed the NMT capstone semester.

In July 2001, the National Science Foundation designated the Pennsylvania NMT Partnership as an Advanced Technology Education (ATE) Center for Nanofabrication Manufacturing Education. This designation represents a major milestone in the continuing development of the Pennsylvania NMT Partnership, enabling a range of initiatives to strengthen this innovative educational partnership. For example, the NSF Center for Nanofabrication Manufacturing Education is enabling the development of baccalaureate degree programs addressing nanofabrication by the 14 state-owned, comprehensive public universities of the Pennsylvania State System of Higher Education. These 14 State System universities are not related to Penn State

On Sept 11-12, 2002 a workshop organized by the Director of the Penn State Nanofabrication Facility, Professor Stephen Fonash, was held at the National Science Foundation to explore the challenges and opportunities in the emerging and important area of nanotechnology undergraduate education. As noted in the final report of the workshop (Pennsylvania State University, 2002), nanotechnology offers an opportunity to achieve several long-standing higher education goals. For example, nanotechnology offers a unique opportunity to achieve the goal of interdisciplinary education and research that has been pursued within the higher education community for several decades, because nanotechnology spans traditional disciplines like biology, chemistry, physics, and the engineering fields. Nanotechnology education also requires hands-on experiences for students, necessitating increased involvement by undergraduates in research.

In addition, because nanofabrication workers are needed at all levels, from associate degree technicians to PhDs, nanotechnology offers an opportunity to establish matriculation pathways from secondary schools, including vocational-technical schools, through associate degree programs to baccalaureate programs and beyond. Further, because rewarding career opportunities are available at all levels, nanotechnology may afford a unique opportunity for lifelong learning, whereby individuals may move from associate degree through baccalaureate and graduate education programs over many years while pursuing their careers. Because of this, students from economically disadvantaged and underrepresented groups may be more readily attracted into nanofabrication education programs.

Baccalaureate degree programs addressing nanofabrication are needed if the nation is to successfully exploit the nanotechnology opportunity. The final report of the NSF workshop emphatically states, however, that as important as the field is, stand-alone baccalaureate degree programs in nanotechnology are not needed at this time. Rather, options, minors, and concentrations in nanotechnology associated with traditional programs and departments are recommended. It is further argued that rather than

competing with existing programs and departments, such an approach can invigorate and revitalize traditional science and engineering programs by infusing them with nanotechnology concepts, examples, and experiments.

The Pennsylvania NMT Partnership and the NSF Center for Nanofabrication Manufacturing Education provide a foundation for developing such baccalaureate degree programs addressing nanotechnology in Pennsylvania. In fact, baccalaureate degree programs addressing nanotechnology are already in various stages of development. For example, as noted earlier, Pennsylvania's 14-university State System of Higher Education is developing concentrations in nanofabrication within existing Bachelor of Science degree programs in physics, chemistry, biology, and other fields through the Center for Nanofabrication Manufacturing Education. These programs will incorporate the NMT Partnership's 18-credit capstone semester between the end of the first and second years of existing four-year programs, and will require development of at least two new upper-division (300 and 400 level) courses in nanofabrication.

At the same time, efforts are underway within several colleges and departments of Penn State to develop options, minors, or concentrations in nanofabrication within existing programs. A key factor driving these efforts, in addition to nanotechnology career opportunities, is the need for students to be are prepared during their undergraduate years to support major new nanotechnology research programs as graduate students. The Department of Materials Science and Engineering in the Penn State College of Earth and Mineral Sciences is working to establish a multidisciplinary minor in nanotechnology. The curriculum focuses on providing knowledge and hands-on experience encompassing:

- the synthesis and manufacture of nanostructures and nanoscale surface patterning;
- materials selection at the nanoscale level, including establishing connections between the nanoscale science and the macroscopic properties of materials, structures, and devices;
- characterization of nanostructures by surface (AFM) and bulk (TEM) techniques including extensive laboratory requirements, as well as application of traditional instruments/techniques (DSC, NMR, DMA) to probe details at the nanometer level;
- a seminar series on nanotechnology (with invited external speakers from industry, and academia), including field trips to industrial sites; and
- a senior project (or capstone thesis for the engineering majors).

Efforts are also underway within the Department of Engineering Science and Mechanics of the Penn State College of Engineering to develop a minor course of study in nanotechnology. The cornerstone of this effort is an existing senior year/graduate course in nanotechnology, which has already been offered two times to more than 50 students. This course, entitled Nanotechnology: Methods and Applications addresses the question of "why smaller is better", surveys the rapidly increasing list of nanotechnology success stories, surveys nanotechnology fabrication approaches, and addresses the largely unsolved issues arising from trying to establish manufacturing at the nanoscale. The following topics are covered:

- What is nanotechnology? Where did it come from?
- Why has smaller become better? What's the advantage?
- What is "top-down" nanofabrication?
- What is "bottom-up" nanofabrication?
- Key steps of top-down fabrication: deposition; etching; pattern transfer (photo, e-beam, and soft lithographies).
- Key steps of bottom-up nanofabrication: self-assembly (chemical, steric, and electrophoretic); solution chemistry; pattern transfer.
- Hybrid nanofabrication.
- Applications and phenomena, including: molecular detection arrays; molecular sorting structures; novel materials fabrication; molecular electronics; nano-fluidics; novel electromagnetic phenomena and devices; photonics; quantum size effects; and surface to volume effects.

A second existing course within the Department of Engineering Science and Mechanics also complements the effort to develop a minor course of study in nanotechnology. This course, entitled Nano/Microelectromechanical Systems (N/MEMS)/Smart Structures (E.Sci. 481/E. Sci. 581) is offered for both undergraduate and graduate students, and addresses the following topics:

- Materials
- Unit Processes
- Integrated Processes
- Applications (Sensors and Actuators)
- Smart Skins and Electronic Integration
- Control Algorithms and Systems
- Packaging Technologies

Recent efforts within the Department of Engineering Science and Mechanics have been aimed at revising and expanding the above courses into a set of 300 and 400 level experiences, which will include substantial hand-on laboratory components. Nanotechnology "modules" focusing on aspects of the technology would also be inserted into existing engineering science courses. These unique courses together with the modified courses with the nanotechnology modules would constitute a minor in nanotechnology.

Further, the Department of Electrical Engineering within the College of Engineering offers courses related to these efforts, including Solid State Device Technology (EE 418/EE 419), and is developing other related courses. Further, numerous federally sponsored nanotechnology research programs are now underway at Penn State, creating opportunities for undergraduate students in hands-on nanotechnology research. Integrating all of these ongoing efforts into a multidisciplinary curriculum offered across all relevant traditional majors is a key goal.

Much activity in the area of nanotechnology undergraduate education is underway within both the Pennsylvania NMT Partnership and Penn State. Over the coming year, an integrated approach will be pursued that leverages all of these efforts and activities to jointly develop a set of upper division Penn State undergraduate nanotechnology courses

and course modules. Various departments within Penn State will use these courses and course modules to create nanotechnology options, minors, and concentrations within existing degree programs. In addition, the NMT Partnership will be used to make these upper division nanotechnology courses and course modules available to State System of Higher Education institutions.

Such courses and course modules must have significant hands-on components and should make maximum use of the Penn State Nanofabrication Facility. Further, pathways will be designed to give graduates of the associate degree programs in nanofabrication at Pennsylvania's community colleges ability to matriculate into Penn State baccalaureate degree programs having the new nanotechnology options, minors, or concentrations. To achieve these goals, three activities are being undertaken:

1. Engage faculty members and administrators within various Penn State departments and colleges, and State System universities, in a process to jointly develop upper division nanotechnology courses of study. The aim of this effort is to develop nanotechnology options, minors, and concentrations within existing baccalaureate degree programs and avoid independent, piecemeal, duplicative efforts by the many relevant academic departments and colleges within Penn State as well as other Pennsylvania universities. The Penn State Department of Engineering Science and Mechanics is providing overall leadership for the effort. Other participants include the Penn State Department of Electrical Engineering, the Penn State Department of Materials Science and Engineering, the Penn State College of Education, the State System of Higher Education, and others.

2. Jointly design one 300-level and one 400-level undergraduate nanotechnology course, with significant hands-on laboratory components, to be offered across colleges and departments within Penn State and by State System universities. There is an immediate need within the Pennsylvania NMT Partnership and Penn State for upper division undergraduate courses in nanotechnology. These courses should have substantial hands-on laboratory components, and be offered across multiple departments and colleges within Penn State as well as other institutions. The Penn State Nanofabrication Facility should be fully leveraged. With these as the broad, guiding principles, an effort will be undertaken to design one 300-level and one 400-level course in nanotechnology, leveraging existing components where available. The two courses will be developed following a standard, systematic instructional design approach (See: Seels and Glasgow, 1998; Dick and Carey, 1996).

3. Create a "two-plus-three" baccalaureate degree program through which qualified graduates of community college associated degree programs in nanofabrication can complete a Penn State Bachelor of Science in engineering with minor in nanotechnology in three years. Graduates of community college associate degree programs in nanofabrication will have the opportunity to obtain an ABET accredited Bachelor of Science in engineering with a major in engineering science and a minor in nanotechnology, through the Penn State Department of Engineering Science and Mechanics. Engineering science is the undergraduate

honors program of the Penn State College of Engineering for students who demonstrate superior academic potential or achievement. The community college graduates will complete the nanofabrication minor over three years because of the calculus-based math and physics required for the Bachelor of Science degree in engineering with a major in engineering science.

This project is being carried out during calendar year 2002. The project team has been selected to ensure a strong mix of relevant expertise and a cross-section of academic and administrative units, and is being assisted by two graduate students. Formative and summative evaluation is carried out during the project period by the project team, and will continue in ensuing years as part of the ongoing evaluation activities of the Penn State Department of Engineering Science and Mechanics.

REFERENCES

Breslau, Karen, "Big Future in Tiny Spaces: Nanotechnology is Moving From Labs to Business," Newsweek, December 23, 2002, pp. 48-49.

Dick W. and Carey, L., The Systematic Design of Instruction, Fourth Edition, (New York: Harper Collins College Publishers), 1996.

Fonash, Stephen J., "Education and Training of the Nanotechnology Workforce," Journal of Nanoparticle Research, (2001, Vol. 3, pp. 79-82)

Hallacher, Paul M., Stephen J. Fonash and Douglas E. Fenwick, "The Pennsylvania Nanofabrication Manufacturing Technology (NMT) Partnership: Resource Sharing for Nanotechnology Workforce Development", International Journal of Engineering Education, (2002, Vol. 18, No. 5)

Hallacher, Paul M., Stephen J. Fonash and Douglas Fenwick, "A Regional Center for Manufacturing Education in Nanofabrication", Proceedings of the 2002 Conference of the American Society for Engineering Education, June 2002

National Science and Technology Council, "Natonal Nanotechnology Initiative: Leading to the Next Industrial Revolution," A Report by the Interagency Working Group on Nanoscience, Engineering, and Technology, Committee on Technology, February, 2000).

National Science and Technology Council, Committee on Technology, Subcommittee on Nanoxcale Science, Engineering, and Technology, "National Nanotechnology Initiative: The Initiative and Its Implementation Plan," (July, 2000).

Pennsylvania State University, Nanotechnology Undergraduate Education: A Report and Recommendations Based Upon a Workshop Held On September 11-12, 2002 at the National Science Foundation, Stephen J. Fonash, Organizer, September 11-12, 2002.

Seels B. and Glasgow Z., Making Instructional Design Decisions, (Upper Saddle River: Merrill), 1998.

Siegel, Richard W., in "Nanostructure Science and Technology: A Worldwide Study," National Science and Technology Council, (September, 1999).