# Nanomaterials Science and Engineering: An Enabling Paradigm Shift for Photonics, Energy, Electronics, and Biology

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## Abstract

The Department of Ceramic and Materials Engineering at Rutgers, The State University of New Jersey (http://ceramicmaterials.rutgers.edu/) has developed a sequence of multidisciplinary courses in the field of nanomaterials and nanotechnology as part of a NJ Commission on Higher Education grant. These courses are team taught by faculty members from School of Engineering Departments, Chemistry, and Physics, giving the students an opportunity to learn the material in an interdisciplinary environment. In addition to developing the courses, the department has also created an aggressive outreach program including research internships for high school students and college undergraduates, half-day symposia, and newspaper science pages, resulting in an increase in students selecting ceramic and materials engineering as their major.

## Introduction

In 2001, the NJ Commission on Higher Education (CHE) introduced the High-Tech Workforce Excellence Grant to help New Jersey colleges and universities develop nationally recognized programs of technology excellence and give local businesses the quality workforce they need.[1] From a group of 58 proposals, nine awards were made including Nanomaterials Science and Engineering (NMSE): An Enabling Paradigm Shift for Photonics, Energy, Electronics, and Biology. The total award was a $2.5 million grant award from the New Jersey Commission on Higher Education in addition to $3.2 million of matching funds from the School of Engineering and the Rutgers University Vice President for Academic Affairs

The grant had 8 goals designed to benefit the students and the department. The first goal was to renovate undergraduate laboratories, providing $2.3 million in new state-of-the-art equipment. This equipment is used in the seven new undergraduate elective courses in nanomaterials developed in accordance with the second goal. These classes include three laboratory courses. The third goal is to provide local industry with graduates that have an appropriate level of excellence in concepts important to the field of nanomaterials and nanotechnology. This curriculum development is being spearheaded by new faculty members who were hired in fulfillment of goal number four of the grant. Goal number five is the development of high school and elementary school outreach programs. These programs are designed to raise an interest in the opportunities that exist in nanotechnology and the role that materials development will play. These programs are also intended to educate teachers about the field and to encourage them to introduce these concepts and opportunities in their classrooms. The sixth goal is to provide summer research internship experiences for high school and undergraduate students in the department's laboratories. These experiences give the students hands-on experience in working in science and engineering. It is also a way to let students know what materials science is for those who would not usually be exposed to the field. The next goal is to identify industrial cooperative learning experiences for the department's undergraduate students. Finally, the goal of any vibrant department is to improve itself in the eyes of its peers. The goal is to increase the quality and reputation of the department. Thus far, feedback from the materials science national academia has been quite positive as they learn about this program. For more information regarding the grant, see http://ceramicmaterials.rutgers.edu/NMSE/. This paper describes a number of the outcomes and successes resulting from the NJ CHE program in nanomaterials.

## Rationale for CHE Workforce Excellence Program

For a number of years, the NJ CHE has recognized that one of its goals is to identify areas of industry that will be critical to the economic environment of New Jersey and expend resources in those areas. Despite these efforts, the fact remains that surpluses and shortages within the labor market are difficult to respond to in a timely fashion with the appropriate number of well-prepared college graduates.[2] Therefore, the Commission identified and awarded High-Tech Workforce Excellence Grants in four pivotal academic areas in a effort to improve the state's position in the global marketplace:

- Computer Science and Information Technology
- Physical, Life and Health Sciences
- Engineering and Engineering Technology
- Science and Mathematics Teacher Education[1]

"The road to developing a world class economy in New Jersey begins with high-tech workforce training. The world we send our graduates into each year is continually becoming more global, and they need up-to-date technical skills to succeed," said Donald T. DiFrancesco, the acting Governor when the awards were announced. He continued, "By providing greater investment in the programs that supply these skills we respond directly to the needs of New Jersey's employers."[4] The CHE believes that these higher education programs will help to improve the workforce, create new jobs, and boost the overall economy of New Jersey.[1] As such, the state's institutions of higher learning have a responsibility to develop courses to educate scientists and engineers to develop and use new technologies as these new processes and technologies as they are adopted by New Jersey businesses.[3]

## Rationale for NMSE Workforce Excellence Program

According to the National Science Foundation (NSF), worldwide need for the nanotechnology workforce will be about 2 million in the next 15 years.[5] It was estimated that 800,000 to 1 million of this workforce would be needed in the United States. Furthermore, the NSF approximates the current number of nanotechnology workers at about 20,000 worldwide.[5] Creating this workforce is both a challenge and an opportunity for U.S. colleges and universities. The opportunity arises from the fact that someone must provide this education and expertise. For the U.S. to remain a world leader in technology and science, that someone needs to be U.S. institutions of higher learning. The number of students graduating from this nation's institutions of higher learning has increased approximately 1.5% per year since 1985 to 1,237,875 in 2000. However, the number of engineers graduating in the same 15 years has decreased about 1% per year from 76,225 to 58,427. From the peak in 1985, where 7.7% of college graduates received an engineering degree, the percentage of engineering degrees conferred has dropped to 4.7% of total degrees.[6] The enrollment in the science, technology, engineering, and mathematics programs presents a huge challenge to U. S. universities and colleges.

Other troubling statistics compounded the situation for the CME department at Rutgers. Over the past decade, the ceramics industry in America has been undergoing a significant decline, while the broader materials industry is growing. The decline in the ceramics industry is indicated by the membership in the professional societies. Since 1990, membership in the American Ceramic Society is down 36.2%, from 10,430 regular members to 6,653 in 2001. Student membership has seen an even more drastic decline, down 60% to less than 800 individuals. Meanwhile, membership in The Materials Research Society (MRS) has consistently shown a modest increase over the same time period, from 8,619 regular members in 1990 to 9,845 or 14.2%. Student membership increased from 1,819 to 2,727 over the same time period, or 49.9%. Overall, MRS membership has increased 20.4% in this time.[7] This data trend is an indication of how the materials industry is shifting away from a materials-specific focus, i.e. ceramics, toward the broader, more inclusive "materials systems" focus. The student membership statistics are particularly telling in that they indicate a shift of many ceramic engineering programs to materials science & engineering (MSE).

The department has seen a parallel decline in its undergraduate enrollment, from >50 seniors for the class of 1990 to a low of 17 for the class of 2005. While this decline in enrollment is not unique to this ceramic engineering curriculum at Rutgers, the trend is troubling. The department felt that the addition of seven NMSE undergraduate elective courses would help revitalize the curriculum while filling an identified need.

These new classes have the potential to excite a percentage of students already in engineering school. This new interest in nanomaterials may help counter the decline of enrollment in ceramic engineering, but it does little to deal with the decline of enrollment in engineering disciplines. Therefore, an aggressive outreach program is an integral part of the activities in the grant. These programs will be discussed in detail in a later section of this article, but they include professional development opportunities for local teachers, open houses for high school students, internships for high school students and college undergraduates, and appearances at NJ science teacher events.

Naturally, students expect that the education they receive will be from experts and leaders in their fields. In order to make the NMSE program a success, faculty members with research expertise in nanomaterials and nanotechnology are critical. In order to spearhead the development of these courses, and the overall program, new faculty members were hired in the areas of nano-biomaterials, synthesis and development of nanostructures, electronic materials processing, and energy materials. These individuals, Dr. Manish Chhowalla, Dr. Adrian Mann, and Dr. Dunbar Birnie, III have made and will continue to make a strong impact on the future maturation of the courses and the program.

## New Courses

The primary purpose of the grant is to provide the students with education and experience that prepares them to be a part of the expanding nanotechnology workforce. This goal is accomplished through the introduction of new courses. The successful completion of the four lecture courses earns the student a certificate of completion of the nanomaterials curriculum. The four lecture courses are (1) Introduction to Nanomaterials Science and Engineering, (2) Structural, Mechanical and Chemical Applications of Nanostructures and Nanomaterials, (3) Photonic, Electronic and Magnetic Applications of Nanostructures and Nanomaterials, and (4) Biological Applications of Nanostructures and Nanomaterials. The seven courses are rounded out by lab courses associated with the latter three lecture courses. The following is a brief synopsis of each lecture course.

### Introduction to Nanomaterials Science and Engineering

Nanotechnology involves behavior and control of materials and processes at the atomic and molecular levels. This interdisciplinary course introduces the student to the theoretical basis, synthetic processes and experimental techniques for nanomaterials and nanotechnology. This course is the introduction and a pre-requisite for 3 advanced courses in (1) Photonic, Electronic and Magnetic Applications of Nanomaterials and Nanostructures, (2) Structural, Mechanical and Chemical Applications, and (3) Biological Applications. Students interested in nanomaterials science and engineering should take this Introduction first, and then choose 1 or more of the advanced courses. Course topics include the synthesis of nanomaterials, clusters, particles, fullerenes via different methods, such as the vapor phase, liquid phase, aerosols, laser methods. The class also covers nanofabrication methods, including lithography and thin films and e-beam deposition. Particle consolidation and crystal growth kinematics is followed by characterization techniques like scattering, diffraction, and atomic force microscopy. The course also includes properties and applications of nanomaterials and nanotechnology.

### Structural, Mechanical and Chemical Applications of Nanostructures and Nanomaterials

Topics covered will be fundamentals of grain boundaries and surfaces, application of nanomaterials to batteries, fuel cells and catalysts and mechanical applications such as hardness, yield strength, superplasticity, tribology and wear, micro-electro-mechanical systems (MEMS). Students are expected to develop an understanding and appreciation for nanomaterials technology, learn to seek out the literature on current research topics, develop an understanding of new techniques used in studying nanomaterials, and understand some of the theory describing differences between nanostructured and microstructured materials.

Photonic, Electronic and Magnetic Applications of Nanostructures and Nanomaterials

This course has been formulated to complement the other nanomaterials-related classes currently being offered within the Department  The focus in this class is nanomaterials synthesis, characterization and application "by design" for optical, electronic, optoelectronic, and magnetic materials.  The basic physics and fundamental mechanisms responsible for nanoscale-induced changes in properties are stressed.  Representative advances in each of the targeted topical areas are discussed and examined to provide students with some insight with regard to the potential future impact of nanomaterials and nanotechnology. This course is designed to introduce students to the fundamental changes in photonic, electronic, and magnetic properties which occur when particle sizes approach atomic and molecular dimensions.  It provides students with linkages between, for example, changes in electronic band structure of materials as more atoms reside near the surface of nanoparticles and the modification of physical properties that takes place.  A goal is to provide students with a design tool based on nanotechnology that will allow them to engineer next generation materials and devices. This course is designed to give students an appreciation of the different properties offered by nanostructured materials, particularly when it comes to their interactions with light, electric and magnetic fields.

Biological Applications of Nanostructures and Nanomaterials

This course is divided into 4 different sections: nanoscale in biology and biomimetic materials, characterization and fabrication of nanoscale systems and devices, nanodevices in medicine, and current applications.  The first section looks at the nanoscale structure of natural and artificial materials such as mineralized tissues, apatite crystals, organic/inorganic matrices, precipitation, artificial bone, cell structure, membranes, actin, macromolecules, bioadhesion, ligand-receptor interactions, collagen structure, bone morphogenic proteins, cell migration, cell attachment, phagocytosis, macrophage response.  The next section identifies and discusses how to characterize them with tools such as scanning probe microscopy and nanotweezers.  It also looks into how these materials are made, artificially and naturally via electron microscopy, molecular manufacture, nanofabrication, nanolithography, focused ion beam, and electron beam lithography.  Next, devices used in nanomedicine are discussed. Topics such as navigation, manipulation, locomotion, power, specificity, design parameters, capabilities, limitations, surface and intermolecular forces, and viscous forces are talked about. The course concludes with current applications such as DNA manipulation, artificial skin, nanosensors, communication, drug delivery, molecular sorting, hard tissue engineering, soft tissue engineering, cell response to nanotexturing, and nanoparticles for magnetic imaging.

Structural, Mechanical, and Chemical Applications of Nanostructures and Nanomaterials Lab

This laboratory course consists of five modules (1) Hot Pressing of Nanocrystalline Superplastic Powders; (2) Nanomechanical Testing; (3) Atomistic Modeling and Simulation of Nanomaterials; (4) Evaporation-Condensation Synthesis of Nanoparticles; and (5) Nanomaterial Batteries. Students get hands-on experience in experiments instructed by the faculty member(s) and/or TA in charge of each module in the faculty member's research laboratory.  Each module consists of two 3-hour sections in consecutive weeks.  Students combine scientific understanding from the corresponding lecture course with hands-on experience in experiments in the research laboratory.  They also learn how to use start-of-the-art instrumentation and advanced experimental methods in nanomaterials science and engineering and are exposed to frontier research areas in nanomaterials science and engineering.  Ultimately, through the lab instruction, they develop an experimental understanding of structural, mechanical, and chemical properties of nanomaterials and their applications.

Photonic, Electronic and Magnetic Applications of Nanostructures and Nanomaterials Lab

This course consists of two multi-week lab modules.  The first is Plasma Enhanced Chemical Vapor Deposition of Carbon Nanotubes.  In this laboratory, the process for synthesizing aligned multi-walled carbon nanotubes using PECVD will be completed from start to finish.  The experiments are designed to expose you to various vacuum and plasma apparatuses routinely used in nanotechnology.  In addition, you will also use two very important nano-analytical instruments, the atomic force microscope (AFM) and the scanning electron microscope (SEM). The module will consist of following experiments:

1. Cleaving, cleaning and patterning of silicon substrates and loading them into the sputtering vacuum chamber.
2. Sputter deposition of ~ 5nm $SiO_2$ diffusion barrier layer and the 5nm Ni catalyst thin film.  In addition to thin film catalyst, nanometer sized Co and Fe catalyst particles will also be deposited by dipping some $SiO_2$/Si substrates in Co/Fe acetate solution.
3. Observation of Ni thin film and acetate catalysts using the AFM.  Also, the thickness of the thin film will be verified using the AFM.
4. The catalyst coated substrates will be annealed to $600^{o}$C on the graphite heater in our PECVD system.  The break up of the catalyst thin film into islands will be verified using the AFM.
5. The catalyst islands will be placed back into the PECVD chamber and nanotube growth will be initiated.
6. After nanotube growth, the substrates will be examined in a scanning electron microscope. The SEM should allow us to view the structure, density and orientation of nanotubes.

The other lab module consists of 1) Preparation of  silica preforms by the MCVD process, 2) Synthesis of rare earth doped nanopowders by chemical vapor condensation (CVC), and 3) Optical characterization of the MCVD and CVC specimens to show spectral variations and differences as a function of processing.

Biological Applications of Nanostructures and Nanomaterials Lab

This course consists of four lab modules, which each student is to complete.  These labs consist of (Experiment 1) BET Surface Area Measurement of Trabecular Bone, Cortical Bone, and Hydroxyapatite (HA) Powder, (Experiment 2) Particle Size Measurement of HA Particles by Dynamic Light Scattering, (Experiment 3) Electrophoresis of HA Particles at Different pH Values Introduction using Brookhaven ZetaPals, and (Experiment

4) Atomic Force Microscopy for Trabecular and Cortical Bone Sections.

In Experiment 2, average particle size and size distribution of hydroxyapatite samples are measured. The determination of particle size is a very important issue when dealing with nanoparticles, such as hydroxyapatite particles because this information might affect different material properties (mechanical, electrical, optical, etc.) of the final product. Dynamic Light Scattering (DLS) is a very useful method to do this. Colloidal suspensions exhibit a wide range of particle sizes, and in many cases, it is necessary to know the number of particles in each size range rather than just knowing the maximum or minimum particle size in the suspension. Although distribution of particles sizes is interpreted per weight or number basis, there are other averages like surface average, volume average, etc which are also examined. Before performing the experiment, students perform literature searches and predict what results they expect to get from the experiment. They also must research the equipment to determine its capabilities.

Each course is team-taught, meaning that more than one professor is responsible for the course material and instruction. The course that takes the most advantage of this is the Introduction to Nanomaterials Science and Engineering class. Professor Lisa Klein is the class coordinator, but lectures are given by 9 other professors from the Ceramic and Materials Engineering, Physics, Chemistry, Electrical and Computing Engineering, and Mechanical and Aerospace Engineering. Students from different departments take the class, resulting in classroom discussions that are very lively and students share their different points of view. An example of this is a question that was asked on the midterm exam the first time the class was offered. While the students were urged to keep an open mind and try new approaches, their tendency was to be somewhat focused. Notice the question and responses to the problem. Prof. Vicki Colvin, Rice University, has an excellent web site for those interested in nanotechnology. She poses a riddle called the French Knives. The riddle goes like this:

*Imagine you had a knife, which you cut in half, then cut in half again, then again and again and again. At what point would the knife no longer be a knife? Here are 4 possible answers:*

A. *When you could no longer pick up the knife.*
B. *When the cutting edge of the knife became too small to cut.*
C. *When there was only one atom of the metal blade left.*
D. *When you could no longer see the knife pieces*[8]

What was interesting was the bimodal response to this question. None of the students considered the answers “no longer see” or “no longer pick up” as the best answer. The engineers in the class strongly supported the answer relating to the function of the knife, that is, when the cutting edge became too small to cut. The physicists chose the answer when only one atom was left, even though some speculated that given enough acceleration, even one atom could cut. The materials scientists disputed the idea of one atom, since most materials are alloys and compounds. In the end, this exercise was instructive in illustrating the focus that the engineers place on function. This is not to say that such a focus is wrong; it only serves to illustrate the divergence taken by engineering students and science students at an early stage of their college experience. A lesson here is that while some separation of the roles of engineers and scientists is inevitable, it is important to maintain enough common ground between them that they can communicate and collaborate. The interdisciplinary, team-teaching approach to the NMSE courses does this very well.

Another reason this multidisciplinary approach is critical is the working environment that most graduating engineers now face. Ten years ago, a department graduate was likely to end up working for a large, integrated manufacturing company. This model no longer holds. These classes aim to prepare students to work in the field of field of materials and nanotechnology. Presumably, many of the jobs in this field will be in small companies and start-ups, where one cannot go down the hall to the Engineering Division or the Analytical Laboratory for advice! These students are going to need to communicate and solve problems with scientists and engineers that have been exposed to different training, education, and experiences. The nanomaterials courses are excellent models to test ways to solidify the concept that problems are solved by trying many ideas and by making an informed choice. No matter how many times it has been said that an engineer has to deal with an interdisciplinary team, undergraduate engineers seem to reach senior year thinking that they will join a company populated entirely by engineers with their same degree. A few years later, of course, they return to their professors acknowledging that they should have listened when they were told that they would be interacting with other disciplines, both technical and non-technical. A goal of designing these courses has been to make thinking and problem solving in an interdisciplinary team second nature by giving the students experience in other disciplines as early as possible.

Faculty who have participated in the teaching of these courses is listed in Table 1.

Table 1 Faculty Teaching Participants

| Name | Department |
|---|---|
| Roger Cannon | Ceramic and Materials Eng. |
| Steve Garofalini | Ceramic and Materials Eng. |
| Mina Pelegri | Mechanical and Aerospace Eng. |
| Stephen Tse | Mechanical and Aerospace Eng. |
| Bernard Kear | Ceramic and Materials Eng. |
| Jun John Xu | Ceramic and Materials Eng. |
| Adrian Mann | Ceramic and Materials Eng. |
| George Sigel | Ceramic and Materials Eng. |
| Richard Riman | Ceramic and Materials Eng. |
| Manish Chhowalla | Ceramic and Materials Eng. |
| Michael Gershenson | Physics |
| B. Jane Hinch | Chemistry |
| Thomas Tsakalakos | Ceramic and Materials Eng. |
| Yicheng Lu | Electrical and Computer Eng. |

Since the inception of these courses, the enrollments have increased steadily. Even when the introductory course was offered both in the Fall and Spring semesters to increase the number of students with the prerequisite for the advanced topical course, the enrollment has remained at greater than 20 students. The number of students from departments other than Ceramic and Materials Engineering has increased to more than half of the students each semester. The courses are being recommended more widely to satisfy technical electives.

The new faculty members have been critical to designing the courses, as well. Dr. Adrian Mann studies the early stages of diseases in mineralized tissues, including dental caries and osteoporosis in bone, using nanoscale materials characterization techniques. Using AFM, near-field scanning optical microscopy, and advanced modeling techniques, Dr. Mann studies the deposition, growth, chemistry and mechanics of thin protein films on biomaterial surfaces. This research is essential to understanding how the human body responds to man-made and natural biomaterials. His research and expertise is critical to the design of the Biological Application of Nanostructures and Nanomaterials Lecture and Lab courses, which he coordinates. This course is popular with both ceramic and materials engineering and biomedical engineering students.

Dr. Manish Chhowalla's research is geared towards synthesis and applications of carbon and related nanomaterials. He and his research group aim to efficiently synthesize and understand the growth mechanism of carbon nanomaterials such as single and multi-walled nanotubes, nano-onions and single wall nanohorns and to utilize them in electronic, energy storage, and biological applications. These research interests give him the background to coordinate the Photonic, Electronic and Magnetic Applications of Nanostructures and Nanomaterials Lecture and Lab courses. Professor Mann and Chhowalla both joined the faculty in 2002 and have made an immediate impact on the teaching of these courses.

Another new faculty member that will have a positive and immediate impact upon these courses is Dr. Dunbar P. Birnie, III, who recently joined the department faculty as the Corning/Saint-Gobain /Malcolm G. McLaren Distinguished Chair in Ceramic Engineering. His research mainly focuses on spin coating and sol gel science. Applications for his work include inorganic and organic thin films for dielectric/insulating layers for microelectronics fabrication, magnetic disk coatings, flat screen displays, television tube phosphors antireflection coatings, and photoresist for defining patterns in microelectronic circuit fabrication. Professor Birnie's other research interests include ferroelectric device fabrication, phase transformation modeling, solid state chemistry and point defect properties, crystallography and structure determination, phase diagram determination, and advanced nanomaterials for solar energy applications. Dr. Birnie joined the faculty in August 2004.

## Program Outcomes

### NanoDay

A very successful outreach event that was started in conjunction with the CHE grant is NanoDay. NanoDay is a semiannual event targeted toward local high school and middle school teachers and their students. Teachers receive a short training on concepts of nanomaterials that they can introduce in their classrooms and curricular materials to assist them. The day begins with a breakfast reception, followed by an introduction from department faculty. The guests are given a brief introduction to the School of Engineering and the CME department. A short presentation on the nanomaterials curriculum and the motivation for NanoDay and other outreach events follows. The visitors are then given a tour of the facilities and an introduction to the research that is being conducted within the participating departments. During the tours, the guests get a chance to interact with the Rutgers students who lead the groups.

After the tours, the high school students get an introduction to the summer internship program. We usually get one or two interns to come back and speak about their experiences with the program. During this session, the students are given the opportunity to interact during a hands-on demonstration of some applications of nanomaterials.

At the same time, the teachers work with Professor Holly Crawford during a "Teach the Teachers" session. Topics of discussion include ways in which the CME faculty at Rutgers could work with individual schools to help integrate nanotechnology topics into their curriculum, government funding opportunities for secondary school teachers designed to help further their education in nanotechnology, and expectations secondary school teachers have from university professors with regard to educational partnerships and outreach programs. More importantly, the teachers are given an "Exploring the Nanoworld" (Materials Research Science and Engineering Center at the University of Wisconsin-Madison) kit, and are given a few pointers on how to use it in their classroom. One of the more tangible experiments in the kit involves the diffraction gratings. This makes a wonderful analogy of how x-ray diffraction is used to study crystal structure and has been useful in providing evidence for many scientific findings, including the double helix structure of DNA. The day is then completed with a catered lunch and light discussion of future opportunities that may exist between Rutgers and the visitors. More information about the program is available at http://www.ceramicmaterials.rutgers.edu/NMSE/nanoday.php.

The first NanoDay attracted 14 teachers and the same number of students, while the most recent attracted almost 25 teachers and close to 70 high school students!

The target for NanoDay is teachers, and a significant portion of the day is spent in developing relationships between department faculty and the teachers. The motivation for this approach is that it is difficult to make a significant impression on a large number of students throughout the year. If the department hosts two NanoDays each year with 20 teachers and 50 students each, it only sees 100 potential students for a few hours. On the other hand, the 40 teachers interact with 100 each on average for 10 months out of a year. That's 4000 students! Teachers develop personal relationships with their students and can provide information to them in their college or major decision-making. Teachers' input will carry a significantly larger impact on the students' decision-making than 4 hours in our department.

It is also considerably more efficient to keep in touch with teachers than students. Once teachers find a school district they are happy with and tenure begins, they normally do not move on to new districts. The logistics of dealing with a list of students and keeping track of whether they are sophomores, juniors, or already graduated is time consuming. Keeping the teachers up-to-date on the department's activities is easy to do with an email every few months, even if it is simply to invite them to the next event or to ask them to encourage their students to apply for the summer internship program.

### Summer Internship Program

The Summer Nanomaterials High School Internship Program has been a very successful program for the department as well. From late June to mid-August, in 2002-2004, the department has hosted 12-15 talented high school students to perform summer research with Rutgers faculty and staff in the area of nanomaterials and nanotechnology. Project topics include: nanomaterials for energy storage in batteries and hydrogen storage for fuel cells, synthesis of carbon nanotubes, materials for drug delivery, and nanolithography for electrical circuits. Students receive a nominal stipend of $500 for their experience. While it is likely they could make more money "flipping burgers" for the summer, this experience is obviously much more meaningful to them.

Through the contacts the department has made with high school teachers, supervisors, administration, etc, advertising the internships is straightforward. Teachers are enthusiastic about encouraging their best and brightest to apply for these internship positions which makes each position very competitive. Not only is it a great experience for the student, but teachers are proud of their students and want to see them succeed. For the Summer 2004 internship, we received 57 applications for 12 spots! Needless to say, selecting the twelve participants was very difficult. Student selection is an exciting opportunity to invite a variety of excellent students to the campus. Over the three years of the program, 47% of the participants in the internship program have been from groups that are traditionally underrepresented in science and engineering. This is consistent with Rutgers University's commitment to a diverse student population.

Students participating in this internship are also encouraged by their teachers and the department to submit their research to local and national competitions. In fact, a number of these students have had success in these competitions. Among the honors are 1st prize at the 41st annual Monmouth Junior Science Symposium hosted by Monmouth University (Student: Leo Barinov, Mentor: Dr. Michael Gershenson), an American Chemical Society scholarship and Project SEED scholarship (Bader Scholar) (Daniel Diaz, Dr. Richard Riman, Second Place in the Hudson County Science Fair (Ubaldo Espinal, Dr. Jun John Xu), and a Gold Medal at the Regional International Science and Engineering Fair at the Liberty Science Center (Thong Vo, Dr. Richard Riman). Leo Barinov was also invited to present at the National Junior Science and Humanities Symposium in Colorado Springs, Colorado. These honors serve to show that these wonderful students had a bona fide research experience that wasn't watered down. These students made the most of their opportunity and learned a great deal about research, engineering, and science.

In addition to the research they performed, the students had the opportunity for enrichment activities such as visiting the NJ Nanotechnology Consortium (NJNC) at Lucent Technologies at Murray Hill. The NJNC, launched in early 2003 by Lucent Technologies, the State of New Jersey, and the New Jersey Institute of Technology, provides NJ companies and universities access to world-class nanotechnology research plus development services. The students got a chance to see the 16,400 $ft^2$ of class 100/10 clean room and the 3,600 $ft^2$ class 100 electron-beam facility (one of the world's only nanolithography e-beam tools), both of which are essential in the production of nano-devices.

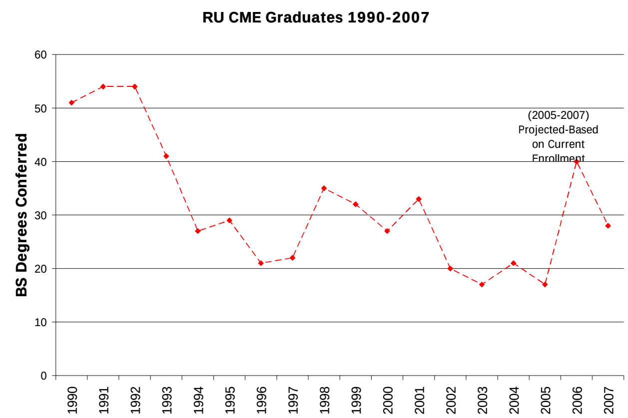
The NJ Governor's School for Engineering and Technology is held at Rutgers each summer and the department participates in the program by hosting approximately 10 students and allowing them to work in the laboratories. A typical project focuses on processing of nanoparticles via the sol-gel process. These students are typically some of their schools' brightest so exposing them to materials science and engineering is an exciting prospect for our department.

Increased Department Enrollment

As indicated earlier, the department's enrollment has been decreasing since the early 1990's. This has been a disturbing trend and is similar to what is seen nationally.

Figure 1 shows the department's graduation statistics and current enrollment since 1990. Due to these outreach efforts and to an increased focus on individualized recruiting, the enrollment for the class of 2006 jumped an impressive 135% in one year. The Class of 2007 enrollment was a bit disappointing, but was still an improvement over the past few years and serves a reminder that recruiting is an "all the time thing," not a quick fix. For the Class of 2006, enrollment was aided by certain professors who met individually with students who had expressed an interest in ceramic and materials engineering after the orientation lectures that first-year students receive from each department. The department was not as attentive to the benefits of doing this with the class of 2007, but it intends to continue this time-consuming, yet effective, process with the Class of 2008.

Figure 1: CME Department Graduates and Current Enrollment




The fact of the matter is, however, that the results of our labor in terms of the outreach events and relationship building with teachers will not be known for a few years still, since the high school students that come to NanoDay are sometimes freshmen or sophomores and won't even be in college for two or three years. Additionally, relationship building with teachers takes time. Teachers will not learn all about ceramic and materials science and engineering after a few hours at an outreach event.

Another positive outcome is that of the enrollment of the classes in the NMSE curriculum. As mentioned previously, the enrollment has been steadily increasing as more departments recommend these classes to their students in fulfillment of technical electives. This increase is good news for the future as seniors and juniors recommend them to the students who will take the courses in the future. As word spreads, more people will be interested and learn more about materials. These undergraduates from other majors are not likely to change their major, but there is a chance to inspire them to graduate study in materials.

## Future Directions

While these programs have been quite successful, there is more work to be done if the department is to continue to increase its enrollment and the recognition of nanomaterials science and engineering as a major option for students. The department is looking into the possibilities of offering new programs such as a summer institute for teachers. This summer institute would provide the participating teachers with knowledge, hands-on experience, curricular materials, and a background in concepts of materials science. While ideas for this program are still in its infancy, the department is looking forward to introducing new programs and opportunities for attracting and educating today's elementary, middle, and high school students.

## Summary

The Ceramic and Materials Department at Rutgers, The State University has implemented exciting new undergraduate courses in nanomaterials science and engineering and outreach programs to excite high school teachers and students about ceramic and materials engineering. The seven new courses offer both education in the newest technologies and actual experience using those technologies. After taking the courses, students are prepared to knowledgably enter the workforce equipped with an understanding of recent research and concepts relating to nanotechnology. Similarly, the high school students who participate in the internship program and the outreach events, such as NanoDay, leave the programs with a increased sense of the opportunities that exists in nanotechnology and materials science. While the department still feels there is work to be done, significant progress has been made toward the goals outlined in the grant and towards the overall goals of the department.

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