INTRODUCTION

TO A SPECIAL SECTION ON THE

Patten Centennial Scientific Workshop:

THE NEXT MILLENNIUM IN CHEMICAL ENGINEERING

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Over the past several years, a number of chemical engineering programs around the country have been honoring the 100-year anniversaries of their origins. The 2004-05 academic year marked a similar time at the University of Colorado. In 1904-05, coursework for a B.S. in chemical engineering included Slide Rule, Surveying, Oil and Fuel Laboratory, and Heat Treatment of Steel, whereas today's curriculum includes courses such as Engineering Computing, Environmental Separations, Polymer Science, Particle Technology, Tissue Engineering, and Pharmaceutical Biotechnology. Similar—if not greater—changes to the chemical engineering discipline are expected during the next century.

To commemorate the centennial year, a scientific workshop dedicated to discussions on the future of the discipline was hosted by the Department of Chemical and Biological Engineering at the University of Colorado on Feb. 3 and 4, 2005. The participants included Professors Kristi Anseth (Univ. Colorado), Bob Armstrong (MIT), Arup Chakraborty (UC Berkeley), Ed Cussler (Univ. Minnesota), Mike Doherty (UC Santa Barbara), Richard Felder (NC State), and Jerry Schultz (UC Riverside)—see Figure 1, next page. The workshop consisted of two parts, namely oral presentations and panel discussions. This feature section is intended to share these exchanges with the greater ChE community.

In the first portion of the workshop, each of the seven participants was asked to give an oral presentation on a topic of his or her choice, with a theme that is both broad in scope and forward thinking. An ordered listing of the talks is given in Table 1, next page. Corresponding written perspectives were requested of each participant; these perspectives are contained in the accompanying group of articles. The manuscripts cover pedagogical issues (Professors Armstrong and Felder), a view on the current chemical industry (Professor Cussler), and outlooks on emerging areas (Professors Doherty and Schultz).

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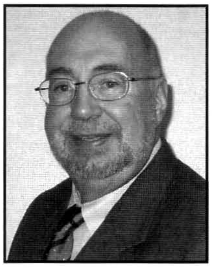

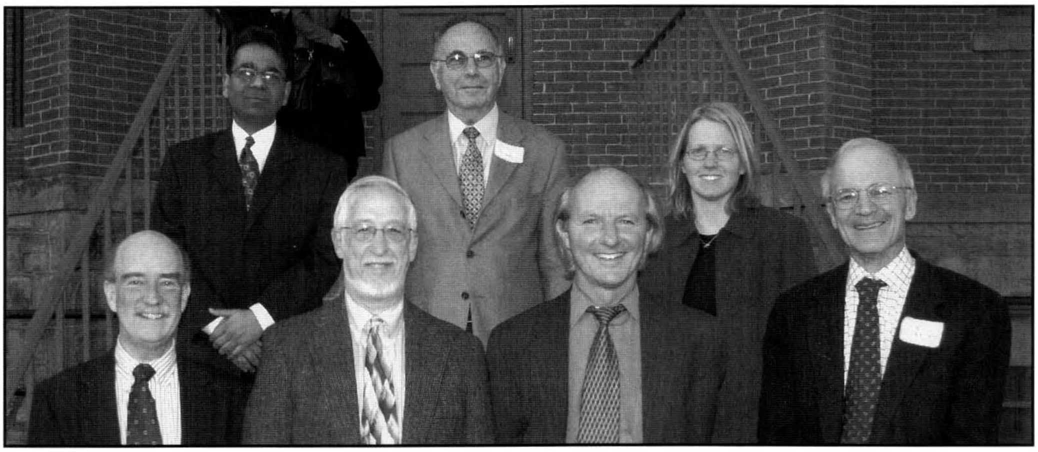

Figure 1. Participants in the Patten Centennial Scientific Workshop—University of Colorado, February 2005. Top row: Arup Chakraborty, Jerry Schultz, Kristi Anseth. Bottom Row: Bob Armstrong, Richard Felder, Mike Doherty, Ed Cussler.

Q AND A

The second portion of the workshop comprised two panel discussions, both of which were driven by questions from the attending faculty and graduate students. A paraphrased overview of this exchange, grouped according to topic, is given below. The respondents are indicated according to their initials (see Table 1). Since these discussions took place after individual presentations, the reader may choose to read this portion after the ensuing manuscripts to keep the chronology of the interactions intact.

Curriculum

Question (to BA): How do you envision the curriculum change you have proposed occurring (*see related perspective by Bob Armstrong*)?

BA: I think we should start with a clean slate and start by adding back in the most important areas and then stop adding when four years are full. I think the approach should not include adding more classes than we currently have, as that will lead to an overcrowding of schedules and then the students would have no time to think about what they are learning.

We have not changed the curriculum in the last 40 years due to the large research engine created after World War II. Faculty were too busy with research to improve significantly the content in the classroom. Faculty have to take time from research, for example to write textbooks or Web modules. We need to do this together as a community of universities. You have got to reward faculty for implementing change.

EC: There is no way that we could possibly do what Bob is saying. Also, committee books are really bad usually. I think modifications need to be done one course at a time. Let me liken it to the past when periodic tables were put on the classroom walls. At that time, boiling points were the only important properties we

TABLE 1
Presentation Listing

Participant	Title
Prof. Richard Felder (RF)	Teaching Engineering in the 21st Century with a 12th-Century Teaching Model: How Bright is That?
Prof. Bob Armstrong (BA)	A Vision of the Chemical Engineering Curriculum of the Future
Prof. Arup Chakraborty (AC)	Quantitative Cellular and Molecular Immunology: A New Opportunity for Chemical Engineering
Prof. Jerry Schultz (JS)	In Vivo BioImaging: Advances and Challenges
Prof. Ed Cussler (EC)	A Different Chemical Industry
Prof. Mike Doherty (MD)	Crystal Engineering: From Molecules to Products
Prof. Kristi Anseth (KA)	Chemical Engineering in 2020: Return of the J.E.D.I.?

needed to know because everything was petrochemicals. Now, chemical engineers are using the information on the periodic table.

Question: With all the changes and additions that have been suggested, do you think there will need to be a five-year undergraduate degree? Or is it time that we separate the curriculum into new majors (*e.g.*, tissue engineering, metabolic engineering)?

RF: We cannot put in all the content, since the content is always changing. We have to emphasize how to learn, skills, flexibility.

BA: You need to learn a good way of thinking—the courses are just vehicles. I think it is a mistake to fractionate into subareas at the undergraduate level. As a career evolves you are always introduced to new areas, so you learn to augment knowledge. Incidentally, the renaming of many departments that has occurred recently—to include "bio" in their name—is very different than the splitting into subareas we are talking about. The inclusion of "bio" in a department name reflects the change in our underlying molecular core science from chemistry alone to a combination of chemistry and biology.

EC: If you put in new material, you have to chop out fluff. We can do that by compressing courses (*e.g.*, transport phenomena). But we also need to adapt to what is relevant. For example, I think it is a tragedy that at Minnesota we teach thermodynamics without covering the topic of ionic solutions, which has tremendous biological relevance.

KA: It is important to consider which industries we want to serve when implementing changes into our curriculum.

Textbooks

Question: A number of the items discussed thus far have been about modifying courses and teaching new courses. One problem set I foresee is: Where are the textbooks, when will they come, and how will authors be rewarded?

MD: Scholars are responsible for writing research papers, books, patents, and grants. There is a need to de-emphasize papers and make a global contribution like writing texts. It's so hard to write a book. Role models are key—if role models write books then others will be written; if they don't, then there will be no books. A large problem is that there is insufficient reward for writing texts. Nevertheless, academics should do it as part of their job.

RF: It is hard to write books—hard and time consuming. Don't write a book before you have tenure. Rewards? Don't do it for rewards. A book only counts as a publication and the effort it takes is the same as for 25-50 publications. Write it because you want to write it—it will be a better book if it's a labor of love.

BA: People need to step forward and do it—or at least convince others to do it. One reward is that the reputation of the school gets better when books are written by faculty. The rewards are not well-translated to individual rewards. One answer may be to get teams of faculty to write books. The books become much more interesting and have broader perspective if they are done as truly collaborative efforts, and there's less work per person.

Role of Biology

Question (to JS): What do you see as the future for division of labor between materials science and bioengineering?

JS: We will have some aspects of materials science tailored to bioengineering. Why should a name be changed to Biochemical Engineering? There was no change to Plastic Chemical Engineering when plastics were the popular topic in chemical engineering. To be successful, engineering programs must collaborate with true biology programs. Also, engineers design new products based on physics, chemistry, and biology. Now that we can manipulate biology, biology is becoming more quantitative.

Question (to AC): Did basic biology prepare you for the biological research you are undertaking?

AC: The curriculum Bob talked about is exactly what is required. Learn the general idea and work from the molecular up to the macroscopic.

Teaching Methods

Question (to RF): Do you believe distance learning is better? I'm asking about isolationism vs. learning in the presence of other students?

RF: Compared with an active-learning class, distance learning is not better. There are some things technology can never replace. I don't believe software will ever be able to motivate students. That's not to say we can't supplement an active-learning classroom with technology.

Question: How should industry perspectives be incorporated into the undergrad classroom?

RF: Take industry problems and bring them into the classroom. Use a problem-solving method and let students take the lead in making decisions.

JS: Bring in industry representatives to be a part of the design team and problem-solving effort. Use real corporate resources and financial support to solve real, relevant, industrial problems.

MD: From real-world consulting experience with DuPont, I understand that engineers typically have very short windows in which to make decisions with limited information. It is important to develop skills to quickly and hierarchically make these decisions. Each result should yield a "yes" or "no" response for continuing or changing paths.

EC: Define complex problems and have some process for judging if a commercial product is likely to work. Expose students to situations where they have to make decisions with limited data.

Enrollments / Future of the Discipline

Question: What is happening with ChE enrollments?

EC: Although we are seeing decreasing enrollments, we should look at the bigger picture. There has been an increase of 50% in ChE programs and a decrease in enrollment—that makes sense. On my way here, I was doing a little research and did you know that there are 11 Ph.D. programs in the state of Ohio—that's silly! I think it is time to start killing programs for undergraduates and graduates.

BA: Undergraduate enrollment is on the increase again. In 2000, there were 6,000 undergraduates enrolling per year. Enrollment since 1973 can be fit with a sine wave and seems to follow job growth. Times change. It is up to educators to know what industries are growing/shrinking and make students aware of it. My concern is not so much at the B.S. level as it is to where are all the Ph.D.s are going to go for jobs?

AC: Ph.D. enrollment is flat during the same time.

JS: In ChE, enrollment varies up to about 10% a year. The amount of high school graduates going into the field of engineering, however, is about the same. It's all dependent on jobs.

Question: Say I am a high school senior who is really good at math and science. How would you convince me to be a chemical engineer?

JS: Out of all engineering, chemical engineering has the widest range of basic science. Chemical engineering offers students a good systems base for the next 30-50 years.

BA: Chemical engineering is preparation for a diverse range of career types.

MD: Our primary asset is that we can provide quantitative solutions. This differentiates us from chemists, biologists, etc. With a ChE B.S., one can go out into the real world with a good-paying job. Chemists and biologists tend to have a more difficult time finding more challenging, higher-paying jobs at the B.S. level.

RF: This is the only discipline that can put together so many sciences. Chemical engineers can be found in many, if not most, technical fields in industry. Also, most students don't know what they are interested in, so it keeps doors open (*e.g.*, environmental, heath care).

Global Competition

Question: With the battle for global economy and our standard of living in jeopardy, what are your thoughts on lower-cost plants and research moving to other countries? How do we innovate and bring new products/technologies to market quickly to win? What can faculty do?

BA: We need to teach our students marketing, how to identify real needs, and how to solve problems to meet those needs. We can only succeed if we innovate—*not* by becoming a service-based country. One minus for the United States is that our culture is not one that tends to save money. There are concerns that we will not have money required for investment in R&D.

MD: There is a natural progression in history that the same main group of countries innovates, and the new technologies/products become more commodity and move to other places, *e.g.*, steel. In the 1880s, the 20 richest places in the world included North America, Europe, and Australia. In the 1980s the list had not changed much, with few exceptions, including the addition of Japan to the list. It is fairly hard to screw things up! Well-established systems and stable governments lead me to believe things will remain the same.

Energy and Water Research

Question: In the next 50 years, what will be the biggest problem of the world and what role will chemical engineers play in solving it?

EC: Energy and water. I do not think ChEs will dominate health care or food. Regarding water, ultrafiltration to remove viruses is needed. Regarding energy, gas will cost $6 a gallon in 10 years. Because of that there will be a renaissance to energy research. A hydrogen economy is controversial and nonsensical. Fuel cells will need a major breakthrough, and one which is more applied in nature than universities are used to. Thus, universities won't dominate fuel-cell research.

MD: Energy is a huge problem—a national strategic problem. The developing world, including India and China, will increase the demand for energy. Two million cars were sold in China last year. In 10 years, there will be more cars in China than in the United States. India will be much the same as China. Bombay today is wall-to-wall cars. There will be a massive demand for energy, and not all will come from fossil fuels due to CO_2 problems. An H_2 economy does not change that because H_2 is also from fossil fuels. The best prospect is nuclear energy. Also, methane is a big area that needs research funding. Currently, nothing can be done with methane unless it is compressed to LNG (liquefied natural gas). Right now, 4 billion cubic feet of methane is flared per year. That amount of energy is equivalent to 300 million barrels of oil. If it were liquefied and consumed by offshore units, the energy produced would be very useful. Methane can also be changed to other forms for transport but it is not a priority to the government so success is slow coming. National governments need to make priorities, balancing CO_2 generation, global warming, and the risks of nuclear energy. A succession of U.S. governments have had their heads in the sand, which is a strategic mistake for this country.

BA: Hydrogen is only a carrier—the energy must come from some primary source such as nuclear. There is a huge need for energy carriers for automobiles. Other areas of energy research include biomass and carbon sequestration so that CO_2 problems can be alleviated. There are, of course, many alternative energy sources including solar (most expensive now), wind (farms are unpleasing aesthetically, but most economically sound right now), and biomass (two times the cost of wind). We need a government willing to admit that energy is a problem and then federal research money will be available. One really good way to get revenue for research is to tax gasoline at something on the order of 10 to 50 cents per gallon.

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