# GRADUATE EDUCATION FOR PARTICLE SCIENCE AND TECHNOLOGY

## At The NSF Engineering Research Center

## — A Model for the Future —

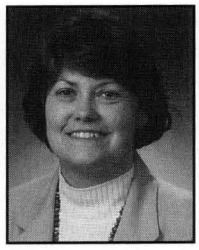
ANNE E. DONNELLY
*University of Florida • Gainesville, FL 32611*

The need for change in the traditional graduate engineering curriculum was described in 1995 by the Committee on Science, Engineering, and Public Policy[1] (COSEPUP), which documented that less than half of all new PhDs enter academia. In recognition of this shift, the Committee called for graduate education to move away from a narrowly defined, single-department focus to a broader student experience. There was acknowledgment by the Committee that students were not being prepared to function in the multidisciplinary environment that characterizes industry today.

This call for a "new PhD" coincided with publication of a paper[2] by three industrial researchers, Ralph Nelson and Reg Davies of DuPont, and Karl Jacob of Dow. This group also called for a shift in engineering education to allow the chemical industry in the United States to remain competitive in the global market. The following summarizes the key concerns described in this report:

- Particle processing is of major importance to many industries
- The need for researchers trained in Particle Science and Technology (PS&T) is increasing
- Foreign companies have an advanced mastery of the application of particle science to chemical processing
- The U.S. engineering curriculum has not adequately prepared students in the field of particle technology
- To meet industrial needs, U.S. companies must recruit graduates from abroad

***Anne E. Donnelly*** *is the Associate Director for Education and Outreach at the ERC. She manages the ERC educational programs, including Graduate Student activities, the Undergraduate Research and Scholarship Awards, module and textbook production, and consults with the Industrial Partners Program on particle science and technology issues of mutual concern.*





A growing recognition of the need for an educational program that focuses on PS&T, coupled with a call for a move away from traditional single-discipline degrees, coincided with the development of a program at the NSF Engineering Research Center for Particle Science and Technology at the University of Florida. The NSF concept behind the development of engineering research centers (ERC) was to foster collaboration between government, universities, and industry to enhance the competitiveness of American industries and to promote new educational models to meet the changing needs of research and industry. The establishment of a national center for PS&T with a focus on multidisciplinary research provided a venue for answering industry's need for students adequately trained in this heretofore neglected, but critical, field.

### INTERDISCIPLINARY ORIENTATION

Particle science and technology is by its very nature a multidisciplinary field. Fluidization operations, particulate separation, and colloidal and interfacial phenomena are just several of the areas of PS&T relevant to chemical engineering. Particle science issues can also be found in materials science and engineering, chemistry, physics, microbiology and cell science, computer and information sciences, and in

environmental, biomedical, aerospace, mechanical, coastal, and agricultural engineering. This makes an interdisciplinary approach necessary.

The fit between engineering research centers across the country and the recommendations made by the COSEPUP report were discussed at the 1996 ERC annual meeting and were summarized by Costerton.[3] The ERC for PS&T has established a graduate education program that simultaneously meets the mandate for a new PhD described by COSEPUP and the request from industry for U.S.-trained students in PS&T. The Center currently funds fifty graduate students. They are assigned to work with one of the ERC faculty members and are registered with the home engineering or science department of their major professor. They receive their degree from the home department while participating in research projects funded by the ERC. This increases the breadth of the student experience while at the same time giving the student a firm foundation in a traditional discipline.

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ERC graduate students are assigned to one of five research thrust groups:

- ▶ Advanced Measurements and Characterization
- ▶ Advanced Separation Processes
- ▶ Dispersion, Agglomeration and Consolidation
- ▶ Engineered Particulates
- ▶ Transport and Handling

There is also a recently added Targeted Technology Team Project initiative in Chemical and Mechanical Polishing

Chemical engineering students work in these research groups with students from many other departments. For example, chemical engineering students in the Advanced Separation Processes thrust group work with graduate students from materials science and engineering, environmental engineering, and microbiology and cell science. These students meet weekly with the thrust group faculty members to make research presentations and to discuss current projects. Faculty representation in the thrust groups also reflects the multidisciplinary nature of the field, so in addition to being exposed to students from other departments, these graduate students also have regular contact with faculty members from other disciplines. The ERC currently has 34 faculty members representing eleven different engineering and science departments. This "cross-talk" across departments allows students to become familiar with other departments and prepares them to function on the kinds of interdisciplinary teams that typify industry today.

Interdisciplinary team training is also a critical part of the training of those students entering academia. In order to train the students of the future using this new model, faculty must be able to function and demonstrate the skills necessary to work in interdisciplinary teams and the ability to collaborate across departments and with industry. The ERC for PS&T has brought together faculty from across campus, who themselves have had to learn to function in collaborative teams in order to foster these same skills in their students.

In addition to daily research and weekly group meetings, the ERC provides students with other opportunities to meet with and discuss particle science with students from all of the research thrusts. A monthly Student Seminar series provides a forum for students to practice presentation skills and allows students from other groups to learn about research projects in other labs. This series is also open to undergraduates, to encourage them to learn about research across the ERC.

## PARTICLE SCIENCE COURSES

The engineering curriculum has been enhanced by the addition of several courses in particle science available to both ERC and non-ERC students who desire to broaden their academic exposure to PS&T. Particle Science and Technology: Theory and Practice, Particulate Interfacial Systems: Science and Engineering, Physics of Colloids, and Optimization, Scale-Up, and Statistical Experimental Design have been previously described.[4] In addition, two other graduate-level courses dealing with particle science have been offered: Biomimetics and Biomineralization, which explores the mechanisms used by organisms to control mineralization in order to identify new biomimetic strategies for the engineering of particles and composites, and Numerical Simulation Techniques for Particle-Dynamics (see Table 1). These courses allow students to supplement their coursework with material covering a variety of particle science topics.

## INDUSTRIAL CONNECTION

An equally important feature of ERC graduate training is that the research conducted in the ERC is industrially relevant. The ERC has a network of industries that support its purpose of investigating particulate materials to enable the invention and development of innovative particulate processing technologies for new products and devices. These

industrial partners recognize the value of the type of training ERC students receive. In 1997, NSF published a survey of ERC industrial partners from across the country[5] that concluded that industrial partners who have hired ERC graduates ranked this connection to top-quality students as the most valuable benefit of ERC participation. Furthermore, industries that hired ERC graduates reported that they were superior to non-ERC-trained employees in items including breadth of technical understanding, ability to work in interdisciplinary teams, depth of technical understanding, and overall preparedness. These observations have been echoed by the industrial partners of the ERC for PS&T, who have made it clear that a key feature of the Center is the interdisciplinary model and that the traditional degree path is no longer adequate to meet industrial needs.

Graduate students benefit from this partnership with industry in many ways. They are invited to present their research work at the semi-annual meetings of the Industrial Advisory Board. All students are also given the opportunity to participate in poster sessions held at each meeting, during which industrial representatives have the opportunity to meet and discuss research progress with the students involved. These posters typically reflect the team approach by listing faculty, graduate students, and undergraduates who have contributed to the work.

The ERC culture provides additional opportunities for graduate students to enhance their knowledge of PS&T. The ERC sponsors several short courses each year on a variety of topics. These courses are offered to industrial representatives and attract approximately 150 attendees each year. A listing of courses held in the past two years is found in Table 2. ERC graduate students attend these session at no cost, exposing them to additional training in selected PS&T topics. Participation in these meetings facilitates communication between students and industrial representatives, thereby improving student understanding of issues confronting industry today. ERC students are also encouraged to attend and make technical presentations at professional society meetings and provides financial assistance when possible to facilitate these experiences.

## VISITING SCHOLAR PROGRAM

ERC graduate students have a unique opportunity to expand their awareness of global issues in PS&T as a result of the Visiting Eminent Scholar Program where world-renown researchers in PS&T are invited for extended visits to the ERC. While in residence at the Center, these researchers present seminar series or workshops that graduate students are invited to attend. Students may also arrange to meet one-on-one with the visitors to discuss areas of mutual interest. This exposure to internationally known researchers adds to the students' appreciation of the global perspective of PS&T.

**TABLE 1**
**Topics Covered in the Graduate Course "Numerical Simulation Techniques for Particle-Dynamics"**

| | |
|---|---|
| Section 1A | Overview of multiple-particle simulation techniques |
| Section 1B | Instantaneous collision models (primarily for spheres in 1, 2, or 3D) |
| Section 2 | Hard-sphere MD, collision detection, searching and computer-memory considerations |
| Section 3 | Soft-sphere simulations with engineering-mechanics contact models |
| Section 4 | Soft-particle code structure |
| Section 5 | Details of realistic-contact models (why quasi-static force-displacement relations work for dynamics) |
| Section 6 | Elastic frictional contacts (Mindlin's analysis, implications, and limits of validity) |
| Section 7 | Inclusion of other forces (Van der Waals, JKR, liquid meniscus, lubrication, and viscous effects) |
| Section 8 | Diagnostics |
| Section 9 | Simulation results |
| Section 10-15 | Detailed discussion on selected subtopics, including non-spherical particles, suspension models, dilute gas-solid models, continuum models, and others |

**TABLE 2**
**Selected Short Courses Offered by the ERC for PS&T**

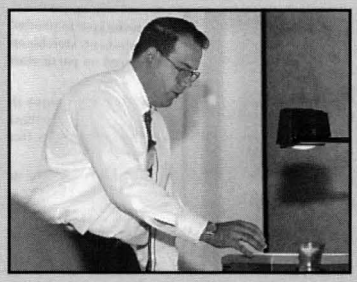
- Dispersion Technology: Fundamentals, Processing, and Applications
- Improving Standards in Particle-Size Measurement
- Surfactants: Principles and Applications
- Stability of Dispersions: Theory and Practice
- Solids Handling: Flow and Conveying of Bulk Solids
- Special Topics in Particle Science and Technology

**TABLE 3**
**Topics Covered in the Seminar Course on Professional Development**

***Section 1: Basic Tools for Conducting Successful Research***
- Introduction to resources available for doing research
- Lab safety
- Organizational skills
- Technical writing and presentations
- Time and stress management

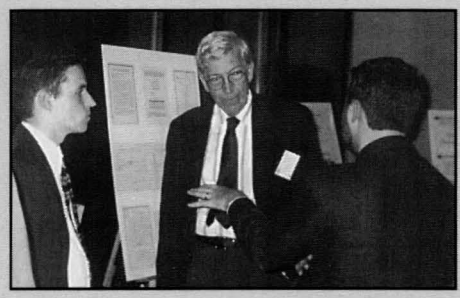
***Section 2: Resource Development and Professional Ethics***
- Academic research
- Funding for research in science and engineering
- Basic tenets of professional ethics

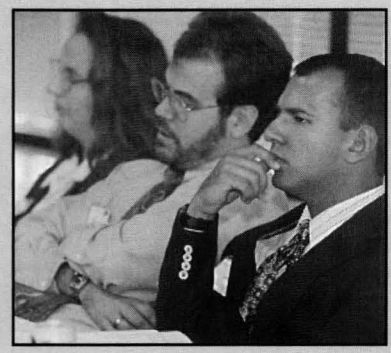
***Section 3: Post-Graduation Issues***
- Requirements of a typical research position in industry
- Academic and governmental positions



▲ *Jim Fitz-Gerald, ERC graduate student, describes his research work through a formal presentation to the Industrial Advisory Board.*

*ERC graduate student Aaron Clapp discusses his research work with Industrial Advisory Board member Ralph Nelson and ERC faculty member Richard Dickinson at a recent poster session.* ▼





▲ *ERC students Byron Palla, Steve Truesdail, and Kathryn Shaw participate in an ERC short course.*

Recent exit surveys completed by ERC graduates asked them to describe how the ERC experience was different from that of their colleagues who did not participate. They reported that the ERC provided them with a solid link to industry, provided experience in interdisciplinary team work, and improved their technical writing and presentation skills. One student commented that "I will go into industry with an increased confidence in my ability to take on and successfully complete a project."

## LEADERSHIP TRAINING

In an update of their earlier remarks, Nelson and Davies state that there has been some progress in addressing the concerns raised by their article.[6] They note that in addition to the ERC, new courses are being added at City College of New York, New Jersey Institute of Technology, University of Pittsburgh, Yale University, and the University of Cincinnati. They then challenge universities to take the next step by not only educating students in PS&T but also encouraging them to enter management.

Leadership skills that are important in the development of managerial abilities are fostered by the ERC in several ways. The ERC funds undergraduate research work each semester. These students are assigned to a graduate student, who assumes primary responsibility for supervising them. This experience helps train students to be the managers of the future. A leadership skills class has also been developed in which students discuss topics outlined in Table 3. The ERC has established a Student Leadership Committee composed of graduate students from a variety of thrust groups to advise ERC administrators on issues of concern to students and to serve as a liaison between the staff and the students.

The ERC focus on interdisciplinary teamwork is the new paradigm for graduate education called for by COSEPUP. It is interesting to note that the type of interdisciplinary training that ERC students are being exposed to has anticipated the new ABET Engineering Criteria 2000. Under these guidelines, universities must demonstrate that graduates have acquired the skills necessary to function on multidisciplinary teams. It is clear that the ERC experience will help engineering colleges meet this criteria.

The establishment of a national Center for Particle Science and Technology by NSF was a major step toward meeting the challenge of improving the state of PS&T education in this country. The Engineering Research Center for Particle Science and Technology offers graduate students an unparallelled opportunity to become the industrial and academic leaders of PS&T for the future.

## ACKNOWLEDGMENTS

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