Multidisciplinary Aspects of Novel Process Engineering

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Abstract

This paper describes a NSF-funded Undergraduate Faculty Enhancement Workshop on Novel Process Science and Engineering. The project DUE-9752789 supports two hands-on, industry integrated workshops that will have a major impact on upper and lower level engineering, technology and science instruction as well as having a secondary impact in the preparation of future teachers. One workshop was held in July 1998 and another one is scheduled for July 1999. Participants will gain experience in process engineering through hands-on laboratories, industry experts, and interactive demonstrations. Through industry involvement from 10 process engineering companies, faculty were given an initial networking base. Companies contributing industrial speakers include Sony Music, Inductotherm, DuPont Engineering, Chemical Industry Council of New Jersey, Cochrane, Tasty Baking Co., DuPont Pharmaceuticals, DuPont Nylon, Hyprotech, and Mobil Technology Co. Participants use the given methodology to integrate novel processing into their curricula and develop an action plan for their home institution. Active learning methods were employed in the workshop and participants were encouraged to incorporate this experience into their teaching style.

Introduction

An innovative and state-of-the-art workshop on the multidisciplinary aspects of novel process science and engineering was held at Rowan University, Glassboro, New Jersey, July 26-30, 1998. This workshop is one of the many excellent programs supported by the National Science Foundation's Undergraduate Faculty Enhancement Program. The purpose of this workshop is to meet the needs of faculty who teach undergraduate students. Of particular importance are programs that expose faculty to recent technological developments and present methods to incorporate them into the undergraduate curriculum.

Process engineering is critical to virtually all modern products used by society. In addition, process engineering spans many disciplines including chemical, petroleum, biochemical, environmental, food, materials production and manufacturing. In many cases the interface of science and engineering is critical to advancements and future trends. Many faculty do not have the experience in novel process engineering required to teach this information to students. For example many new faculty from engineering, science and technology are hired with no industry experience and have a highly specialized knowledge of one particular field. This workshop gives faculty experience in many emerging process science and engineering areas. This is accomplished through lectures, hands-on experiments, industry experts, and interactive demonstrations. Through industry involvement, faculty are given an initial networking base for process engineering. Participants will be required to use the given methodology to integrate

novel processing into their curricula and develop an action plan for their home institution. This state-of-the-art workshop in process engineering will facilitate the integration of engineering practice into the undergraduate curriculum.

The workshop has introductory lectures on the field of process science and engineering and emerging areas of the chemical industry. Detailed lectures on specific topics are presented by experts from industry. Laboratory experiments and demonstrations are integrated throughout the workshop. These bench-scale experiments are designed so that they can be effectively integrated into the curriculum at the participants' home institutions. The workshop has a computer session on the use of simulators in the process industry. The workshop also has sessions devoted to curriculum development. The workshop instructors utilized an active teaching and learning style. Lecture and laboratory sessions were held in Henry M. Rowan Hall, home of the College of Engineering.

Background

Virtually all modern products depend on chemical and biochemical process engineering. The U.S. is the second largest exporter of chemicals producing one quarter of the world's chemical output. The U.S. chemical industry is the country's number one exporter with exports of $60.8 billion and a $20 billion trade surplus in 1995. In addition, this industry has the highest spending in research and development and has the highest number of new patents. In New Jersey, the chemical processing industry employs the largest number of workers and has the largest share of the state's GDP.

The recently issued report, "Technology Vision 2020," [Ame96] concluded that the growth and competitive advantage of the industry depends on individual and collaborative efforts of industry, government and academe to improve the nation's R&D enterprise. They also concluded that in this age of reorganization, the synergy of collaboration often has a multiplier effect on the nation's pool of talent, equipment, and capital available for R&D. This workshop addressed an approach to answering some of these concerns by educating the faculty who will teach the next generation of engineers and scientists.

The area of process engineering is broad and encompasses many fields such as chemical, petroleum, biochemical, environmental, food, materials production and manufacturing [Heg92]. The future of processing and manufacturing in the 21st century will be more inter- and multidisciplinary using a team environment [Ame96]. This is why the various aspects of "process" engineering must be taught to all of the engineering and technology disciplines. This workshop will give engineering, technology, science and math professors experience in this dynamic, high-technology industry.

Process science and engineering dates back to the 1930s and is the foundation for the development, scale-up and design of modern chemical manufacturing facilities [Rey83]. This consists of engineering technologies, engineering science, and engineering design, scale-up and construction. Taken together, these provide the basis for manufacturing excellence and sustainable competitive advantage.

Emerging engineering technologies are in the areas of environmental processing, hazard evaluation and control, materials engineering, particle processing, bioprocessing, and novel unit operations. Although an understanding of the scientific principles underlying these technologies

is beginning to mature, the innovative processes are generally applied using empirical, semiquantitative techniques that permit their safe development, design and operation [Ame96].

Engineering process science includes thermodynamics, kinetics and mechanisms; transport phenomena (mass, energy, and momentum); and materials. Engineering design, scale-up and construction include process synthesis and conceptual design, process development and scale-up, and engineering facilities design and construction. A continuum extends from process synthesis to production design and construction.

The standard view of chemical engineers is to divide a complete process into unit operations or processes that perform various functions - mixing, reactions, separations, heat transfer, etc. [McC93]. To manufacture the latest consumer demands, whether they are in health care (new drugs) or entertainment (CD's), requires a complex manufacturing facility that utilizes many novel processes arranged in an optimal sequential order [Gar94]. Two strategic approaches are utilized: replacing an existing unit operation with a new and emerging technology; and redesigning the complete manufacturing process with the new process technology. Both the advantages and disadvantages of these approaches are presented. The advanced processes used today to make the novel products are more complex requiring faculty to be up-to-date with these new concepts.

The application of process engineering is somewhat fragmented, often sequential, and frequently driven by immediate business needs. These technologies are also applied to operating manufacturing facilities to reduce operating costs, increase capacity, and to comply with environmental regulations. State-of-the-art advances in process engineering will allow industry to have higher capital utilization, improve yields, reduce waste production, and improve protection of human health, safety, and the environment. All this results in greater international competitiveness for U.S. corporations.

Beginning to emerge are concepts in non-traditional chemical processing, such as bioprocessing, pollution prevention, environmentally benign processing, recycling, cryogenic processing, inorganic and solids processing, optical, photonic and electronics materials processing, and new reactor/separations technologies [All97, Gar94, Amu88]. Many new commercial processes will use recycled raw materials as feedstocks. New, economic, high yield and high quality processes with improved environmental impact will characterize much of industry's production capacity in the next century. Many new commercial processes will be based on non-traditional chemistry. They will include nontraditional reaction and separation process systems: plasma, microwave, photochemical, biochemical, supercritical, and cryogenic, reactive extraction and distillation, and membrane reactors [Gar94, Heg92].

A frequent question is often raised among engineering educators: how do we make processes relevant for instruction of students? This and other topics are addressed in the workshop by i) first presenting the important areas of modern processing as applied to various engineering fields and ii) showing ways to creatively integrate them into the curriculum through courses and hands-on laboratory experience. A major thrust of the workshop is hands-on process experiments that are conducted by the participants with brainstorming on new experiments and how to integrate them effectively into traditional lecture and laboratory courses. This state-of-the-art workshop facilitates the integration of novel process engineering practice into the undergraduate curriculum.

The project is co-directed by Dr. C. Stewart Slater, Professor and Chair of Chemical Engineering and Dr. Robert P. Hesketh, Associate Professor of Chemical Engineering, at Rowan University. Dr. Slater has extensive experience as both a teacher and scholar in the field of engineering education and separation process technology. He has been recognized nationally by several awards, based on his excellence as an innovative educator: George Westinghouse Award (ASEE), John Fluke Award (ASEE), Dow Outstanding Young Faculty Award (ASEE) and the Ralph R. Teetor Award (SAE). Dr. Hesketh has been awarded numerous educational awards including Ray W. Fahien Award (ASEE), Dow Outstanding New Faculty Award (ASEE), Joseph J. Martin Award (ASEE), Professor of the Year and a DuPont Young Professor Grant. Both Drs. Slater and Hesketh have conducted previous NSF workshops (Young Scholars and Undergraduate Faculty Enhancement Programs)

Workshop Program

The objectives of these multidisciplinary workshops in novel process science and engineering are to:

- Introduce new and emerging engineering process technology to faculty
- Give faculty hands-on experience in process science and engineering through laboratories, interactive demonstrations and case studies.
- Facilitate faculty networking with industrial experts in the area of state-of-the-art engineering processing.
- Bring engineering practice into the undergraduate curriculum, especially to the lower levels
- Expose faculty to multidisciplinary aspects of process science and engineering.
- Apply creative problem solving techniques to process engineering
- Synthesize new and emerging technologies into advanced process simulation software.
- Apply methodologies to integrate novel processing into the curriculum and develop an action plan for the participants' home institution.
- Have the faculty evaluate new educational methods of active learning and incorporate this experience into their teaching style.

This project covers a period of two years (24 months) and includes two summer workshops in 1998 and 1999. The first workshop is designed for chemical engineering faculty and the second workshop will include a broader audience, e.g., science and other engineering/ technology faculty. The content of each workshop is constructed to match the skills and knowledge of the participants.

Workshop faculty participants in 1998 were:

Dr. David Arnold, Univ. of Alabama
Dr. Francis J. Bonner, Univ. of Massachusetts-Lowell
Dr. Richard Davis, Univ. of Minnesota Duluth
Dr. David Dixon, South Dakota School of Mines and Technology
Dr. Ashish Gupta, University at Buffalo, SUNY
Dr. Deran Hanesian, New Jersey Institute of Technology
Dr. David Kauffman, The Univ. of New Mexico
Dr. Mayuresh V. Kothare, Lehigh Univ.
Dr. Carolyn W. Lee, Rose-Hulman Institute. of Technology

Dr. Thuan Ke Nguyen, California State Polytechnic University, Pomona
Dr. Angelo J. Perna, New Jersey Institute of Technology
Dr. Philip A. Rice, Syracuse Univ.
Dr. Keith Schimmel, North Carolina A&T State Univ.
Dr. Mikhail Skliar, Univ. of Utah
Dr. Steven Sternberg, Univ. of North Dakota
Dr. Ben J. Stuart, Ohio Univ.
Dr. Ronald J. Willey, Northeastern Univ.
Dr. Bob Ybarra, Univ. of Missouri-Rolla

The overall philosophy of each one week workshop is to give the participants hands-on experiences in state-of-the-art process engineering. Each day contains laboratory experiments, computer simulations, cooperative learning exercises and essential lectures. The central portion of the workshop will integrate industrial experts from new and emerging fields into the laboratories, teamwork exercises, and lectures. The final day of the workshop is devoted to incorporating the participants' experience with leading-edge process engineering gained from this workshop into their home institution's curriculum.

The Workshop Program that follows outlines the first year's activities. Further details on the sessions can be found on a NSF Workshop web page at Rowan University's site: www.rowan.edu.

Saturday July 25		
12:00-9:00pm	Optional early registration, check-in	
Sunday, July 26		
9:00am-12:00pm	Registration, Free period, No activities planned	
10:00am-1:00pm	Brunch/Lunch (you are on your own)	
1:00-1:15pm	Welcome to Rowan University	*Donald J. Farish, President*
1:30-3:30pm	Workshop overview Introduction to process engineering and multidisciplinary aspects Reverse engineering of a coffee maker	*C. S. Slater, R.P. Hesketh Rowan University*
3:30-3:40pm	Break	
3:40-4:50pm	Process needs and future trends in emerging areas of the chemical/process industry	*C. S. Slater, R.P. Hesketh*

	chemical/process industry	
4:50-6:20pm	Experiment: Processing principles applied to coffee makers	*R.P. Hesketh, C. S. Slater*
	Dinner	
Monday, July 27		
	Continental Breakfast provided each morning in Room 104 starting 8:00am	
8:30-8:45am	Greetings from the College of Engineering	*James H. Tracey, Dean*
8:45-10:00am	Process needs and future trends in emerging areas of the chemical/process industry	*C. S. Slater, R.P. Hesketh*
10:00-10:10am	Break	
10:10am-11:30pm	Creative problem solving in process engineering	*R.P. Hesketh, C. S. Slater*
11:30am-12:10pm	Update on the chemical process industry	*T. Zita* **Chemical Industry Council of New Jersey**
12:10-1:30pm	Lunch	
1:30-2:30pm	Next generation CD manufacturing technology	*C. Dawson, G. Maenza* **Sony Music**
2:35-3:35pm	Induction melting technologies	*O. Fishman* **Inductotherm**
3:35-3:45pm	Break	
3:45-5:10pm	Mixing in the process industries	*A. Etchells* **DuPont**
	Dinner	
Tuesday, July 28		
	Continental Breakfast provided each morning in Room 104 starting 8:00am	
8:30-10:15am	Future trends in environmental technology	*H.L. Fleming* **Cochrane, Inc.**
10:15-10:25am	Break	
10:25am-12:10pm	Experiment: Reverse osmosis using a small-scale system	*C.S. Slater, R.P. Hesketh Staff*
12:10-1:30pm	Lunch	
1:30-2:15pm	Experiment (1st part): Automated bread maker	*R.P. Hesketh, C.S. Slater Staff*
2:15- 4:00pm	Baking science and technology: Present and future	*J. Bauer* **Tasty Baking Co.**
4:00-4:10pm	Break	
4:10-5:10pm	Experiment (2nd part): Automated bread maker	*R.P. Hesketh, C.S. Slater Staff*
	Dinner	
Wednesday, July 29		
	Continental Breakfast provided each morning in Room 104 starting 8:00am	
8:30-10:15am	Selected topics in pharmaceutical processing	*I. Valvis, J. Chung* DuPont **Pharmaceuticals**
10:15-10:25am	Break	
10:25am-12:10pm	Polymer processing and fiber spinning with applications to consumer products	*J. Kurian* **DuPont Nylon**
12:10-1:30pm	Lunch	
1:30-3:15pm	Experiment: Fluidized bed polymer coating process	*R.P. Hesketh, C.S. Slater Staff*
3:15-3:25pm	Break	

3:25-5:10pm	Simulators in the process industry	*C. Sowa,* **Hyprotech** R. Gould, **Mobil**
Bus leaves Rowan Hall 5:30pm	Microbrewery tour and banquet	Poor Henry's (Philadelphia)
Thursday, July 30		
	Continental Breakfast provided each morning in Room 104 starting 8:00am	
8:30-10:15am	State-of-the-art in petroleum refining	*R. Saeger, R. Gould, D. Marler* **Mobil Technology Co**
10:15-10:25am	Break	
10:25am-12:10pm	Experiment: Catalytic oxidation of volatile organic compounds (VOC's)	*R.P. Hesketh, C.S. Slater Staff*
12:10-1:30pm	Lunch	
1:30-3:30pm	Curriculum and lab development New Jersey initiatives in Freshman programs: Rowan Univ. and New Jersey Institute of Technology (NJIT)	*R.P. Hesketh, C.S. Slater* *D. Hanesian, A. Perna* **NJIT**
3:30-4:15pm	Follow-up activities /dissemination plan Workshop wrap-up	*C. S. Slater* *R. P. Hesketh*

The workshop started with an "Introduction to Process Science and Engineering and its Multidisciplinary Aspects". This presentation included a brief history of process science and engineering and an overview of the different fields/disciplines involved. This was followed by a hands-on laboratory experiment, "Reverse Engineering of a Coffee Machine" [Hes96]. This experiment was used to reinforce the concept of process engineering and unit operations. The participants took apart a coffee maker to see how it worked, identifying major components and engineering principles. This experiment was an example of an introductory type lab that could be used in a Freshman engineering course.

The next set of lecture sessions were adapted from the report, Technology Vision 2020 [Ame96], which was supplied to the workshop participants. These sessions explored "Emerging Areas Utilizing and Requiring Advances in Process Technology". Each topic area was further broken down into *current state*, *needs and challenges*, and *getting there*. The topics covered by Drs. Slater and Hesketh were

- chemical syntheses and separations
- bioprocess and biotechnolgy
- materials technology
- energy and transportation
- information and communications
- environmental protection
- process development and design

In each topic area a case study was given on a particular item of interest.

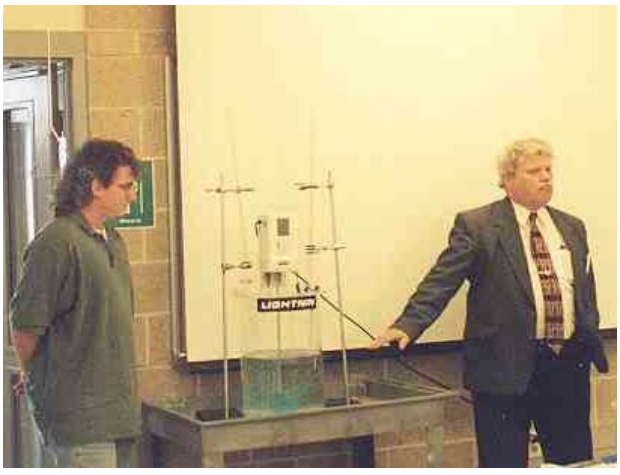
The next experiment in the program was a follow-up to the coffee machine reverse engineering case. "Process Principles Applied to Coffee Makers" exposed the participants to a experiment involving data acquisition of various process parameters, such as temperature and pressure. This experiment was designed so that the faculty could tie together basic processing concepts and integrate computers for data acquisition and data reduction/correlation.

"Creative Problem Solving in Process Engineering" was presented using an active learning style by Robert Hesketh on the workshop's second day. This interactive presentation was supported by the ASEE award winning text Stategies for Creative Problem Solving [Fog95] (which was also supplied to the participants). The steps in the problem solving heuristic and several case studies applied to chemical processing were discussed.

An "Update on the Chemical Process Industry" was presented by Ms. T. Zita, of the Chemical Industry Council of New Jersey (CIC-NJ). She presented data from her trade group that represents chemical processing/manufacturing firms in the state. She talked about economic and sector trends and related information about "driving forces" in the industry. Of particular note were the impact of environmental regulations and public policy initiatives.

The "Next Generation CD Manufacturing Technology" was presented in a unique "theater" setting by Chet Dawson and Glenn Maenza of Sony Music. They described the advanced materials and manufacturing techniques behind CD production and talked about Sony's latest venture into the world of DVD technology. The participants learned by example, seeing segments of the movie Twister in DVD format to exhibit the features available. All of the participants received CD's of their favorite artist to take home courtesy of Sony Music.

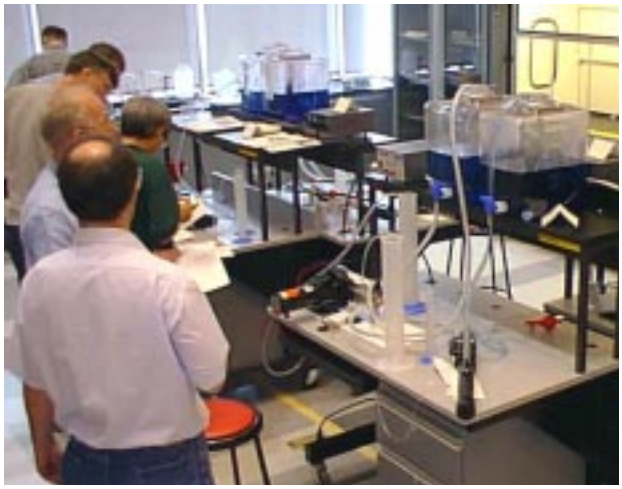
Dr. Oleg Fishman of Inductotherm Industries described innovative "Induction Melting Technologies" used in manufacturing. Inductotherm Industries is the one of the companies owned by our University's benefactor, Mr. Henry Rowan. Dr. Fishman described how induction melting uses a unique electromagnetic process system and how it has revolutionized the metals refining and processing industry.



"Mixing in the Process Industries" was presented by Dr. Arthur Etchells of the DuPont Company. His presentation focused on the many applications that mixing has for multiphase processing. Dr. Etchells included a demonstration in his seminar which showed mixing dynamics. Several key areas of mixing as applied to the products manufactured by DuPont were discussed.

Day three of the workshop started with a presentation by Dr. Hu Fleming of Cochrane, Inc. on "Future Trends in Environmental Technology". This presentation included may of the innovative separation techniques such as reverse osmosis, ultrafiltration,

pervaporation and their application to industry. Dr. Fleming discussed the use of both emerging and traditional process techniques in hybrid systems.



This presentation was followed by a laboratory experiment on reverse osmosis. This experiment showed the participants the use of membrane technology in water purification and provided a way to easily introduce an advanced concept into the laboratory. The experiment used a bench-scale reverse osmosis system in which a blue dye salt water solution was separated to produce pure water [Hes97b]. The participants measured the separation efficiency and production rate of the unit. This experiment was an example of a cost-effective laboratory unit that can be used in mass transfer and separations courses.

The afternoon of day three had a food technology theme. The lecture was presented by Dr. Joesph Bauer of the Tasty Baking Company, manufacturer of the region's best know snack cake, *Tastykake®*. Dr Bauer explained the role of scientists and engineers in product development and how to respond to consumer needs. He used an interactive participant lesson to explain the use of flavor technology in the marketing of products. After the presentation he gave all of the workshop participants a sample case of *Tastykakes.*

The laboratory experiment that complemented this lecture was the engineering of an automated bread maker. This experiment showed workshop participants how to teach heat transfer and data acquisition to a students, at the same time they are making something fun. The aroma of the bread baking in the lab also added to the interest. This cost-effective experiment consisted of faculty participants weighing out all of the raw materials and then "batching" them in an automated bread machine. The off-the-shelf unit was modified to accommodate thermocouples that measured the bread baking at different points. Additionally, power measurements were made on the unit. After the participants analyzed the profiles of the bread baking over time via the computer, they ate their product.

Two Dupont presentations were given in the morning sessions of day four. The first was on "Selected Topics in Pharmaceutical Processing" given by several research engineers from

DuPont Pharmaceuticals. This presentation focused mainly on the new processing techniques in bulk pharmaceutical production and the challenges in using new technologies.

Dr. Joe Kurian of DuPont Nylon gave an interesting presentation on "Polymer Processing and Fiber Spinning with Applications to Consumer Products". His presentation covered the history of polymer production at DuPont and its importance to the company's growth. He then discussed the trends in producing some of the best know consumer polymer products, e.g., Nylon, Teflon, Kevlar, Lycra, Tyvek. His presentation also focused on fiber production and some of the challenging processing steps in manufacturing. He concluded with a unique show-and-tell in which he displayed numerous consumer products made of DuPont polymers and their native form.

The afternoon of day four started with another cost-effective experiment that can be easily integrated into the curriculum. A "Fluidized Bed Polymer Coating Process" was utilized to show both the process engineering aspects of flow in packed and fluidized beds and a unique process of polymer coating. The experiment uses a small bench-scale packed bed with a polymer powder as the packing. Air flow through the bed and resulting pressure drops can be measured. Because the experiment uses a Plexiglas column with colored polymer powder as packing, participants can readily see the bed of solids become fluidized. The experiment is made even more interactive by the participants heating a substrate (metal washer) to be coated. The hot metal part is dipped into the fluidized bed and within seconds the object has a uniform polymer coating.

An interactive computer session "Simulators in the Process Industry" was presented by Chris Sowa of Hyprotech and Ronald Gould of Mobil Technology Co. This presentation reviewed the applications of process simulators to various cases with an emphasis on petrochemical production.

The evening of the fourth day was spent at the Poor Henry's Microbrewery and Restaurant in Philadelphia, PA for a microbrewery tour and workshop banquet. This unique facility has a newly installed $4M brewery through

which the workshop participants toured. They got to see first hand the brewing process from raw materials to bottling. The highlight was the stainless steel fermentation kettles and control system.

A group of engineers from Mobil Technology Company gave a talk on "State-of-the-Art in Petroleum Refining" on day five. Their presentation looked at both upstream and downstream technologies and some innovative developments that Mobil is pioneering. One of the speakers, Dr. Ronald Gould, specifically addressed the use of innovative membrane process and had a membrane module for the participants to examine.

Day five's experiment was "Catalytic Oxidation of Volatile Organic Compunds (VOCs)". This experiment used a tube furnace with a palladium catalyst similar to the catalytic converter in an automobile. The objectives of the experiment were to determine the reaction kinetics of propane oxidation by varying the propane concentration and reaction temperature. Process streams were analyzed on-line with an FTIR.

The afternoon of day five was spent on curriculum development issues. Cooperative learning and planning sessions were conducted to brainstorm approaches to innovate the engineering curriculum with the new ideas and concepts learned at this workshop. Several sessions were lead by Drs. Slater and Hesketh on where to integrate novel processes in the curriculum. A special session addressed New Jersey Initiatives in Freshman Programs with talks by Rowan and New Jersey Institute of Technology faculty. Workshop follow-up activities and dissemination plans were discussed.

Summary

This innovative undergraduate faculty enhancement workshop was quite successful in meeting its objectives. Faculty were exposed to new areas of process science and engineering. There was a high degree of cooperative learning among the workshop participants and the instructors. Experimental methods played a key role in the success of the workshop and some faculty have already integrated new concepts into the undergraduate curriculum at their schools.

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References Cited

[AIC97] "Major Changes Foreseen in Future Refineries," AIChExtra a supplement of chemical Engineering Progress, May 1997.

[All97] Allen, D.T., K.S. Rosselot, Pollution Prevention for Chemical Processes, John Wiley & Sons, New York, 1997.

[Ame96] American Chemical Society, American Institute of Chemical Engineers, The Chemical Manufacturers Association, The Council for Chemical Research, The Synthetic Organic Chemical Manfacturers Manufacturers Association, Technology Vision 2020, American Chemical Society, Washington DC, 1996

[Amu88] Amundson, N.R., E.R. Mason and J. Wei (National Research Council, Committee on Chemical Engineering Frontiers), Frontiers in Chemical Engineering: Research Needs and Opportunities, National Academy Press, Washington, DC, 1988.

[Fel 95] Felder, R.M., "We Never Said it Would be Easy," Chem. Eng. Educ. 29(1) 32 (1995).

[Fel88] Felder, R.M., L.D. Silverman, "Learning and Teaching Styles in Engineering Education," Engineering Education 78(7) 764 (1988).

[Fel91] Felder, R.M., "It Goes Without Saying," Chem. Eng. Educ. 25(3) 132 (1991).

[Fel92] Felder, R.M., "How About a Quick One?" Chem. Eng. Educ. 26(1) 18 (1992)

[Fel93] Felder, R. M., "Reaching the Second Tier –- Learning and Teaching Styles in college science Education," J. College Science Teaching 23 286 (1993).

[Fel96] Felder, R.M., "Matters of Style," Prism, p.18 Dec. (1996).

[Fog95] Fogler, H.S. and S.E. LeBlanc, Strategies for Creative Problem Solving, Prentice Hall, PTR, Englewood Cliffs, 1995.

[Gar94] Garside, J. and S. Furusaki, The Expanding World of Chemical Engineering, Gordon and Breach Science Publishers, Amsterdam, The Netherlands, 1994.

[Gri97] Grisham, J, "Students Rate Science, Hands-on Learning High," Chemical and Engineering News, p. 62, 5 May (1997).

[Heg92] Hegedus, L.L. (National Research Council, Committee on Critical Technologies), Critical Technologies: The Role of Chemistry and Chemical Engineering, National Academy Press, Washington, D.C., 1992.

[Hes96] Hesketh, R.P., "Wake-up to Engineering", Chemical Engineering Education, 30, 210, 1996.

[Hes97a] Hesketh, R. P., K. Jahan, A. J. Marchese C. S. Slater, J. L. Schmalzel, T. R. Chandrupatla, R. A. Dusseau, "Multidisciplinary Experimental Experiences in the Freshman Engineering Clinic at Rowan University," Paper No. 3, 1997 Annual Conference of the American Society for Engineering Education, Milwaukee, WI, June 15-18, 1997.

[Hes97b] Hesketh, R. P. and C. Stewart Slater, "Demonstration of Chemical Engineering Principles to a Multidisciplinary Engineering Audience," Paper No. 6, 1997 Annual Conference of the ASEE Milwaukee, WI, June 15-18, 1997.

[Kin87] King, C.J. (National Research Council, Committee on Separation Science and Technology), Separation and Purification: Critical Needs and Opportunities, National Academy Press, Washington, D.C., 1987.

[McC93] McCabe, W.L., J.C. Smith and P. Harriot, Unit Operations of Chemical Engineering, 5thed., McGraw-Hill Co., New York, 1993

[Par94] Parkinson, G., "Hands-on Learning: The New Wave in Ch.E. Education," Chemical Engineering, 101, 45, 1994.

[Pau90] Paul, E.L. and C.B. Rosas, "Challenges for Chemical Engineers in the Pharmaceutical Industry" Chemical Engineering Progress, p. 17 Dec 1990.

[Rey83] Reynolds, T.S., 75 Years of Progress, American Institute of Chemical Engineers, New York, 1983.

[Sla94a] Slater, C.S., "A Manually Operated Reverse osmosis Experiment," International Journal of Engineering Education, 10, 195-200, 1994.

[Sla94b] Slater, C.S., "Education on Membrane Science and Technology," in Membrane Processes in Separation and Purification, K.W. Boddeker and J.G. Crespo, eds., Kluwer Academic Publishers, Boston, 1994.

[Sla94c] Slater, C.S. and R.N. Occhiogrosso, "Enhancing Undergraduate Faculty Skills in Advanced Separation Processes," Proceedings of the 1994 ASEE Annual Conference, pp. 2224-2235, 1994.

[Sla96] Slater, C.S, T.R. Chandrupatla, R.A. Dusseau and J.L. Schmalzel, "Development of Multifunctional Laboaratories in a New Engineering School," Proceedings of the 1996 ASEE Annual Conference, 1996.

[Wan93] Wankat, P.C. "What Works: A Quick Guide to Learning Principles," Chem. Eng. Educ. 27(2) 120 (1993).

Biographical Information

C. Stewart Slater is Professor and Chair of Chemical Engineering at Rowan University. He received his B.S., M.S. and Ph.D. from Rutgers University. Prior to joining Rowan he was Professor of Chemical Engineering at Manhattan College where he was active in chemical engineering curriculum development and established a laboratory for advanced separation processes with the support of the National Science Foundation and industry. Dr. Slater's research and teaching interests are in separation and purification technology, laboratory development, and investigating novel processes for interdisciplinary fields such as biotechnology and environmental engineering. He has authored over 70 papers and several book chapters. Dr. Slater has been active in ASEE, having served as Program Chair and Director of the Chemical Engineering Division and has held every office in the DELOS Division. Dr. Slater has received numerous national awards including the 1999 and 1998 Joseph J. Martin Award, 1996 George Westinghouse Award, 1992 John Fluke Award, 1992 DELOS Best Paper Award and 1989 Dow Outstanding Young Faculty Award.

Robert Hesketh is Associate Professor of Chemical Engineering at Rowan University. He received his B.S. in 1982 from the University of Illinois and his Ph.D. from the University of Delaware in 1987. After his Ph.D. he conducted research at the University of Cambridge, England. Prior to joining the faculty at Rowan in 1996 he was a faculty member of the University of Tulsa. Robert's research is in the chemistry of gaseous pollutant formation and destruction related to combustion processes. Nitrogen compounds are of particular environmental concern because they are the principal source of NOX in exhaust gases from many combustion devices. This research is focused on first deriving reaction pathways for combustion of nitrogen contained in fuel and second to use these pathways to reduce NOX production. Robert employs cooperative learning techniques in his classes. His teaching experience ranges from graduate level courses to 9th grade students in an Engineering Summer Camp funded by the NSF. Robert's dedication to teaching has been rewarded by receiving several educational awards including the 1999 Ray W. Fahien Award, 1998 Dow Outstanding New Faculty Award, the 1999 and 1998 Joseph J. Martin Award, and four teaching awards.