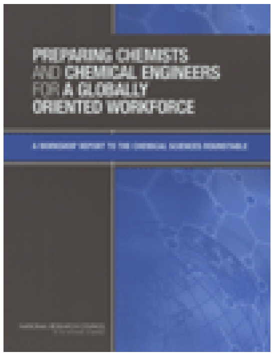

Preparing Chemists and Chemical Engineers for a Globally Oriented Workforce: A Workshop Report to the Chemical Sciences Roundtable

Donald M. Burland, Michael P. Doyle, Michael E. Rogers, and Tina M. Masciangioli, Editors, Chemical Sciences Roundtable, National Research Council

ISBN: 0-309-53179-9, 90 pages, 8 1/2 x 11, (2004)

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Chemical Sciences Roundtable

Board on Chemical Sciences and Technology

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THE NATIONAL ACADEMIES PRESS
Washington, D.C.
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This study was supported by Research Corporation under Grant GG0066, the U.S. Department of Energy under Grant DE-FG-02-95ER14556, the National Institutes of Health under Grant N01-OD-2139, Task Order 25, and the National Science Foundation under Grant CHE-0328197.

Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the organizations or agencies that provided support for the project.

International Standard Book Number 0-309-09203-5 (Book)
International Standard Book Number 0-309-53179-9 (PDF)

Additional copies of this report are available from the National Academies Press, 500 Fifth Street, N.W., Lockbox 285, Washington, DC 20055; (800) 624-6242 or (202) 334-3313 (in the Washington metropolitan area); Internet, http://www.nap.edu

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Preface

The Chemical Sciences Roundtable (CSR) was established in 1997 by the National Research Council. It provides a science-oriented apolitical forum for leaders in the chemical sciences to discuss chemistry-related issues affecting government, industry, and universities. Organized by the National Research Council's Board on Chemical Sciences and Technology, the CSR aims to strengthen the chemical sciences by fostering communication among the people and organizations—spanning industry, government, universities, and professional associations—involved with the chemical enterprise. It does that primarily by organizing workshops that address issues in chemical science and technology that require national attention.

A workshop was organized by the CSR on the topic of "Preparing Chemists and Chemical Engineers for the Global Workforce." The workshop was held to provide a forum for discussing the implications of an increasingly global research environment for a chemistry and chemical engineering workforce. Discussions explored how the chemical enterprise—academic, industrial, and government—is influenced by international activities and how it might respond to prepare chemists and chemical engineers for the changing environment. The workshop presentations described deficiencies in the current system and identified successful approaches that could be adapted to create and sustain a globally aware workforce. The organizers would like to acknowledge the time and effort that Doug Raber and Tina Masciangioli committed to both the planning and realization of this workshop. Without their help the workshop and this document would not have been possible.

Other than the Introduction and Summary, each chapter in this workshop summary is an edited transcript of speaker and discussion remarks at the workshop. The discussions were edited and organized around major themes to provide a more readable summary. In accordance with the policies of the CSR, the workshop did not attempt to establish any conclusions or recommendations about needs and future directions, focusing instead on issues identified by the speakers.

Donald M. Burland, Michael P. Doyle, and Michael E. Rogers

Acknowledgment of Reviewers

This workshop summary has been reviewed in draft form by persons chosen for their diverse perspectives and technical expertise in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published workshop summary as sound as possible and to ensure that the summary meets institutional standards of objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this workshop summary:

William F. Carroll, Occidental Chemical Corporation
Sue B. Clark, Washington State University
Ruth A. David, ANSER (Analytic Services Inc.)
Billy J. Evans, University of Michigan (retired)
Marye Anne Fox, North Carolina State University
John M. Malin, American Chemical Society
Douglas Selman, ExxonMobil
Gerson S. Sher, U.S. Civilian Research & Development Foundation

Although the reviewers listed above have provided many constructive comments and suggestions, they did not see the final draft of the workshop summary before its release. The review of this workshop summary was overseen by **Robert L. Lichter**, of Merrimack Consultants, LLC. Appointed by the Division on Earth and Life Studies, he was responsible for making certain that an independent examination of this workshop summary was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this workshop summary rests entirely with the authors and the institution.

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Introduction and Summary

Donald M. Burland
National Science Foundation

Michael P. Doyle
University of Maryland

Michael E. Rogers
National Institutes of Health

CONTEXT

Science is an international endeavor, global in its practice as a profession, and impacting virtually every facet of the quality of life on this planet. It is also practiced in a world that is changing, increasingly growing smaller and more accessible to the average person. That the world is becoming smaller can be illustrated by a few salient facts:

- A three-minute phone call between New York and London in 1960 cost (in constant 2000 dollars) $60.42; the same call in 2000 could be made for $0.40.
- Average air transportation revenue per passenger-mile in 1930 was $0.68 (in constant 1990 dollars); it had been reduced in 1990 to $0.11 (Masson, 2001).

The increasing globalization of the world economy has also resulted in the movement of industrial production and labor markets. There are daily news stories about displaced U.S. workers in the textile and steel industries and the movement of computer programming jobs from the United States to India and China. The nature of the industrial research and development enterprise in the United States is also changing in response to global developments. In 2000, foreign corporations spent $26 billion on research and development activities in the United States, and U.S. corporations spent $20 billion on these activities in other countries (National Science Board, 2004). From the point of view of large corporations, R&D is already very much an international activity. Why is this happening? Is this a real trend? What are the economic, sociological, and scientific factors behind this trend? What does increased globalization mean for the education and development of U.S. undergraduate, graduate, and postdoctoral students, and faculty in the chemistry and chemical engineering professions?

The impact of international discoveries that benefit health, increase energy production, and lead to improved understanding of the environment indicate that the consequences of globalization have a particularly significant impact on the chemistry and chemical engineering professions. A major factor driving chemical, pharmaceutical, and biotechnology industries is that they are now multinational in scope and find it necessary to have a workforce that is proficient in operating at an international level. These companies are seeking new ideas, a trained workforce, and new market opportunities wherever they may be found. Scientific research and development are on the rise not only in the United States, but also around the globe. Indeed, opportunities may be arising faster in other countries.

The increasing globalization of scientific research thus requires that our educational systems be alert to this changing landscape and produce globally aware scientists and engineers. The National Science Board, the oversight and policy-making body for the National Science Foundation, has recently (NSB, 2001) emphasized "the importance of increased international cooperation in fundamental research and education, particularly with developing countries and by younger scientists and engineers." Academic researchers must collaborate with colleagues throughout the world to remain at the leading edge of research; like their industrial colleagues, they need to be comfortable when operating at an international level. Governments are confronting difficult problems that require international cooperation, as well as timely scientific advice. However, distances, borders, differences of language and societal values, and differing research

The views expressed here are those of the authors and not those of the National Science Foundation, the University of Maryland, or the National Institutes of Health.

infrastructures raise barriers to international cooperation and decrease visibility and accessibility among international scientists.

The implications of globalization for the training of chemists and chemical engineers were discussed at this workshop. The goal of the workshop was to explore existing and possible new mechanisms for creating an internationally engaged workforce. This is of particular importance to U.S. institutions involved in research and development in the chemical sciences, because the United States has not had to address these issues explicitly in the recent past. A major outcome of this workshop was a rich discussion of trends in globalization that are impacting or about to impact the U.S. workforce in chemistry and chemical engineering, and the changes that need to occur in the way U.S. chemists and chemical engineers are prepared for this new environment.

Though changing rapidly, the world is by no means an even playing field. Although globalization has done much to boost the economies and standards of living of the developed world, there are serious discrepancies between the developed and underdeveloped worlds. The gross domestic product (GDP) per capita in 2001 was $27,000 in the high-income countries (Europe, United States, Japan, and Korea) but only $1,300 in the least-developed countries (in parity purchasing power in U.S. dollars). Life expectancy in the least-developed countries was 50 years, compared to 78 years in the high-income countries (UNDP, 2003). These disparities in quality of life do not represent a stable situation, but as E.O. Wilson (2002) has noted, "For every person in the world to reach U.S. levels of consumption with existing technology would require four more planet earths." Bringing the world economies into equilibrium is going to require international cooperation and ingenuity. Other problems of current importance that require an international approach include global warming, SARS (severe acute respiratory syndrome), AIDS and other worldwide epidemics, the production of adequate potable water supplies, and energy conservation.

The United States in recent years has been reassessing its role in global affairs. It has withdrawn from the Kyoto Treaty on global warming, declined to sign the Land Mines Ban Treaty, withdrawn from the ABM Treaty of 1973, and declined to ratify the Law of the Sea Treaty. *Nature* (Brumfiel, 2004) recently pointed out that as a result of visa restrictions imposed after 9/11, the total number of visiting scholars in the United States declined in 2002-2003 for the first time in at least a decade.

The substantial impact that heightened security needs have had on the ability of U.S. laboratories to bring in or extend the tenure of foreign scientists, i.e. visa problems, was mentioned at the workshop. These issues merit detailed examination, but were not part of the focus of this workshop. The issues mentioned above provided the context for this workshop. Attendees and speakers at the workshop included leaders in chemistry and chemical engineering from industry, academia, government, and private funding organizations.

OVERVIEW

Matthew J. Slaughter, a labor economist at Dartmouth College's Tuck School of Business, opened the workshop by describing how global influences affect national labor markets. He pointed out four factors that influence globalization of the labor force: (1) the number of trained people in a given country choosing to be in the labor force, (2) the range of business activities that companies choose within a country, (3) the prices those activities command on the world market, and (4) the capital and technology used for the activities. National labor forces become more global when cross-border flows—people (immigration), goods and services (trade), and multinational capital and technology (foreign direct investment, FDI)—influence one or more of these four factors. In considering globalization, he noted that immigration is typically the focus of discussion, where it is often simplistically assumed that jobs exported from a country result in a net loss of jobs in that country. He said that this assumption fails to recognize that the dynamics of the job market might not be a zero-sum game, and overlooks the increasing influence of trade and FDI. A conclusion from this analysis is that chemists and chemical engineers should encourage global participation in U.S. research and development activities while simultaneously increasing the number of U.S. citizens who pursue careers in these areas.

THE INDUSTRIAL PERSPECTIVE

Speakers representing three major multinational chemical producers—**Miles P. Drake,** Air Products and Chemicals; **Karin Bartels,** Degussa; and **Thomas M. Connelly,** DuPont—discussed industry's perspective on the global workforce.

The overall message from these speakers was that dramatic changes are occurring in the chemical industry as a result of the ease with which companies can manufacture and distribute across the world, and that these changes are influencing how research and development is being conducted in international corporations. Today, research neither is carried out via the colonial model—where central headquarters controls what work will be done around the world—nor does it operate by the independent regional or "separate-but-equal" model. In this separation between regional locations and headquarters, work is partitioned and fragmented, whereas developments in global communication have made it critical for international corporations to evolve to an intradependent model—where a corporation's activities around the world are seamlessly integrated into a coordinated whole.

Given these changes in the corporate research environment, the importance of developing "soft skills" (also called "higher-order skills") in all workers was frequently mentioned. These skills include the ability to work on teams, to communicate ideas orally and in writing, and to be flexible in learning new subjects. Professionals who have the "ability to go out and connect with others" are especially valued. Globalization has added the requirement that researchers be culturally sensitive, which includes having language skills. Research is and will continue to be communicated predominantly in English. The need for U.S.-trained scientists and engineers to develop language skills is thus important for gaining insight into other cultures, not just for communication purposes. In this new environment, U.S. chemistry and chemical engineering students with study-abroad experiences will have a competitive advantage in employment. Recruiting and preparing researchers from diverse backgrounds within the U.S. workforce and around the world is also desired because different perspectives help stimulate creativity and provide broader thinking on future product applications and improving design. Ultimately, research and development is tightly linked to and will follow the market place.

THE ACADEMIC PERSPECTIVE

Professors from three research-intensive universities—**Matthew V. Tirrell,** University of California, Santa Barbara; **Alvin L. Kwiram,** University of Washington; and **Mostafa El-Sayed,** Georgia Institute of Technology—discussed the effect of globalization on education of the chemistry and chemical engineering workforce.

The overarching focus of these educators was very similar to the industrial perspective—academic activities must become more globally integrated in order for the United States to remain competitive. There are concerns that a decline in the U.S. capacity to compete in science and engineering (as other countries increase their capacity) could be damaging to the overall U.S. economy. Decreasing enrollments of U.S. students in science and engineering (including chemical disciplines) and changes in attracting foreign talent are fueling such concerns. Major challenges discussed by these three educators were how to increase the numbers of students choosing chemistry and chemical engineering majors, and how to provide the appropriate level of preparation to compete in the global marketplace.

For example, the current U.S. style of chemical engineering education was examined. It was noted that engineering has been described as embodying design under constraints—where many of the constraints are social, political, and ethical. One need only consider the current discussions surrounding genetically modified foods and stem-cell research to see that different cultures and differently organized societies respond in quite different way to the introduction of new technologies. In training students to operate within these constraints, the case was made for treating engineering as more of a profession than a major, which means expanding the 4-year engineering degree to a 5-year program.

At the same time, it was pointed out that the overall number of technical subjects with which a modern chemist or chemical engineer in the U.S. must have at least some familiarity has increased tremendously. This trend has had the effect of squeezing liberal arts education out of the science or engineering curriculum and makes study-abroad experiences difficult to accommodate. Yet it is the development of skills in such fields as languages, management, and political science that industry is seeking in its scientists and engineers. The need for additional courses in the curriculum is competing with another trend: the need to reduce the already too-long time to degree.

Many potential solutions to the problem of developing a globally aware science and engineering workforce were discussed: (1) improve overall science and engineering literacy (K-12 education), (2) create alternative graduate degree programs, (3) increase and take advantage of industrial internships and cooperative experiences, (4) encourage more international experiences—through existing funding opportunities such as from NSF, and (5) provide more international research collaboration such as through the U.K. based Worldwide University Network, which seeks to create worldwide research institutions to promote research collaborations, e-learning, and graduate student and researcher exchanges.

THE INTERNATIONAL PERSPECTIVE

Representatives of two internationally engaged organizations—**Robert P. Grathwol,** of the Alexander von Humboldt Foundation, and **Sharon H. Hrynkow,** of the National Institutes of Health (NIH) Fogarty International Center—discussed their roles in the development of a global workforce.

Both of these speakers described the small numbers of students and faculty who have been involved in international study or research collaborations. Only 1 percent of U.S. college students travel abroad to study, and about 80 percent of U.S. faculty members have never collaborated with foreign scholars. Each speaker described opportunities that are available for students and researchers to gain international experience. However, it was pointed out that the need for international partnerships will continue to expand, with or without substantial U.S. participation, for a number of reasons: (1) The problems that must be solved are increasingly global. (2) The ease of worldwide communication has made collaboration much more effective than in the past. (3) Support is available, not only from NIH and the Humboldt Foundation, but also from such organizations as the Bill and Melinda Gates Foundation. (4) Global scientific culture of peer review, ethical norms, and communication with the public, is developing.

CONCLUSION

The subject of this workshop was broad, and the discussions raised many questions that will require further thought and discussion:

Supply of Quality Scientists

- Is there in fact a shortage of quality scientists in or a decreasing flow of intellectual capital to the United States?
- Assuming that we are at the beginning of a decreased flow of intellectual capital to the United States, do we need a stronger effort to attract more U.S. citizens into the scientific enterprise?

Soft Skills

- What, explicitly, are "soft skills" that are so important to global collaboration and communication?
- Should skill in a foreign language be re-emphasized in graduate education?
- Can teamwork and networking skills be fostered in a graduate environment?
- How does one add "soft skills" to an already crowded curriculum without increasing the time-to-degree?
- Are there successful or evolving models that others can adapt and adopt?
- Whose job is it to provide scientists and engineers with these skills? Industry? Universities? Government agencies?
- What skills beyond those currently emphasized in U.S. universities are necessary for attacking problems that are worldwide in nature, such as global warming, malaria epidemics, and water availability? What government and institutional support systems for these efforts are needed beyond those currently available?

Gaining International Experience

- How can we communicate the enrichment and scientific opportunities that foreign research experiences create for U.S. students and faculty? How can the downsides for students of being absent from the U.S. workforce for extended periods be minimized?
- Can we leverage the existing international flavor of U.S. graduate programs to enhance global educational experiences?

International Collaboration

- Is international collaboration in research and development really a good idea? Will it not just lead to a further drain of intellectual property and jobs away from the United States?
- How can the universities, industry, and government work together to take full advantage of globalization?
- What are the mechanisms for successfully conducting collaborative research with underdeveloped and developing countries? What benefit do U.S. researchers receive from such collaborations?

REFERENCES

Brumfiel, G., D. Cyranoski, C. Dennis, J. Giles, H. Hoag, and Q. Schiermeier. 2004. As One Door Closes . . . , *Nature*, 427, 190-195.

Masson, Paul R. 2001. "Migration, Human Capital, and Poverty in a Dual-Economy of a Developing Country" *IMF Working Papers* WP/01/128 Washington, DC: International Monetary Fund.

National Science Board (NSB). 2001. *Toward a More Effective Role for the U.S. Government in International Science and Engineering* (NSB01-187). Arlington,VA: National Science Foundation.

National Science Board. 2004. *Science and Engineering Indicators 2004* (NSB 04-01). Arlington, VA: National Science Foundation.

United Nations Development Program (UNDP). 2003. *Human Development Report* Oxford: Oxford University Press.

Wilson, E.O. 2002. *The Future of Life*. New York: Alfred A. Knopf.

Context and Overview

1

How Do National Labor Forces Become Global, and Who Should Care?

Matthew J. Slaughter
Tuck School of Business, Dartmouth College

INTRODUCTION

The basic idea in economics and business is that firms tend to pay people according to their productivity. Labor unions and profit sharing are important, but looking at the big picture of the whole world over decades, they have not been as important as paying people according to their productivity.

In addressing how labor forces become global, I will discuss income, wages, and earnings, not unemployment. This is because the United States and comparable countries have adequately flexible labor markets. There are always business-cycle considerations, and in the United States there has been a business-cycle downturn in the last few years. The economy seems to be picking up now, but over the last couple of years unemployment rates have been higher than they were in the middle and late 1990s. People tend to be able to price themselves in the labor market. Therefore, it is more helpful, in understanding the forces that affect people in the labor market, to focus on earnings as opposed to how many people are working.

This presentation provides a quick survey of international economics to explore how labor forces become more global and what it means for the U.S. economy, its workers, and the chemical and allied enterprises in particular.

HOW LABOR FORCES BECOME MORE GLOBAL

In general, a number of key factors influence globalization of labor forces:

- The number of people in a country who choose to be in the labor force,
- The activities that firms choose in the country,
- The prices that these activities get on world markets, and
- The capital and technology used for the activities.

National labor forces become more global when cross-border flows—people (immigration), goods and services (trade), and capital and technology (foreign direct investment)—influence one or more of these four factors. These flows are relevant for understanding the integration of labor markets across countries.

Immigration—Flow of People Across Borders

Immigration influences other cross-border flows and affects the number of people choosing to be in the labor force. In much of the policy discussions about globalization, it is presumed that immigration matters most and that its economic impacts are obvious. People may say that if more people are in the labor force, wages will tend to go down. That is why some politicians think that immigration should be carefully controlled. In fact, the cap on H-1B visas (for temporary workers in specialty occupations) in the United States has been reduced by two-thirds, in part because of the presumption that too many skilled immigrants are entering the country and pushing particular occupational wages in the country down. Immigrants, however, constitute important flows of knowledge and capital across borders.

Back in the early 1800s, the textile industry was the high-tech, high-productivity industry—the most cutting-edge production activity in the world. Many countries had very strict laws on the export of that technology, either the capital goods or the knowledge embodying the technology.

This is an edited transcript of speaker and discussion remarks at the workshop. The discussions were edited and organized around major themes to provide a more readable summary.

FIGURE 1.1 Foreign-born fraction of U.S. population. Note: Data for 2000 are estimated. SOURCE: Borjas et al. (1997, Table 1).

Much of the early production of textiles in the United States came about because people went to various places in England, worked in factories, and because they were not permitted to write anything down, memorized the structure of particular machines. They then came to the United States and were able to replicate the capital goods that they saw abroad. The early production in textiles in the United States was one of the main manufacturing activities that enabled the country to grow more quickly and was the direct result of immigrants' bringing in the ideas.

More recently, there have been comprehensive surveys of startup companies in information technology (IT), especially in the Silicon Valley of California in the 1980s and 1990s. About one-third of startup companies in Silicon Valley between 1995 and 1998 were either started or headed by immigrants from India or China (Saxenian, 2002). In 1998, they headed 2,775 Silicon Valley high-tech firms, employed 58,000 people, and had total sales of $16.8 billion.

When we think about where new and creative ideas come from, reducing the number of immigrants potentially reduces the creative dynamism that generates new products and companies. The situation is more complicated than just simply allowing in more immigrant workers that put pressure on wages. Management flows in capital and in technology can influence much of what firms decide to do.

More immigrants are coming to the United States. The data points in Figure 1.1 are taken from the decennial U.S. population census (Borjas, 1997). The foreign-born fraction of the total U.S. population was at a minimum in 1970, and has been rising steadily since then. About one-tenth of the current U.S. population is foreign born. This trend has been driven, in part, by a change in U.S. immigration policy in the middle 1960s that oriented it toward considerations of family reunification. The figure does not detail the skill mix of the immigrants coming in. There has also been substantial variation in whom the United States is letting in, with respect to both the country and the individual states.

When coming to the United States, immigrants tend to go to the immigrant gateway states of California, Texas, New York, New Jersey, Florida, and Illinois. Between 1995 and 2000, about 60 percent of the 5.6 million foreign-born population who moved to the United States entered the country through these states (U.S. Census Bureau, 2003). The total U.S. population in 2000 was about 281 million, and the foreign-born population was 31.1 million. To understand immigration, it is appropriate to consider California, because California, even among the gateways, stands out as a very attractive destination for immigrants.

The skill level of those coming to the United States is unevenly distributed, with many high-school dropouts at one end and many advanced-degree people at the other end. By 1990, 10 percent of people working in California were immigrant high-school dropouts. The estimate for 2000 is that the figure will be about 15 percent. At the other end of the distribution, California has attracted a disproportionate share of highly skilled people with Ph.D.s, M.D.s, and M.B.A.s.

With all the high-school dropouts coming into California, it would seem that the wages of less-skilled workers in California must have plummeted during the 1990s and on to today. An alternative is that firms, when they are faced with people with different skills coming in, choose to conduct different activities. California has absorbed the influx of people, and some industries have consequently grown in California more than in the rest of the United States. With a more-than-average number of less-skilled and more-skilled workers coming into the state, firms have in fact changed their activities.

Relative to the rest of the United States, the fast-growing industries in California over the 1980s were machinery (such as computers and office products), finance, insurance, real estate, and legal services, all of which are related to the IT boom and involve a high skill set. At the other end of skill intensity, California also had a boom in textiles and apparel. In Los Angeles County in 1980, there was essentially no production of textiles and apparel; by the end of the decade, the county had developed a thriving apparel and textile industry, whose production was second in magnitude only to that of the New York City area. Personal and household services also saw a boom, and most of the employees were immigrants.

The absorption of immigrants is more dynamic than the presumption that immigrants are going to be bad for the native-born workers' wages. Immigrants can bring in much additional technology and capital. Even if they do not, firms can absorb people through changes in the mix of output in ways that are not necessarily going to put pressure on wages. In fact, if one looks at the economics literature on immigration, it is difficult to find clear downward pressure on native wages averaged across all sectors due to immigration. That is true for the United States and for many other countries.

For example, in the early 1990s, there was a surge of Russians who left with the breakup of the Soviet Union and headed to Israel—one of the biggest immigration shocks a country has ever seen. It is hard to find pressure on Israeli wages caused by all these Russians. They were absorbed by firms hiring them in industries such as IT on one end of the distribution and construction on the other; the Russians needed places to live.

Trade—Flow of Goods and Services Across Borders

Trade is another important globalizing influence. Even if borders are closed and immigration is not allowed, the labor markets can become integrated as goods and services flow across borders. For instance, textile production has declined in the United States, and this has had a lot to do with import competition.

Trade will affect the prices that activities fetch on world markets. As international markets become more integrated, prices that firms can charge in different countries can change, and this will have a direct impact on wages. A growing body of evidence in international business shows that trading goods and services is an important way for capital and technology to flow among countries.

Especially in the United States, the term "trade" often leads to a discussion of numbers of jobs. Those who do not like fair trade argue that international trade destroys jobs. Those who like international trade argue that international trade creates jobs. Both arguments are both right and wrong. International trade does not destroy jobs or create jobs. If we take a long-perspective (decades) look at living standards, the issue has more to do with the number of jobs in the economy rather than the kinds of jobs. Only through the simultaneous destruction of some jobs and the creation of other jobs can international trade on the average, benefit economies along the lines that economists are so fond of talking about.

From the economist's point of view, international trade is on average a good thing for countries. The gains that economists talk about—a firm specializing along the lines of competitive advantage and consumers having wider choice—come about only when firms get out of some lines of business in a country. From the standpoint of the welfare of the United States it may be a good thing that firms in textiles and apparel and footwear shut down. It is only by releasing the people, capital, and technology that are in those industries and allowing them to move into industries such as chemicals, IT, and aircraft—industries in which the country is better than the rest of the world—that the gains economists talk about are accomplished. Overall, international trade both destroys jobs and creates jobs, and it is hard to find any evidence that it has any net impact.

However, the impact of international trade on labor markets is not uniform. Trade globalization tends to be good for countries on the average, but "on the average" is an important phrase. When countries, on the average, gain from trade, not every person, firm, or geographic region benefits

FIGURE 1.2 Share of imports and exports as fraction of GDP.

from the liberalization. There can be sharp distributional impacts of trade liberalization that underlie much of the political tension in the United States and many other countries about trade liberalization. It is not that people do not acknowledge the aggregate gains, but they worry about the distributional impacts and how individual workers will benefit.

The U.S. economy has become much more integrated in the global economy as seen by changes in the flow of trade with other countries. Figure 1.2 shows the import and export share of the gross domestic product (GDP) from the late 1950s to 2000. Imports and exports have gone up over time and, since 1978, imports have exceeded exports as a share of GDP. In the immediate post-World War II period, the United States was basically a closed economy with respect to international trade. Virtually all of the materials that were produced by firms in this country were sold to people in this country. Today, that is much less the case.

Foreign Direct Investment—Flow of Multinational Capital and Technology Across Borders

Labor markets become more global through foreign direct investment (FDI), which occurs when multinational firms set up, expand, and contract operations around the world. Multinational firms and the capital-allocation decisions they make can be important in terms of determining the number of people who choose to be in the labor force. Multinational firms may choose to have expatriates work in other countries. They may also take advantage of particular visa programs, such as H-1B and L1 (intra-company transferees) in the United States, to reallocate labor in their firms across borders.

Multinational firms can be big forces toward greater competitiveness in product markets. Many studies show that, especially in low- and middle-income countries, entrenched domestic firms face strong competition when multinational corporations come in. There are distributional impacts again, but the competition effects are undeniable. Multinational firms are important when one thinks about flows of capital and technology across borders.

If other firms can make capital decisions across borders, through arm's-length decisions, why should the focus be on multinational firms? Even in countries that host many multinationals, such as the United States, multinationals constitute only a tiny fraction of all firms.

Consider this snapshot of the United States in 1999, the last year for which there is a comprehensive census of all U.S.-headquartered multinationals. At that time, there were 2,494 U.S.-headquartered multinationals. That is, there were 2,494 U.S.-headquartered firms that had at least one foreign business enterprise in which the firms had a meaningful ownership stake. Examples are IBM, Johnson and Johnson, and other pharmaceutical companies. There were also about 8,600 affiliates of foreign-headquartered multinationals in the United States. These included the U.S. subsidiaries of foreign-headquartered multinationals (for example, in pharmaceuticals and automobiles). According to the U.S. Internal Revenue Service, that year there were 17.4 million nonforeign proprietorships, 1.8 million partnerships, and 4.8 million corporations, totaling about 24 million firms in the country. Therefore, less than one-twentieth of one percent of all U.S. firms were parts of multinationals. Why then should we care about multinationals?

Multinationals matter because they constitute such a large share of many macroeconomic aggregates. In the United States, multinationals account for about 25 percent of all employment, about one-third of the national GDP, about 40 percent of the capital investment, 60 percent of the imports, and 80 percent of the exports. Private-sector R&D is accounted for almost entirely by U.S.-headquartered multinationals and their foreign affiliates. The creation of knowledge and new ideas is basically an activity of multinational firms.

In summary, national labor forces become more global through cross-border flows of people, as well as through trade and FDI. If immigration were shut down, international trade and FDI would be at least as important in determining how wages and earnings are set in countries. Over the last 20-30 years of increased integration around the world, multinational firms have been engaged across borders much more than before. For example, the wave of globalization in the decades before World War I was due primarily to the flow of people across borders. Immigration was massive in those decades. Multinational firms were basically nonexistent. The situation now is almost the complete opposite. In recent decades, cross-border flows of FDI have grown much faster than cross-border flows of goods and services and of people (Figure 1.3).

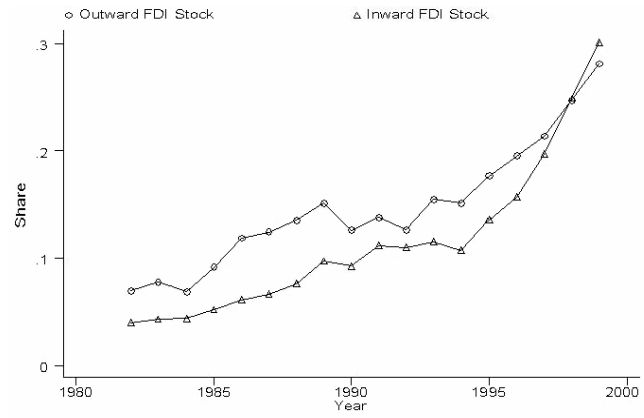

FIGURE 1.3 Cross-border flows of FDI stock as fraction of GDP. SOURCE: Scholl (2000, Table 2), Bureau of Economic Analysis.

WHO SHOULD CARE ABOUT GLOBALIZATION OF LABOR FORCES?

Should firms care about this process of globalization? How about workers? The answer depends a lot on what the rest of the world looks like in comparison.

Workers' Perspective

Wages Around the World

From the standpoint of workers, it is important to look at earnings both inside and outside workers' own countries. What is going on in other labor markets now has an impact on labor markets in countries such as the United States because of the flows of people, ideas, and technology across borders.

Figure 1.4 shows average manufacturing wages in various countries in 1994. There are some high-wage, low-population countries and some low-wage, massive-population countries. There are more than two billion people in China and India, where hourly wages are about one one-hundredth of the wages in developed countries such as the United States.

Those differences across borders are sustained by natural and political trade barriers, such as policy decisions restricting the flow of people, goods and services, and capital across borders. The differences are also influenced by national differences in skills in capital and technology, which depend on the human capital, physical capital, and knowledge that people are able to bring to the workplace. As globalization occurs, some think wages in countries such as the United States are being driven down to the level of Chinese wages. At the same time, history has shown that countries like the United States have had wage increases even though China, India, and others are low.

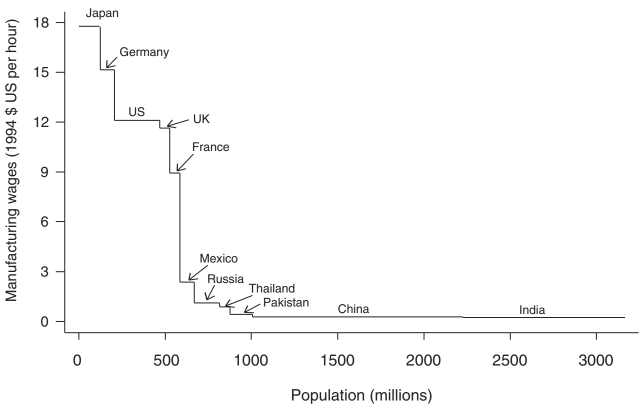

FIGURE 1.4 Average manufacturing wages in various countries in 1994. NOTE: According to the Chinese National Bureau of Statistics and the U.S. Bureau of Labor Statistics, hourly pay in manufacturing for 2001 was about $0.61 in China and $16.23 in the United States. According to U.S. Census data for 2002, the population of China was 1,309,380,000 and the population of the United States was 287,676,000.

Skill Sets

One important distinction between workers in different countries involves the distribution of earnings across skill sets. In the U.S. manufacturing sector, nonproduction workers have a higher level of educational attainment and more experience than do production workers (Figure 1.5). The skill premium, which was about 60 percent in the late 1950s, was actually falling throughout the 1960s and 1970s. In the 1970s, there were provocative discussions about how too many educated people were coming into the labor force. Somewhere around 1980, something started to change in the U.S. economy, and the return to skills has been rising dramatically since then. Different slices of the data related to measuring skills yield slightly different pictures, but the overall trend is a fact: The return to skills in the United States has been going up for almost a generation now. Income equality across skills has also gone up dramatically. The same has been true in many other countries.

It could be said that more-skilled workers are doing well because there are fewer of them in the U.S. economy, but the data do not demonstrate that. The relative supply of more-skilled workers in the country has been increasing, not decreasing. Labor economists look at four main groups of skill sets: high-school dropouts, high-school graduates, those with some college education, and college graduates and beyond. In the 1940s, 76 percent of the U.S. labor force were high-school dropouts. Only 5 percent of the U.S. labor force had college degrees or more. During the second half of the twentieth century, the skill mix of the U.S. labor force increased dramatically because of the GI Bill and rising income. By 1999, about 25 percent of people in the U.S. labor force had college degrees or more.

However, absolute earnings adjusted for changes in price inflation have not been rising for everyone. An example of the decline in these earnings is seen in Figure 1.6, for average private-sector, nonfarm weekly earnings adjusted for price inflation. Real earnings in the United States actually peaked in the early 1970s for a large fraction of the labor force—private-sector, nonfarm workers, who make up 85 percent of all United States workers and are the subject of one of the main available data streams. For a long time, their earnings fell; in the second half of the 1990s, there was a turnaround.

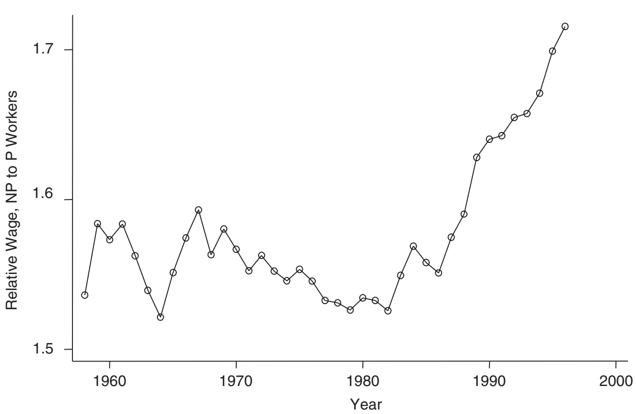

FIGURE 1.5 Skill premium in U.S. manufacturing. SOURCE: National Bureau of Economic Research, Manufacturing Industry Database *http://www.nber.org/nberces*.

FIGURE 1.6 Average private-sector nonfarm weekly earnings. SOURCE: U.S. Department of Labor, Bureau of Labor Statistics, nonfarm payroll statistics from the current employment statistics (*http://www.bls.gov/datahome.htm*).

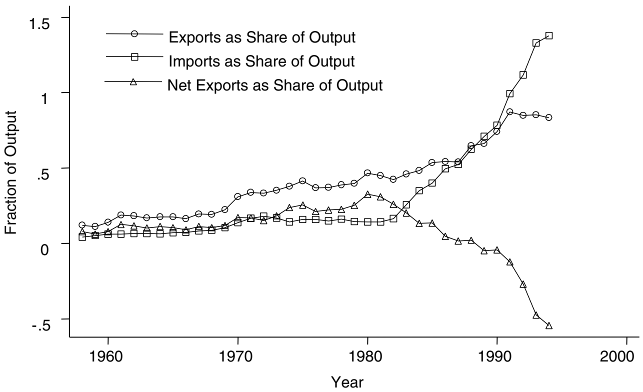

FIGURE 1.7 Import and export shares of output for computers and office products (standard industrial classification (SIC) 357).

Real earnings of different skill groups have been very different. Real earnings of more-skilled workers have been rising, but earnings of the middle- or less-skilled workers were flat or falling throughout the 1970s and the 1980s and into the 1990s. In the second half of the 1990s, there were increases across all parts of the skill distribution.

Multinational Firms

This increase in real wages since 1995 has been largely driven by global integration of the IT sector. Multilateral trade in the computer and office-products industry (standard industrial classification—SIC—357) was sizable and had a growing surplus with the rest of the world early in the time frame of Figure 1.7. Something started to change in the early 1980s in this industry. Exports continued to grow and imports exploded as a share of GDP. The trade balance in this industry then quickly went to zero and became dramatically negative, continuing this way into 2000. In that year, the industry had a trade deficit with the rest of the world of $30 billion.

However, the IT industries are special. Many studies have documented that in the second half of the 1990s, when there was growth in both productivity and in real income in the United States, they were driven by the IT industries such as computers and office products. These industries became much more productive and, as a result, prices went down substantially and firms and all their associated industries demanded a lot more capital in IT. Some of it was a bubble, but it is clear that these are special industries that overall have driven much of the productivity gains in U.S. real income.

The early personal computers in the 1980s, such as the Apple IIe, were not only produced in the United States, they were produced in one location, such as Silicon Valley. Now production is scattered all over the world. Today, a laptop has probably been made in 15 countries: all the components come from different parts of the world in elaborate global production networks that multinational firms have set up.

If in 1980 the United States had closed its borders and not allowed IT to globalize as it did, there probably would not have been the IT boom enjoyed in the 1990s. The IT industries would not have been able to deliver the productivity gains and price declines that they did.

To summarize, research by economists has concluded that in recent decades globalization appears to have been more beneficial for more-skilled workers in the United States than for less-skilled workers. It also seems that the boom time in real wages since 1995, driven largely by IT, has had a lot to do with globalization. These gains from global integration are widely distributed across skill groups.

WHO WILL BENEFIT IN THE FUTURE FROM GLOBAL INTEGRATION?

Demographic Trends

Data from the U.S. Census Bureau indicate that the total U.S. labor force went from a little over 100 million in 1980 to about 140 million in 2000 (Figure 1.8). There will be much slower labor force growth between now and 2020 than in the previous generation. Annualized growth rate for the U.S. labor force was about 1.8 percent from 1980 to 2000. Going forward, it is going to be about 0.8 percent per year. These estimates assume that birth rates and death rates remain as expected. The estimates also take immigration into account; the only wild card in the estimates is what is going to be changing in U.S. immigration policy.

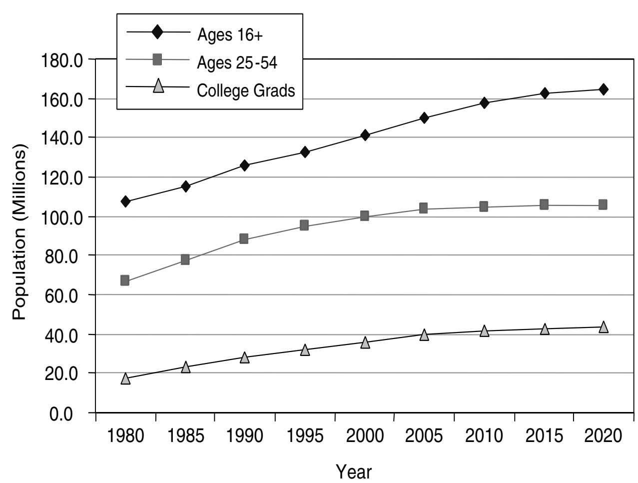

FIGURE 1.8 Projected U.S. labor force. SOURCE: U.S. Census Bureau.

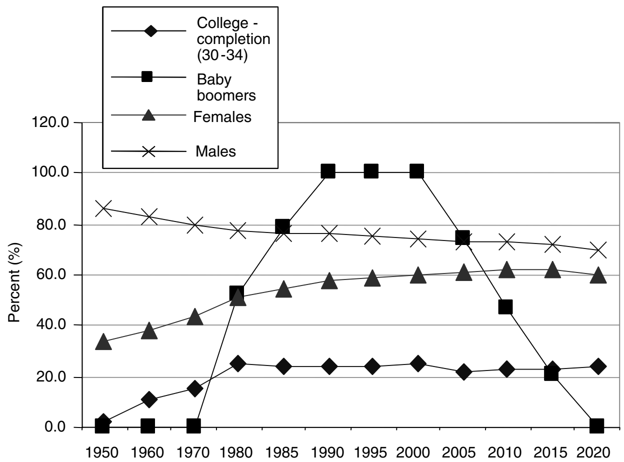

FIGURE 1.9 Projected U.S. labor force participation rates for 25-54 year olds, and for 30-34 year olds who have completed college. SOURCE: U.S. Census Bureau.

The prime age segment of the U.S. labor force, those 25-54 years old, is going to be virtually stagnant in the next 20 years. The projected growth is going to be from about 100 million to about 103 million. In other words, the number of prime-age, highly skilled working people is going to be virtually flat, in absolute terms, in the United States in the next 20 years. The number of college graduates is also going to grow more slowly than it did in the past. Thus, the pool of college-educated, prime-working-age people in the U.S. labor force is hardly going to grow in the next 20 years. In the post-September 11 world, it is more likely that there will be a reduction of U.S. immigrants than an increase.

Part of the slowdown in aggregate growth in the labor force is that there are not enough "baby busters" to replace the baby boomers, who are moving into retirement (Figure 1.9). In addition, the fraction of men who choose to be in the labor force has been declining in the U.S. economy for decades and will continue to decline slightly. This had been the opposite in the past. A major change that drove labor force growth in previous decades was the rise in female participation, driven by equal rights movements and changes in family structures. The fraction that is going to choose to be in the labor force is going to be virtually unchanged in the next 20 years.

College completion rates of people 30-34 years old also have influence. More young people are entering college, but the share that gets a degree has stagnated and will continue to do so.

Multinational Firms

For IT and other areas such as pharmaceuticals and chemicals today, there is a concern that more-skilled workers are at risk—and that good jobs are being outsourced and are leaving the United States. Again, multinational firms have been at the forefront of this process. They mediate substantial flows of the technology, capital, and trade of goods and services across borders. General public opinion is that multinationals necessarily cut back on domestic facilities by setting up production offshore. In hardware and increasingly in software, this is a salient discussion right now. Worker advocacy groups and unions are protesting the movement of production overseas. Politicians are claiming that studies are needed. Here in the District of Columbia, there have been hearings about this in Congress. There was an important hearing in the House of Representatives in June 2003[1] about the outsourcing of U.S. white-collar IT jobs and whether the economy can survive it.

Consider a U.S.-based pharmaceuticals producer. Suppose that in response to a fall in labor costs abroad, it decides to relocate some of its R&D activities to India. What happens to labor demand in the firm's U.S. operations? There are three possibilities to consider: (1) Substitution effect—labor in the United States and labor in India are substitutes for each other, a decrease in Indian labor costs mean a cutback in the U.S. labor demand. However, it may be that Indian labor and U.S. labor are actually complements, rather than substitutes. (2) Scale effects—lower costs allow the firm to expand its operations in all lines of business and stimulate demand for workers everywhere, including in the United States. (3) Scope effects—the firm may change the mix of what it does; it could change its activities in the United States. The IT industry has been doing this in recent years: even production workers have started to do other things within the company.

The potentially incorrect idea here is that labor in the United States and labor in India are substitutes for each other, a decrease in Indian labor costs mean a cutback in the U.S. labor demand. However, it may be that Indian labor and U.S. labor are actually complements, rather than substitutes. If the people in India are doing work, then perhaps those in the United States will be more productive. The interchange of computer code and other technical results may make people in the United States more valuable and more productive to the firm.. The actual impacts and net effects are much more complicated than might appear to be the case at first glance. It is an oversimplification to focus on only the substitution effects and conclude that the results will be bad. There is more involved.

Evolution of Chemical Multinationals

For each of the measures of capital stock (K), employment (L), and value of R&D, the fraction of the total world-

[1]Hearing of U.S. House of Representatives Committee on Small Business, June 18, 2003. "The Globalization of White-Collar Jobs: Can America Lose These Jobs and Still Prosper?"

TABLE 1.1 Global Evolution of Chemical (SIC code 28) Multinationals

Year	Parent K ($ Million)	Parent L (Thousands)	Parent R&D ($ Million)	Affiliate K ($ Million)	Affiliate L (Thousands)	Affiliate R&D ($ Million)
1982	73,321	1,365	6,864	15,362	668	658
Fraction (%)	82.7	67.1	91.3	17.3	32.9	8.7
1989	92,149	1,255	12,444	25,661	475	1,912
Fraction (%)	78.2	72.6	86.7	21.8	27.4	13.3
1999	133,513	902	27,400	59,572	532	4,221
Fraction (%)	69.1	62.9	86.7	30.9	37.1	13.3

wide amount done in the U.S. (parent) and in abroad (affiliate) has been determined (see Table 1.1). In 1982, 82.7 percent of the global capital stock of chemical (SIC code 28) U.S.-headquartered multinationals was in the United States. The fraction of capital that is outside the United States increased from 17 percent in 1982 to 31 percent in 1999. The affiliate labor force has increased, with a dip in the 1980s and a dramatic increase in the 1990s. There was a big increase in R&D in the 1980s, but it reached a plateau over the 1990s. In an absolute sense, R&D done abroad has gone up considerably from $1.9 billion to $4.2 billion, but there has been a similarly dramatic increase in the amount done in the United States as well. The overall message is that U.S.-headquartered chemical multinationals are becoming more global in where they are choosing to operate. Whether foreign R&D workers in chemicals are substitutes for or complements to those in the United States is yet to be determined.

THE POLITICAL ECONOMY OF GLOBALIZATION

It is important to keep in mind that a large number of Americans oppose freer trade, immigration, and FDI. However, these preferences tend to cleave strongly across labor-market skills: less-skilled Americans are much more likely to oppose liberalization. This may be the result of labor-market pressures across skill groups. As mentioned previously, less-skilled Americans have not done very well in the U.S. labor force since the early 1970s. If pressures switch towards the more-skilled workers in the future, perhaps the support for globalization will wane.

Unless there is a dramatic policy shift away from global integration; however, flows of goods and services and capital will continue to be more of an influence than the flow of people. The choice to become global has been expanding for firms, including chemical firms, which are increasingly able to take advantage of the situation especially with declines in communication costs. For workers, the direct impact is less certain and will depend at some basic level on how workers in the chemical industries in the United States compare with workers in other countries. In turn, that comparison is going to feed into the substitution, scale, and scope issues that determine what is going to happen to the demand for firms, universities, and workers in the United States. In the longer term, the evolution of the U.S. labor force is going to depend considerably on the skills that national education systems impart, which may be affected by immigration policy and the preparation of students.

REFERENCES

Borjas, G. J., R. B. Freeman, and L. F. Katz. 1997. How Much Do Immigration and Trade Affect Labor Market Outcomes? *Brookings Papers on Economic Activity*. 0(1): p. 1-67.

Saxenian, AnnaLee. 2002. Silicon Valley's New Immigrant High-Growth Entrepreneurs. *Economic Development Quarterly*. Vol. 16 (1). p. 20-31. February 2002.

Scheve, Kennth E., and M. J. Slaughter. 2001. *Globalization and the Perceptions of American Workers*. Washington, D.C.: Institute of International Economics.

Scholl, Russell B. 2000. The International Investment Position of the United States at Year End 1999. *Survey of Current Business* 80 (July 2000): 46–56 Bureau of Economic Analysis.

U.S. Census Bureau. 2003. Migration of Natives and the Foreign Born: 1995 to 2000. Census 2000 Special Reports (CENSR-11).

DISCUSSION

Matthew Slaughter's economic perspective of globalization provided a background for the remainder of the workshop. As the first presentation it generated many questions on such topics as the international constituency of science and technology workers and the policy goal of education. Global competition in R&D was discussed.

Foreign Labor Force

Donald Burland, of the National Science Foundation, noted the high percentage of non-U.S. workers making up the labor force of new R&D facilities being opened in other countries and in the similar high percentage among the graduate students and postdoctoral students in U.S. chemistry departments today. He asked what the impact of this might be as production moves overseas.

Slaughter responded that there is always a question for

R&D-intensive industries about how close the R&D workers should be to the production. The answer depends on what industry or company it is. Some companies are easily able to separate R&D and production geographically. IT hardware is an example. Much of the IT R&D has remained in developed countries like the United States, while production is all over the world. To the extent that production and R&D need to be closer together for working out problems in the production process and for more interfaces between initial manufacturing and testing, R&D may follow production. If foreign students who are getting their education in the United States are not allowed to stay and work in this country, much of the R&D and production may move with the students.

Good profit-maximizing firms try to segment markets in terms of money. For instance, it has made sense for pharmaceutical firms to charge much higher product prices in high-income countries such as the United States than in low-income countries. It is pretty clear that policy in the United States and in other countries will change that business model radically in coming years. One needs to think about how the policy change is going to feed back into knowledge creation, investment, and production.

The political and natural physical barriers that have been in many chemical and pharmaceutical industries are being destroyed by flows of information and by policy choices. That is going to have a big impact on what these companies decide to do.

Ratio of Wages of Nonproduction to Production Workers

Alvin Kwiram, of the University of Washington, requested clarification or expansion of the nonproduction-to-production worker ratio of wages discussed earlier. If the Microsoft effect[2] is removed from the curve of stock options in many high-technology companies in the 1990s, what would happen to that curve in Figure 1.5?

Slaughter replied that further measures of skills, such as occupation or educational attainment, can be plotted for 1980-2000 and the same picture is obtained. Rising income inequality across skill groups is robust to measurement. The magnitudes will vary, but the general pattern does not.

For 2000-2003, there has been a bit more measurement sensitivity; on some measurements, the magnitude of income inequality has stabilized in the last few years, whereas on others, it has continued to increase. That there has been no dramatic reversal is not surprising. Recessions tend to hit less-skilled workers harder. Unemployment rates are measures of the business cycle, and the unemployment rate for college graduates is still about 3.2 percent. The unemployment rate for high-school dropouts is about 9 percent. The increase in aggregate unemployment that has been seen in the last few years has fallen almost entirely on the less-skilled workers.

Policy Goal of Education

James Martin, of North Carolina State University, was struck by the interesting parallel between the discussion of the economy and his thinking about education and training. There was a clear distinction between thinking about the economy from the macro economy and local economy perspectives. The impact of globalization clearly will depend on the perspective. The parallel with education that he saw was that if what is best for the advancement of science and learning in chemistry were articulated, there would be a very different educational course for land-grant institutions that are mandated to educate the local populace. He asked what should be done for training and educating chemists.

Matthew Slaughter believes that the answer depends on the goals. One option would be to aim to raise average earnings and not be concerned with distributional impacts. At land-grant institutions, an increase in the number of students educated may help those universities because more ideas can be generated.

Some may argue that gains are not achieved by adding more people but by having a few great people. Bill Gates and Bill Georges from Medtronic are examples of people that have stimulated much of the aggregate economic impact. In that sense, the focus of the educational system should be on the "superstars," and resources should be channeled into honors programs.

The right track is not known, so it is necessary to try to allocate enough resources to both.

Competition in Research and Development

Douglas Selman, of Exxon-Mobil Chemical, thought that increasing competition, in R&D for example, should also be included in the list of major factors in the globalization of the labor force.

Slaughter responded that not only do multinational firms do the majority of the world's R&D, but the majority traditionally has occurred in a very small number of countries. Scientists in the United States, France, the United Kingdom, Japan, and Germany combined do about 85 percent of the world's R&D. Improvements in living standards have been attained from technological advances, and for a long time, these ideas have come from a very small number of geographical locations, concentrated in developed countries.

[2]In 1990, Microsoft Corporation became the first personal computer software company to exceed $1 billion in sales in a year, with revenues of $1.8 billion. By 2003, Microsoft was selling more than $2 billion worth of software a month and had more than $43 billion in cash. In 2001, Microsoft employees made an average base salary of $89,600. Including stock options and other benefits, they averaged $255,000, nearly seven times the state average (*The Seattle Times,* February 25, 2003).

How do these ideas get from those five countries to the other roughly 195 countries? India and China are obtaining more technology and more skills, because of the availabilities of a workforce capable of R&D. India and China have meaningfully entered the world's economy only in the last five or ten years, so competition is beginning to change.

The U.S.-headquartered multinationals' fraction of affiliate R&D went from 6.5 percent in 1982 to about 13 percent in 1999. This is similar to the trend observed for chemicals (SIC 28). Slaughter predicted that in 2009, the fraction would be up at 20 percent. Looking to 2019, he predicted it would be 35 percent.

How will these numbers affect the United States? The assumption may be that if there is a fixed pool of R&D and if more of it is being done outside the United States, the result will be bad for U.S. R&D workers, which may or may not be true, depending on how U.S. R&D workers are performing. Productivity will probably increase because Americans can complement the work of foreign academics and research assistants. Activities that used to be very high skilled become less skilled over time (e.g., due to technological advances). Perhaps the R&D workers whose jobs were moved overseas are better off moving to something more advanced.

Selman asked whether there is an opportunity to increase the level of U.S. R&D or technology capability to remain on the leading edge. He has noticed that the U.S. competitive edge in science and technology development may be eroding due to rapidly increasing capability in other countries. However, he said the advantage we can possibly sustain longer is our ability to develop commercial application of new science and technology. It appears that it is easier for other countries to develop strong science programs in their universities and government labs than it is for them to master the complex interface between science/technology and business opportunities required to commercial new technology (i.e., innovation).

Slaughter commented that the United States still maintains a big advantage over many of other countries in allowing new ideas and new processes to get out of the laboratory and into the marketplace. In 1994, no one foresaw the impact of the Internet, which was able to commercialize dramatically. It is important that the right business, legal, and educational systems be in place so that fresh ideas can be translated into good jobs at good wages.

Global Universities

Christos Georgakis, of Polytechnic University in New York, cited the recent examples of the Massachusetts Institute of Technology and the University of Michigan establishing links with Singapore. He asked how Slaughter analyzed the driving force of such partnerships and whether more global interactions among universities will begin to take place.

Slaughter responded that educational labor markets are among the most global and that there will be more of these kinds of interactions. He offered two observations. The faculty at the Tuck School of Business at Dartmouth is approximately 20 to 25 percent foreign nationals, and he said it is probably similar in other departments and schools. That mode of globalization is flow of people. Educational output is a lot more productive as a result of international collaboration.

The second observation was that educational global engagement and global competition spur innovation. IT is the one industry in the 1990s that had world liberalization of trade and elimination of all tariffs, specifically, the IT agreement of the World Trade Organization. Brazil did not sign the agreement. It is a middle-income country that thought the best way to develop IT was to protect its firms with big tariffs and big quotas on imports. By many measures, the Brazilian computer industry is not very good. The middle- and low-income countries that succeeded in IT were the ones that allowed multinationals to come in, to bring the ideas, and to get production networks integrated.

The Industrial Perspective

2

Major Trends Shaping the Future Workplace

Miles Drake
Air Products and Chemicals, Inc.

INTRODUCTION

Change is dramatic in the chemical industry at the moment. One major factor is the globalization of industry— the ability to manufacture and distribute across the world very easily and in a well-controlled manner through enterprise software and enabled systems. This interconnectivity is also changing the ability to access, communicate with, and work with talented people around the world.

It seems that the old competitive advantage of inventing and keeping technologies in-house and then using them around the world has become an outdated model. Now, the types of systems in place in a company have more importance. These systems include both the business and the processes, such as trying to create a culture and excitement within a company that stimulates production. In the leading companies, there is an ingrained culture and a belief in the company. To remain competitive, this culture and belief have to be distributed globally.

AIR PRODUCTS AND CHEMICALS, INC., COMPANY STRATEGY

Key roles for chemists and chemical engineers are embedded in Air Products and Chemicals, Inc. (APC), company strategy. There are three ways in which they help the company to grow its products. One is expanding leadership in performance-based materials solutions. This goes beyond selling a product. It involves going out to customers; adapting, developing, and changing a product to suit customer's needs; and then showing how the product is used. This activity requires sensitivity to the commercial needs of customers and detailed knowledge about the company and its products. The second involves leveraging APC excellence in process engineering, systems integration, and operations. This includes installing utilities for oxygen, nitrogen, and argon for large-scale use of industrial gases in the steel, electronics, and chemical industries around the world and then running and operating these utilities at very high efficiency and reliability. The third involves driving service offerings on the basis of unique positions. If performance-based materials cannot be found, then efforts must be made to provide appropriately defined services.

One direction in which APC is going, driven by demographic trends, is getting involved in such things as home medical services for people on respiratory therapy, a fast-growing business for APC. The company also provides services for NO_x abatement and other activities for the chemical industry. APC has $5.5 billion in sales in more than 30 countries now and about 17,000 employees. APC's business is more than 50 percent outside the United States, with the fastest-growing area being the Asian region.

GLOBAL CHANGES

Global trends are very strong drivers for business growth opportunities. Sustainable development and information technology are two examples of these macro trends. People are needed who understand the trends and can help to translate company capabilities into a product or a continuous stream of products that helps customers achieve improved manufacturing efficiency (energy, materials, and environmental footprint) and reliability. For example, one of APC's largest growth areas has been the semiconductor manufacturing process, to which high-purity, high-integrity gases,

This is an edited transcript of speaker and discussion remarks at the workshop. The discussions were edited and organized around major themes to provide a more readable summary.

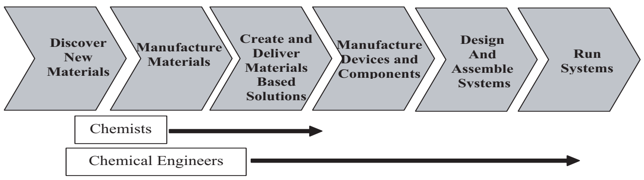

FIGURE 2.1 Generic value chain.

chemicals, and other products are supplied. Such services have been supplied in the United States, to Motorola and Intel, and now this business model has been taken around the world to follow previous and new customers.

Figure 2.1 shows a generic value chain that is changing as businesses become more global. In the past, the chain typically involved a single company in one region. Now, discovery for the most part is still centered in the United States and Europe, but this and the other segments of the chain are increasingly global, particularly in electronics. Today, the world is being supplied with materials for electronics, such as computers and television sets, from just a couple of small sites in Taiwan and Korea.

Changes at AT&T serve as a good example of the changes taking place in this value chain. That company provides communications systems, which require that someone design and assemble the components and systems. Previously, the company had to make a discovery, manufacture the raw materials, provide the materials, and manufacture devices and components. AT&T now has split into pieces and no longer does it all.

Similar things are happening to other large companies in communications. IBM now outsources (and off-shores) more of its chain. Because of the ability to manufacture around the world and to design and communicate well enough to do it, the supply chain is becoming more fragmented. Movement of manufacturing devices and components offshore has dominated in Asia as a result of cost, fast-growing markets, and existing plants in China. Overall, the new model for designing and assembling systems is that manufacturing goes to a region where there are growth markets.

India has also had strong growth in IT systems. Most software is being designed in India. In fact, GE started a huge laboratory there to provide software services, but now that entity is becoming fully functional and is going to be developing, designing, and discovering new science and technology and providing them to GE worldwide.

Anyone entering a global company in the United States has to be aware that designing is done in partnership with people all over the world and that developed products are likely to be used somewhere other than the United States or Europe. Although new discoveries have largely been centered in the United States and Europe for a couple of decades, the paradigm is changing. It is directly related to the numbers of graduates in the United States and those who return to their home countries.

This is particularly true for high-technology companies in Taiwan. Most people have been educated in the United States, they have perhaps worked at companies in the United States, and now they are returning to Taiwan because they want to be with their families and live in a more familiar culture. This seems to be happening more and more. Thus, the quality of people being hired and put into place around the world makes it increasingly probable that discovery is going to occur in China, India, and elsewhere.

AIR PRODUCTS AND CHEMICALS, INC., TECHNOLOGY DIMENSIONS

APC technology is distributed as shown in Figure 2.2, but 20 years ago, technology development was almost exclusively in Allentown, Pennsylvania, with a little bit in the United Kingdom for engineering for the European market. Through acquisitions, APC is carrying out R&D all over the world. There has been a shift to being closer to customers, as in Silicon Valley and Arizona for the electronics explosions there. There has been growth in the United Kingdom with the Basingstoke Laboratory, and APC now has laboratories and facilities in a couple of places in Germany and engineering activities in Shanghai.

The rate of new plant building and the cost of building plants have led the company to Shanghai. Soon there will be highly competent designers there, and eventually many more activities will migrate there. There are also some small laboratories and facilities in Korea and Japan. The challenge now is to know where customers will be and where the predominance of new scientists and engineers will be. There is a huge draw to put resources and capabilities in the Asian region. APC is starting to do that now, and it is certainly going to happen more and more in the future.

The question is going to be what this means for people back in Allentown and whether it presents a threat or an opportunity. There have been some interesting experiments

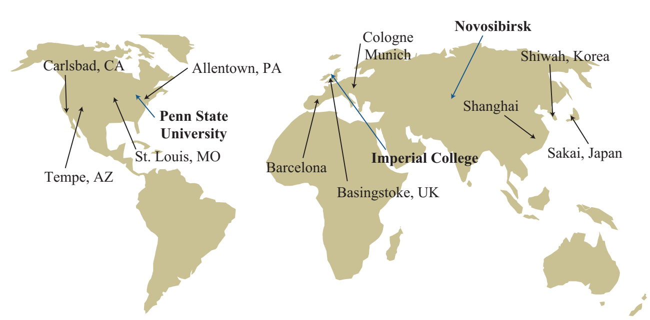

FIGURE 2.2 Air Product and Chemical, Inc., technology R&D dimensions.

in this respect. One group has had more than a decade of collaboration with a group of scientists in one of the republics of the former Soviet Union—a government-funded research center in Novosibirsk. When it started, there was concern that with the lower cost of labor, U.S. jobs would go away. In fact, what happened is what Matt Slaughter discussed earlier. People in Novosibirsk are strong in physics and have extraordinarily good mathematics abilities. The U.S. engineers and scientists, however, have a much better connection to the market needs of the company. Thus, there is a complementary relationship in the jobs being done in the two different geographic locations.

Direct meetings and travel between the two regions took place and helped to foster warm relationships between the two groups of people. People saw that U.S. engineers and scientists brought their own specific creative value to the company and that people in Novosibirsk are complementary because it was difficult to find their skills locally.

More and more, this is how work is being done. One challenge faced by U.S. companies is how they are going to differentiate themselves, other than by just being global companies that hire U.S. graduates. Being able to understand the full breadth of commercial and technical interactions and then being able to think and act globally at the same time are very important. With this sensitivity, they might have an advantage.

However, one has to ask, Does the United States have an educational competitive advantage because of the cosmopolitan nature of its universities? There is a long tradition of training people from overseas, many of whom have stayed in the United States. Now many are returning home; as an open system, this might be better than some of the other systems. It is an important question to think about in trying to design the ideal competitive university environment.

APC is thus heading off on a journey of becoming global. The primary rationale for development of most of the laboratories and facilities outside Allentown is to be closer to customers. There will continue to be unique skills to bring into the company globally, but there is also much to be learned from customers and from the different places to which the company is moving.

Some centers now feed technology into the United States and Asian regions with high efficiency. It is important for a global company to foster the attitude in which people in other regions think of themselves as part of the company. They should want to make a contribution and have a full seat at the table. APC continues to strive to build this kind of environment in the company.

As APC expands its capabilities in Asia, the vision is of a future in which a number of centers provide technology, ideas, and new products to the rest of the world. They will serve the whole global knowledge community, as well as providing for special regional needs. This is how APC sees global activity working.

What, then, is the successful way of innovating globally and across national boundaries? Multiple functions of understanding must be embraced in a large company, beyond providing some technology solution. John Irven, for example, is global head of the package-gas technology group based in Basingstoke, U.K. John has to launch products globally, while maintaining the only center there for Air Products and Chemicals, Inc. That is the global center, based in the United Kingdom. He says these are challenges to developing trust and interpersonal relationships across boundaries. The factors become an important differentiator because it is easy to have good technology but more difficult to get value out of it.

MAJOR GLOBAL TRENDS

Information technology (IT) is dramatically changing knowledge work through activities such as networking for solutions, reuse of stored data, automation of design, and supply-chain operations. Networking for solutions or, as Proctor and Gamble calls it, "connect and develop," is using the ability to connect around the world to find an answer to a problem. Far fewer problems now intrinsically require going to the laboratory to invent something. Much more effort is instead being put into defining problems better and then seeking solutions.

Reuse of stored data is being employed to enable the design of complex engineering plants. For example, swaths of data that the plant has stored are used and are easily adaptable. This has dramatically changed and simplified design engineering. The ability to automate design, experiment, and analysis has helped make design programs much easier. Much more information is now available to run more optimizations around the design process, and this again is changing engineering. Automation of supplychain operations is also being affected by IT advances; this does not have such a direct impact on the engineer's work, but it is certainly changing the way companies think, behave, and connect.

Another major global trend, discussed earlier, is the shift of businesses to the Asian region. This is partially due to the growth of highly trained and motivated people in India and China as the United States continues to provide higher education for foreign-born talent. At the same time, there is a lack of U.S.-born science and engineering talent.[1] Very few people in the United States with unique vision, capability, and knowledge are choosing to go into engineering and chemistry. Many who do say that they would really rather do something else. The movement of chemists and chemical engineers into other fields is powerful for continuing and sustaining the United States as an engine of entrepreneurship, but it is not good for science and engineering. In the

[1]For current data and discussion of this topic see: National Science Board. (2004). *Science and Engineering Indicators 2004* (NSB 04-01). Arlington, VA: National Science Foundation.

future, however, big technical innovations may emerge more in other countries where chemistry and engineering are seen more as ways to personal success. As mentioned earlier, while the United States continues to provide higher education to a large percentage of foreign-born talent including chemists and engineers, the trend now is that a number of people are going back to their own countries as those countries become more attractive places in which to work.

These are big changes and they drastically affect where and how a company hires employees. This suggests big concerns for the educational system.

The Changing Work Environment

For people who want to be involved in innovation, the emerging trend is toward open innovation: solutions to problems are externalized more, instead of having all the people inside a company available to work on every problem. There is more effort to reach out to the world to get answers. Companies are emerging around this idea, such as Nine-Sigma and Intercentive. These are places where problems can be posted for a bounty.

Some 20 or 30 years ago, this might have been impossible to manage or handle. Now it is very easy. A web page can be accessible to almost everyone who might be interested in providing a solution.

Computer modeling in chemistry is changing how chemistry and experimentation are thought about. In fact, some chemists use high-end computational modeling but actually have little wet-chemistry experience. They can quickly pinpoint how something is going to react, where it is going to react, and what issues the reaction presents. It is remarkable how this is changing.

High-throughput experimentation is also changing how chemists and chemical engineers work. Together with design tools and computer modeling, these high-throughput methods make it possible to obtain data to analyze and find answers more quickly than ever before.

The creation of value, as John Irven has discussed, is all about putting together a productive, integrated team of people. These are teams that function across multiple boundaries and time zones, and this becomes a way for the company to differentiate itself from others. People who can operate in this mode are needed.

Success Levers for Innovation

The idea-value chain is the path from ideas to commercialization. People play an extremely important role in developing strategic knowledge. The key is to solicit many good ideas and, once commercialization happens, to apply the best resources and create value.

With respect to globalization and global aspects, the pieces of the knowledge pipeline have different issues and factors. With knowledge creation, there is the example of the scientists in Novosibirsk who create engineering design criteria and fundamental knowledge.

The issue now is to access global capabilities with global strategic coordination. Part of externalizing research will be finding people that can perform various kinds of work and putting them together to build high-value teams. The challenge is to obtain value while maintaining enough openness to redefine things.

It is not possible to keep looking at everything. There must be focus and balance. With regard to training and perspective, people entering the workforce have to think from a truly global perspective about where they can get answers. Fortunately, the nature of science tends to support such thinking.

It is important to overcome company issues of parochialism, to keep thinking that ideas and products can be found anywhere in the world. It is highly probable that in the future most ideas are going to come from outside companies. For example, the Chief Executive Officer of Proctor and Gamble (P&G) has set a target. He wants 50 percent of new products or new technologies to come from outside the company. P&G also has an aggressive process for finding half-baked or fully baked products that it can bring into the P&G system to sell around the world.

Innovation in product development—developing new things and getting them out to customers or getting new plants designed and built—is all about a lot of people coming together with a common culture, understanding, perspective, and teamwork. To be successful in commercialization with only a U.S., national, or company perspective is no longer possible. All of the voices out there must be listened to, and companies need people who are going to be open to input from the outside.

Global Sourcing of New Ideas

Ideas should be accessed and evaluated globally and ideally from inside and outside the company. Picking up on ideas from the outside includes taking advantage of the centers APC has around the world that are responsible for all the technology and leadership of an area. These might be people reporting to that center who are in the United States or somewhere else, but they are the lead group for that particular area for the world. People are needed who are not just thinking about inventing everything themselves, but who are also open to getting ideas from the outside.

Product development and commercialization should be managed from a global perspective with an effectively designed hierarchy. New products, new ideas, and new technologies are generated by centers of excellence; distributed technology service teams and their customers; and then a system of external partners—universities, institutes, governments, and venture capitalists. Bounty hunting is also used. Internally, a whole set of emerging technology identification approaches is used.

APC is forced, for everything being done, to think from this global perspective. Otherwise, any effort is barely worth doing. The company has to reach big markets and broad areas to be successful. As discussed earlier, there are often winners and losers in globalization as capital and people are shifted around the world. The challenge in a global enterprise is to make all involved feel that they are doing something of value for the world and not just replacing one area with another.

IMPACTS ON CHEMISTS AND CHEMICAL ENGINEERS

What will be the qualities of the future workforce for those operating in this increasingly global environment who are now occupied in the United States? This has to do with know-who and know-how. To be a good engineer or a good chemist in the future will mean competing with an extraordinary number of good engineers and good chemists around the world. To be differentiated from the rest, it will be important to have expertise, of course, but it will also be necessary to have the ability to go out and find things and to connect with others.

Willingness to be a team player is essential. There are only a few jobs and a few opportunities for people who are lone experts. In most industrial companies, value is created by multifunctional teams. The ability to perform and provide knowledge and expertise to such teams is critical.

Flexibility is another important quality for success as a chemist or engineer of the future. One must be able to adapt to new areas and learn to integrate knowledge from other fields. That is manifested in terms of a low-growth environment. APC for example continues to hire through its Career Development Program (CDP). People are hired into the company and get 3-year rotational assignments. The CDP has been retained even while some fields have been downsizing, particularly in the United States. At the end of three assignments, those who come in and are flexible are readily taken in by the research group or someplace else within the company. The narrow people, however, are not as fortunate.

As markets change swiftly and as many other fields also move quickly, people who cannot go from one field to another become stranded in the company. They are experts, with expertise that is no longer needed. To perform well in the commercial process in a global environment, people have to understand how they fit into the whole value-creation process and how they connect to people around the world. Obviously, for top talent, international people skills and being able to lead diverse teams are going to be essential for personal growth and success. Broader language skills are also desirable but not requisite.

When chemists and chemical engineers need all these high-value skills to perform well in a company, however, a lot is asked from them. Most at the top of the company now cannot provide this sort of capability, but it will be expected of the next generation. They will have to be better.

CHALLENGES FOR NEW GRADUATES

What role can or should the university play in selecting and developing students, or is it solely the role of industry to find the right people? Are chemists and engineers being prepared to use teams and external resources to supplement what they can do and what they are doing? Does the entire graduate-school process take students down a slightly different path that must be unlearned once they go into industry? Is industry making full use of the new skills and capabilities that new graduates have, and how well are chemists and chemical engineers being trained to understand how their craft will be practiced when they get into industry?

DISCUSSION

The discussion of Drake's presentation began with a question about APC's program in the United Kingdom. Characteristics of the ideal student were also discussed, including high-order skills.

Air Products and Chemicals, Inc., Global Committee in the United Kingdom

Karin Bartels, of Degussa, began the discussion with a question about how well APC's global committee outside the company's headquarters in the United Kingdom is working.

Drake responded that one of the chief executives for that group resides in Belgium, and the team is doing well at operating in a global way. He thinks the committee has been quite successful.

At the next level down, a group in the United Kingdom provides all of the cryogenic innovative applications technology, and the group is centered around the person who built the group up over the last 10 years. There have been some difficulties because some U.S. businesses operate with an older style of thinking. They traditionally thought of APC as a U.S. company and thought that company ideas should come from the United States and then be deployed around the world. The global committee has been successful in changing this thinking so that the products of that group are being deployed rapidly in the United States. A lot of the issues have been overcome.

The challenge now is whether the company has to go way beyond this with its capability in Asia. APC has learned from some of the barriers of the other projects and is thinking about how it can jump-start the work in Asia.

The Ideal Student

Wyn Jennings, of the National Science Foundation (NSF), asked whether Drake would comment on the distinction between the characteristics of students at the doctorate and bachelor's levels and how good the fit is at both levels.

Drake said he does not see much difference between the two levels. There are general characteristics of being able to work across boundaries and teams, and these do not vary much between having a bachelor's or a doctorate degree. He mentioned that one of APC's most creative producers has no degree at all.

Drake is always astounded at how technically capable the people who come into the company are. He said that APC is doing a good job of selecting for good all-around people skills as well. However, he does not know whether the company is choosing only the good ones or whether everyone is being trained to think and be this way. He acknowledged that mistakes are sometimes made, and some people end up being too narrow and unable to understand what is expected of them.

Douglas Selman, of ExxonMobil, commented that people at all degree levels must have global skills in R&D commercialization. Looking at his own company, he thinks the best and brightest from a strictly science and technology standpoint do not have these higher-order skills that have been talked about. As a result, a lot of time is spent with them over their first 5 or 10 years in the company, teaching them the processes consistent with doing that kind of work. If they had more training and experience in these skills, he felt that there would be less inefficiency and more productivity.

Higher-Order Skills

Marshall Lih, of NSF, commented that *higher-order skills* is better terminology than *soft skills*. Technical people assume that if skills are soft, they are not hard and not challenging and, therefore, not worth learning. If these kinds of skills are referred to as higher-order skills, people may be willing to pay more attention. Higher-order skills require sophistication for people to understand other people and other cultures and to build trust.

Drake replied that someone is needed who understands the sophisticated things but can also interact with other people. It comes down to the concept of what knowledge is. To him, knowledge is in people's heads and between people and not in a database. Therefore, higher-order skills are essential.

James Martin, of North Carolina State University, expressed frustration with the national education debate that has kept pushing toward accountability. In pushing for accountability, he said, it is the technical skills and not the higher-order skills that are being accounted for. He said higher-order skills must be included in accountability, but it is not an easy thing to assess and is not possible with "No Child Left Behind"[2] standards.

[2]With passage of No Child Left Behind of 2001, Congress reauthorized the Elementary and Secondary Education Act (ESEA)—the principal federal law affecting education from kindergarten through high school. The amended legislation builds upon four pillars: accountability for results; an emphasis on doing what works based on scientific research; expanded parental options; and expanded local control and flexibility.

3

Boundary-Crossing Technology Networks at Degussa

Karin Bartels
Degussa Corporation

OVERVIEW OF DEGUSSA

Degussa is a newly formed company with an old name. In 2002, Degussa had sales of about 11 billion euros and operating profits of about 1 billion euros. It employs about 46,000 people worldwide and focuses on specialty chemicals that have higher profitability and are less cyclical. The old Degussa was known more or less for its precious-metals and catalyst business. The new company is Germany's third-largest chemical company and considers itself a world market leader in specialty chemicals.

The current trend in most chemical companies is not to make or sell new products but rather to sell system solutions to customers. That is the direction that Degussa has taken. The company knows customers' needs and how to solve challenges, and it provides the appropriate expertise and technical solutions for customers. Degussa typically does not provide end-user products; rather, it makes intermediates that are unrecognizable in the products that people use but that contribute to their performance.

The current Degussa evolved by merging several German companies over the last 3 years. The old Degussa merged with Huels, forming Degussa-Huels in 1999. In the same year, SKW Trostberg acquired Goldschmidt, forming SKW. Degussa-Huels and SKW later merged to form the new Degussa in 2001. The legal entities involved in all of those companies with different cultural backgrounds also came along. Initially, it was quite a challenge to combine all the company cultures and business strategies, and a lot of progress has been made in forming the new Degussa represented in its vision: everybody benefits from a Degussa product, every day and everywhere.

SALES

The portfolio chart in Figure 3.1 shows that commodities substitute for cost-risk factors. Substituting a commodity is more or less low risk, but if it is done with specialty chemicals, they typically have unique applications and compositions, and the cost-risk substitution ratio becomes very high.

Some 40 percent of Degussa's sales are in highly specialized technical solutions. Deceptive specialties make up 27 percent. The latter may include hydrogen peroxide and carbon black, which are often thought of as commodities. However, producing these chemicals and turning them into solution systems are technically much more demanding than people think. The risky specialties are currently at 14 percent and the commodities 19 percent of sales.

As shown in the sales distribution chart (Figure 3.2), Germany accounts for only about one-fourth of total sales; almost 75 percent comes from abroad. That is common in multinational chemical companies: the majority of sales are not in the parent country.

DISTRIBUTION OF STAFF

Doing business in other regions requires that the company manages its workforce in an efficient and global way and that the company have bases in the region to be successful and sustain its competitive advantage.With regard to employees and R&D staff by region, most of Degussa's R&D effort is centered in Germany (see Figure 3.3). One of the fastest-growing areas is Asia, particularly China.

This is an edited transcript of speaker and discussion remarks at the workshop. The discussions were edited and organized around major themes to provide a more readable summary.

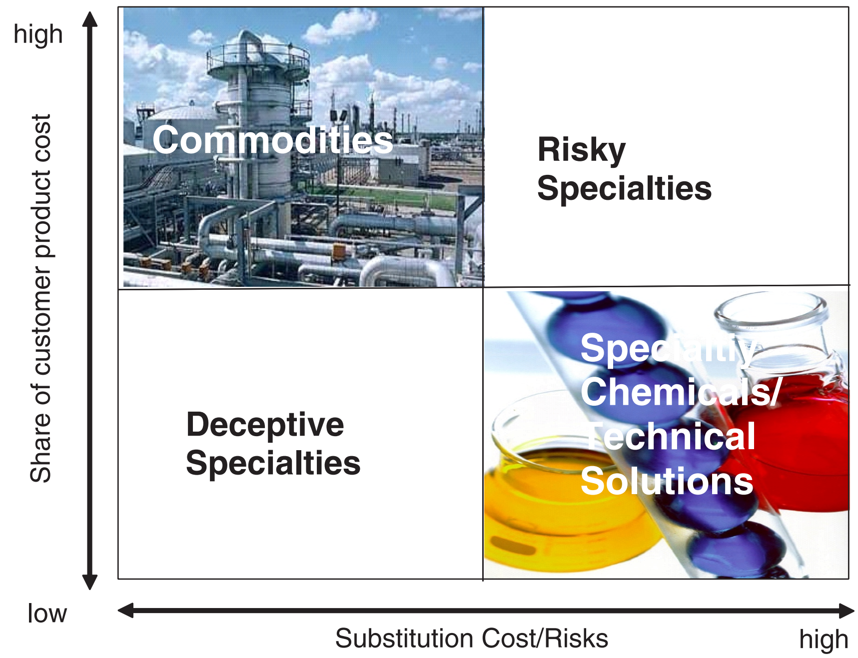

FIGURE 3.1 Portfolio chart.

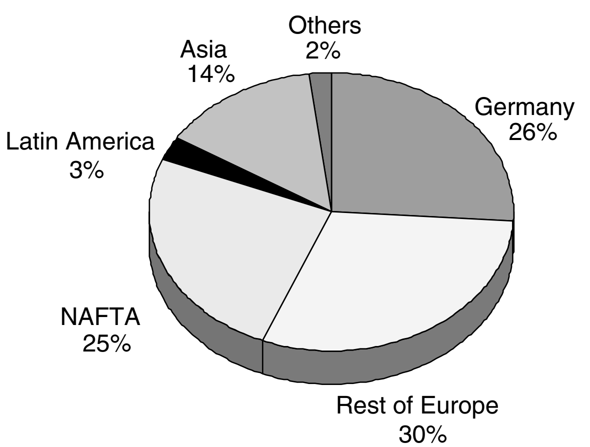

FIGURE 3.2 Degussa's regional sales. NOTE: NAFTA = North American Free Trade Agreement Countries.

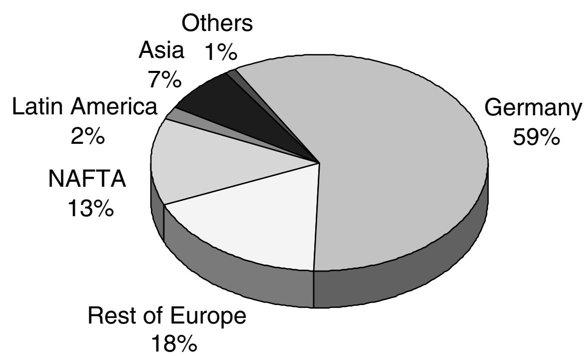

FIGURE 3.3 Location of Degussa's R&D employees. NOTE: NAFTA = North American Free Trade Agreement Countries.

About 3,300 people work in Degussa R&D worldwide, and of those, about 13 percent are in NAFTA (North American Free Trade Agreement) countries. Degussa's R&D activities in the United States focus on product development, applied technology, and customer service. Degussa works very closely with its customers in all regions and emphasizes this strategy. Companies have to position the workforce in a way that is appropriate for market and customer demands in each region.

One of Degussa's business goals was to have a larger presence in China—not just sales offices, but headquarters in China or a site where all of China's activities are coordinated. In November 2002, this goal was accomplished with the foundation of a holding company for China operations, Degussa (China) Co., Ltd. Now, more than 15 companies, including several joint ventures, operate production facilities in China. The broad array of high-quality products is aligned to customer needs not only in China, but all over Asia. Degussa works with both the local workforce and local companies, combining the knowledge and expertise that exist in the region with the workforce that Degussa brings in. For example, in the fine-chemicals field, where the company makes intermediates for the pharmaceutical industry, it has a manufacturing site in Nanning, China, and a sales office in India. A technical center in Shanghai will be inaugurated in January 2004.

The majority of Degussa's workforce and the technical expertise is in Europe. The workforce is also being moved to the Americas and Asia. The goal is to initiate activities and then, once settled into a region, hire from the regional market. Degussa's presence in the United States is strong in hiring chemists and chemical engineers to run production, R&D facilities, and technical centers.

Degussa finds that people are somewhat hesitant to go from the United States to other regions and is now encouraging people to get more experience by working in Europe or Asia. This effort is supported by offering cross-cultural training programs that are open to everyone but are mandatory for employees who are being relocated.

LINKING KNOWLEDGE

Linking knowledge is a large theme in Degussa, because of the company's history, recent acquisitions, and evolution. Most of the research sites are still in Germany, the rest of Europe, and the United States, where many of the legal entities maintain their own production sites, product development, and technical support. It was decided to maintain sites that have a wealth of knowledge and technical expertise, which enable business units to provide customers with appropriate solutions for their needs. The challenge is to make accessible all the existing knowledge in the company, linking different businesses and sites. To learn from and transfer the existing knowledge, Degussa launched a Linking Knowledge project to form an R&D network worldwide (see Figure 3.4) and use the innovation platform and market proximity as integral parts of its entrepreneurial success.

One of the key issues is to link the R&D network with the market and sales groups and generate new ideas to transfer technology from one group to another without reinventing the wheel. There are regular meetings where these groups come together and discuss how to learn from each other. The project was launched nearly a year ago and has already made great strides in developing good ideas. To reward such team activities, Degussa recently launched a Linking Knowledge Award that encourages scientists, business people, and others in the company to work cooperatively and learn from other experts. Thus, this award is dubbed "Not Invented Here" because it encourages exploring existing solutions in other businesses, copying ideas, and adapting them for different applications. For example, a team comprising members of five business and service units in Germany and the United States received an award in the category "Best Technology Transfer" for its new concept and entrepreneurial work in promoting internal growth.

There are many ways to share information; the challenge is to coordinate them efficiently. Progress is being made, the system is in place, and people are communicating more effectively. As Degussa attempts to bring all the regions together, everyone is asked to share knowledge and communicate. The soft (interpersonal) skills are important, as is understanding that fresh ideas and different perspectives can result in better solutions. One of the focuses of Degussa's worldwide R&D sites is to develop new products peculiar to the regional markets and customers' needs. The company is present in regions where there is the largest growth and the potential to sustain a competitive advantage. To encourage innovation and creative ideas that lead to new products, new processes, and new applications for existing products, Degussa launched the Innovation Award right after the company's foundation.

Some of the challenges are still present, and sometimes there is room for improvement; but when everyone works toward a common goal and embraces the global workforce concept, Degussa will succeed, given the highly trained employees and technical skills that its workforce possesses.

DISCUSSION

Karin Bartel's presentation began a discussion about the globalization of the chemical workforce. Language and cultural barriers and collaboration among differing groups were discussed. The quality of new employees in the workforce was communicated and included continuing education, training, and the importance of high-order skills. Another topic was Degussa's competence center in China.

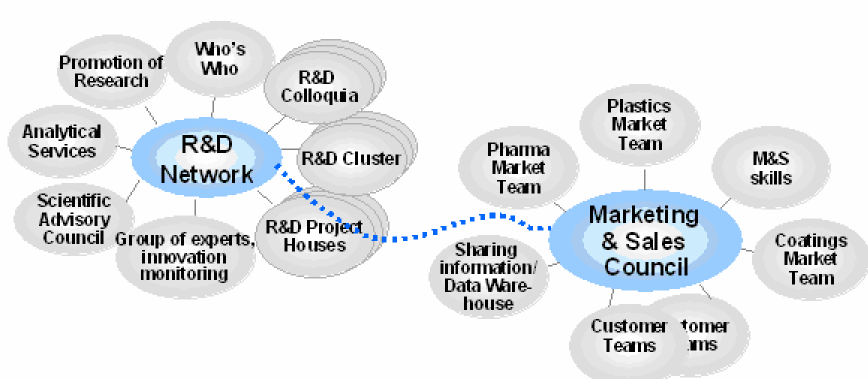

FIGURE 3.4 Linking knowledge from Degussa's R&D network.

Language and Cultural Barriers

Alvin Kwiram, of the University of Washington, asked what disadvantages executives or scientists in our U.S. corporations have when they try to interact either in Europe or in Asia. Should people in the United States worry about the language problems here, or is that not a problem at all because, even in a globalization context, so many other people speak English around the world?

Bartels thinks that language is not a problem here but that understanding a different culture is a problem. By going to a different country and speaking a different language, one has a greater chance of understanding the problems of that country. To do business on a global basis, she thinks it is necessary to pick one language and speak it, and most likely that will be English.

Bartels noted that in Germany there is a perception that there is not a big difference between Germany and the United States, but she thinks it is necessary to get away from that perception. There are differences, and they need to be identified and used to the greatest extent to create value for companies and to use the people in ways in which they can best exploit their skill sets. Some people have a strong technical background but lack interpersonal skills; they are needed, but it would of course be best to have people with the high-order skills and a strong understanding of technical subjects.

Robert Grathwol, of the Alexander von Humboldt Foundation, noticed the large percentage of Germans still being employed by Degussa. He wondered about a situation in which two very qualified candidates applied for a job and both were non-German but only one was competent in German. Who would be hired?

Bartels said that she would value the person that brings a different cultural background to the company. The company still tends to employ people educated in Germany, but Degussa wants to change that. One of Degussa's missions is to become a truly multinational company.

Collaboration

C. Frank Shaw, of Illinois State University, commented that it seemed that all research is typically collaborative. He does not think there should be too much pessimism about the situation but rather a fostering of more collaboration. If there are some subdisciplines of chemistry in which collaboration is not common however, how can it be nurtured?

Bartels thinks that there is already awareness at the university level about breaking up the departmental structures and fostering collaboration among the various departments.

Douglas Selman, of Exxon-Mobil, brought up the obstacle that exists internally, even in a given culture, of the interface between the technical person and the business person. Technical people have learned and tend to collaborate almost naturally in their field and discipline internationally. It is the interface between the marketing person and the Ph.D. bench chemist or the manufacturer that poses the greatest challenge.

Continuing Education and Training

Donald Burland, of the National Science Foundation (NSF), noted that at IBM and other companies, there seems to be a move away from making things to providing solutions and systems. He questioned how this new direction is going to affect the kinds of people entering the chemical workforce and what sorts of jobs they will do.

Bartels thinks that what is needed is to have a well-trained chemist or chemical engineer that has knowledge about the fundamental fields of science. In addition, there is an increasing need to have background in fields such as materials science, nanotechnology, gene expression technologies, and DNA array areas. However, a university cannot do everything, and to build the additional skill sets that are demanded, companies themselves are trying to train engineers and chemists in additional skill sets that are needed.

Michael Rogers, of the National Institutes of Health, asked whether if one group needs to work with another group in another geographic area, Degussa provides the group with specific training in culture and language to be able to perform the job.

Bartels stated that Degussa has a cultural training program.

Higher-Order Skills

Matthew Slaughter, of Dartmouth College, pointed out that he has heard a lot of people say, in different contexts, that it seems that what is increasingly valuable for many multinational firms is not just technical skills, but also soft, interpersonal—or whatever phrasing you want to use—skills of combining people and ideas and creating value through the connections. If ExxonMobil is spending 10 years trying to teach people these skills, is there a sense that there is a problem in the higher-education system in imparting the skills to students in their formal training? If so, what would be ways to teach the soft or interpersonal skills that are so valuable?

Bartels thinks that the focus of the university is to educate people and impart knowledge. However, universities cannot do everything. They cannot teach major subjects and also make students good speakers with excellent interpersonal skills and communication skills. She said she is a bit overwhelmed by what is needed to be successful in the global environment.

Kwiram noted that one of the Integrative Graduate Education and Research Traineeship (IGERT) programs at the University of Washington has a team approach that is unique in that graduate students coming in have to spend the first year working on a joint project as a team, and this work becomes part of their dissertation. The students are enthusiastic about it, and it seems to be a promising type of program.

D. Michael Heinekey, of the University of Washington, noted that in the past, chemists were required to study German as part of their Ph.D. studies in the United States. The reason goes back to the time when the literature was mainly in German. The requirement has been dropped, and he thinks that might have been a mistake. He would not recommend that German necessarily be reinstated, but perhaps an Asian or other foreign language needs to be studied. He recalled that it had been suggested earlier that perhaps culture should be studied as well. Study-abroad programs exist in the sciences and engineering and, although they are not as developed as in the humanities, should be taken advantage of if even for a brief period. He said that students would then be advanced in soft skills that are not typically learned in school and that in general there has to be more of an international perspective in thinking about how to train students.

Bartels agreed and thinks that the interaction between academe and industry to offer internships for students should be increased in all parts of the world in which a company operates.

Marshall Lih, of NSF, provided a short answer to Slaughter's question about teaching higher-order skills. In the middle 1960s, Dartmouth College offered an introductory course in engineering design. The course organized the students in companies to work on actual projects. The higher-order skills that people are talking about are learned by trying to solve a problem and working on a project, such as how to negotiate and how to organize a team. There is no room in the curriculum to teach a separate course, but one project course cannot cover everything. Motivation to learn afterwards is often provided.

Wyn Jennings, of NSF, added further information on IGERT, which is concentrating on the very issue of giving principal investigators and universities an opportunity to experiment with graduate education. The program includes multidisciplinary education; development of career, professional, and personal skills; and instilling a global perspective in which most of the students are, in fact, going abroad for a time. Will it take the student 6-8 years to do it? No. The students are graduating in the normal amount of time. People are accommodating the increase in learning, and the students are doing well in the job market. There are 116 sites working with IGERT in the United States, and a similar program is being implemented in Germany. In addition, workshops and seminars are career development activities that take less than a semester or quarter. Doing something new and exciting does not need to include a three-credit course for a semester.

David Budil, of Northeastern University, discussed how cooperative programs are supposed to help impart higher-order or real-world skills. He said that in some ways, this method is avoiding the issue of what educators have to do, because the students are being sent out into the real world and into industry with the hope that their training will take place there.

Returning to Slaughter's question, Budil asked the corporations whether they could explain more about their training programs and how they would benefit if training were added to the educational program.

Miles Drake, of Air Products and Chemicals, Inc., responded that his corporation has coursework that people can sign up for. It includes the core skills of teaming, management, communication, and negotiation.

According to Bartels, Degussa has an international traineeship, in which students are brought in from companies and from the universities to be trained for higher management positions. The students should have both a business understanding and a technology bachelor's degree—for example, in chemistry or chemical engineering. The students are put on trainee assignments for six months or a year to work in different regions where the company has operations and sales offices.

Competence Center

Miles Drake was interested in the underlying philosophy of the Degussa competence center in China.

According to Bartels, the Shanghai competence center involves about nine business units of Degussa that have gone there to develop new programs. They in a sense are receiving corporate funding to start their business. Degussa puts people from Europe or the United States in the competence center, and then the different businesses within the center try to hire local people. The centers work with universities and with Singapore and China. From the joint ventures, Degussa is trying to bring in and develop people with skills that are specific for the business unit's needs.

4

Evolving Opportunities— Building a Global, Technical Workforce

Thomas M. Connelly, Jr.
DuPont Company

DuPont continues to be committed to science. In the words of DuPont's chairman, Chad Holliday, "DuPont is a science company." It is important that the science move out of the laboratories and into the hands of people who value it. Science is put to work in solving problems to make life better and safer. DuPont is committed to science and recognizes how important it is to DuPont's future growth.

DUPONT'S GROWTH PLATFORM

In February 2002, DuPont aligned its businesses around six market-focused and technology-focused growth platforms: DuPont Electronics & Communication Technologies; DuPont Performance Materials; DuPont Coatings & Color Technologies; DuPont Safety & Protection; DuPont Agriculture & Nutrition; and DuPont Textiles and Interiors, now called Invista. Invista is a wholly owned subsidiary of some of the fiber activities and businesses. The intent is to separate Invista from DuPont.

The other five growth platforms are tightly focused on markets and technologies and enable faster execution and improved capability for innovation and shareholder value creation. This structure supports DuPont's transformation.

Evolving and integrating new sciences are not new to DuPont, which has been doing this since its establishment more than 200 years ago (Figure 4.1). Having spent 100 years as an explosives company, it spent the next 100 years largely as a chemicals and materials business, with a foray into energy through the Conoco operations in the late twentieth century. Looking forward, the chemicals and materials business will be the most important part of DuPont as far as anyone can see. However, new science fields are needed for the ambitions of the company. DuPont is emphasizing such fields as biotechnology, electronics and electronic materials, and safety and security, including a large and growing global safety consulting business. The safety business also contains DuPont products associated with safety: Kevlar®, Nomex®, and Tychem® to protect garments and also DuPont's Clean and Disinfect products.

Perhaps DuPont's willingness to move into new fields of technology and its flexibility are a metaphor for the technical workforce. DuPont has succeeded in business by continually evolving to meet the changing needs of the marketplace and has done this by transforming science into new technologies.

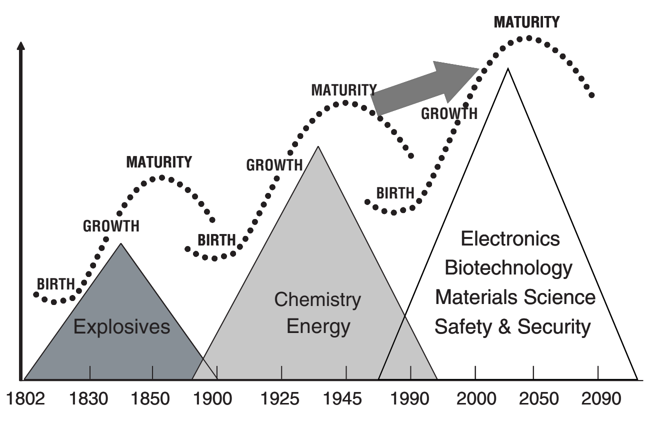

FIGURE 4.1 Evolution and integration of new sciences at DuPont.

This is an edited transcript of speaker and discussion remarks at the workshop. The discussions were edited and organized around major themes to provide a more readable summary.

DUPONT'S WORKFORCE

On some level, DuPont already has a diverse, global workforce. DuPont operates in 70 countries with 367 manufacturing sites, laboratories, and sales offices and about 79,000 employees. The non-U.S. component of its business is the fastest-growing segment. DuPont believes in a global economy and believes that trade policies that foster a global economy are to be encouraged. DuPont also recognizes the enormous opportunities for companies in developing markets. The company believes in the power and value of diversity as a broad concept. Diverse thought and different points of view are important; global thinking is one dimension of diversity.

With regard to broadening DuPont's workforce, the company seeks to recruit diverse research candidates within the U.S. workforce representative of the overall U.S. population. Industry and universities have to work to attract diverse people into the chemical research community. Diversity is crucial to DuPont's hiring for it brings with it diverse perspectives, which help to stimulate creativity, and it provides for broader thinking on future product applications and improved designs.

The development of technical talent is analogous to the development of a technology portfolio: the pipeline must be balanced. A vital related topic is the status of the development and availability of technical talent in the United States. Review of the demographics of research organizations in the company makes it clear that in the next five to ten years, DuPont must hire many more students than it has today. Decreasing enrollments of U.S.-born graduate students in science and technology must be addressed.

DuPont and the rest of the U.S.-based chemical industry are increasingly dependent on students from around the world. This will allow DuPont to staff global laboratories with local talent and it may also affect the type of research done at those locations.

GLOBAL ECONOMIES

It is evident that the emerging economies of Central and Eastern Europe, South America, and East Asia are growing much faster than those of the United States, Western Europe, and Japan. Considering only industrial sectors of the economies, the disparity is much greater.

The U.S. economic recovery has been modest in manufacturing sectors, with production not yet returning to the levels of the late 1990s. Furthermore, the chemical industry has moved into a negative trade balance, undoing more than 70 years of positive trade.[1] Similarly, Europe's industrial production has remained at a plateau for the last several years, without prospects for short-term growth.

Mexico's manufacturing shows robust growth, in part because of the North American Free Trade Agreement (NAFTA). The largest economies of South America struggle from a manufacturing standpoint, although agriculture and other sectors of their economies fare much better.

Asia paints a very promising picture. China has consistently performed positively for the last 20 years. China has been and continues to be a good place to grow a business. Economic growth in Japan has been slow for about a decade, but there are signs of a sustained recovery there. The rest of Asia is somewhere between China's and Japan's performances. Although Taiwan and Korea have had dampened performances, they are now making strong recoveries. India continues to represent a large opportunity for the chemical industry. On the whole, the situation in Asia, Central Europe, and Central America appears to provide a potentially greater opportunity than the more developed parts of the world.

DUPONT'S GLOBAL EFFORTS

DuPont is increasingly interested in Asia Pacific and has been expanding its presence there. East Asia is home to a large population base with very rapid economic growth. Currently, DuPont is present across East Asia, which represents 20 percent of DuPont's business, surpassing Japan as its largest subregion within Asia Pacific (Figure 4.2). Against this economic backdrop, DuPont recognizes that success in Asia takes on strategic importance. Today, Asia represents about 20 percent of the company's revenue, and it is growing much faster than business in other regions.

Even at this level, DuPont is underrepresented. Sales as a percentage of gross domestic product (GDP) should be higher. There is room to grow, particularly in China, Taiwan, and Hong Kong. Economic growth is so rapid that you must be in the region to understand the opportunities. In terms of establishing operations in Asia, DuPont has adopted a diverse approach to locating its facilities as opposed to other companies that have taken a more centralized approach. This has implications for the R&D model even though the vast majority of DuPont research is done in the United States.

Most of DuPont's new laboratories are being added outside the United States. The mission of the new laboratories has been primarily product development and market-focused research rather than basic research. DuPont research has become much more collaborative in its efforts. In the past, whomever DuPont hired moved to its corporate laboratories in Wilmington, Delaware, to work. Today, DuPont understands and appreciates that candidates have more options than in the past. As a consequence, the company is reaching out in new ways to collaborate in research both in and outside the United States.

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[1]For more information see Storck, W.J. 2004 World Chemical Outlook. *Chem. Eng. News* 82(2), 18-20.

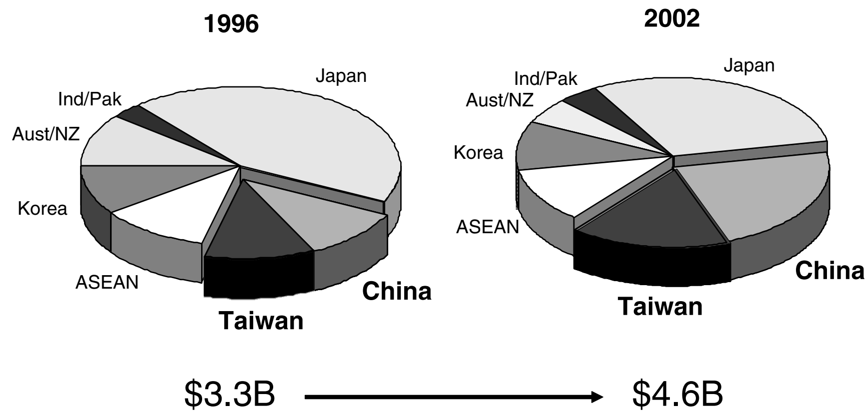

FIGURE 4.2 DuPont sales by country.

DuPont has major laboratories around the world. Kingston Laboratory, located in Ontario, was founded in the 1950s, as was the laboratory in Mechelen, Belgium. DuPont also has Meyrin Laboratories near Geneva, Switzerland. Founded in the 1990s, DuPont's Nambsheim Laboratory in France is focused primarily on agricultural research. DuPont has dozens of small agricultural research facilities spread around the world to take advantage of climate and agronomic differences. The laboratory in Wupperthal, Germany, came as a result of a business acquisition. The laboratory in Utsunomiya, Japan, about an hour north of Tokyo, was founded in 1998. In 2004, DuPont will open an R&D facility in Shanghai, China.

Although there are a number of reasons for undertaking research in non-U.S. regions, the primary one, and usually the first mission for a new DuPont laboratory, is to meet local needs. Product needs are unique to a region. Solutions derived elsewhere are often insufficient to meet those needs.

It is important to think globally and diversely. How does DuPont link this to research capability? Most of the hiring at the Ph.D. level still occurs within the United States, where most of the basic research takes place. People hired in the United States are 29 percent female and 40 percent non-white; of the latter, the vast majority is Asian, primarily non-U.S. born. With regard to DuPont's expectations, the high number of scientists and engineers who began life outside the United States already implies transnational work. DuPont, although still focused on chemicals and materials, is increasing its population of scientists with expertise in life sciences and physics.

RESEARCH AT DUPONT

Teamwork differentiates industrial research from academic research and continues to grow in importance. DuPont's research is done by multifunctional teams. The central laboratory has been reorganized from a competence-based structure to a team-based project structure focused on creating technologies or products of value to the company.

DuPont integrates more fields of science into its research capabilities, and the teams are becoming more multidisciplinary. Some of the new fields in which DuPont is working are biotechnology, bioscience, and electronics. These account for about half the corporate research, and complement the work in chemical, polymer, and material science, even though 75 percent of the current business is focused on the traditional fields. To succeed in these new areas, people must learn from one another. Effective teamwork facilitates learning and leads to success.

For many years within the United States, DuPont has also used collaborations outside the company to obtain technical expertise or for cost-efficiency. As markets become more global, these collaborations mirror them; many more collaborations are spread across the world. For example, DuPont has expanded sponsorship of awards beyond the United States. The award mechanism introduces DuPont science to the global research community and introduces DuPont to leading academics around the world. The awards include the DuPont Innovation Award and the Young Investigators Award, which began in the United States in 1968.

The trends are as follows. Rapid economic growth outside the United States is leading to more rapid sales growth in the rest of the world. As a consequence, production and the supporting technology activities occur in those locations and can include customer support, production support, and ultimately new product development. All this may lead to research activities. Each of these trends has implications for whom DuPont hires and where DuPont hires them.

EVOLUTIONARY CHANGE IN RESEARCH AND BUSINESS

An evolutionary change in research and business is being driven by globalization. Early models in this evolution can be described as dependent or perhaps even colonial: those in charge are at headquarters, and they control what the rest of the world does and how work is done. There are advantages: lines of communication are clear, and decisions can be made and implemented (even if the decisions are not always based on the right data). Many U.S. companies operate this way.

The next stage is an independent regional model. This is the "separate-but-equal" approach. The geographic separation between the regional location and headquarters helps to create the partition. This represents, at some level, progress versus the command-and-control phase, but this "departmental" state is most dangerous. Fragmenting the overall organization forfeits the potential benefits of global optimization for regional optimization. It is critical that organizations in this phase move to the next level: the intradependent model.

The intradependent model is the most difficult to execute because it requires orchestrating the efforts and opportunities of the many separate regions and optimizing them for the benefit of the whole organization. Translated to DuPont, it means that a researcher based in Wilmington, Delaware, must work on the most pressing global problems, regardless of their location, as though the problem existed in his or her home location.

There are three reasons for a company to move into the intradependent model: (1) global customers will insist on it; (2) global competitors will prey on the lack of unity between regions; and (3) resources are limited—few, if any, companies have the luxury of reproducing all that is done in United State in all other regions of the world.

CONCLUSION

In conclusion, industrial research is becoming more collaborative. That is certainly true in the United States. DuPont is collaborating more with universities, industrial partners, and government laboratories. No company can afford to do it all alone. There is an irreversible trend.

Global thinking is more important than global location. The corollary is that the global workforce must be more capable of working across distances, time zones, and cultures. With an organization that thinks globally, there is no need to reproduce globally all that is in one location. Behavior is more important than facilities. This maxim is true for more than research. It holds for marketing and manufacturing. Everyone must be more adept at working across cultures, time zones, and distances.

DuPont's workforce includes, and will increasingly include, researchers born outside the United States. DuPont does not view this as a problem, but the United States does have an issue with attracting enough talented students into careers in science and technology. It is urgent that more be attracted. The next decade presents an important opportunity for DuPont and the rest of the chemical industry with regard to staffing. What are the complementary roles of universities and companies in preparing U.S. scientists and engineers for global careers in chemistry and chemical technologies? Clearly the responsibility must be shared.

This presentation has drawn heavily on my experiences and those of DuPont. The observations may be more broadly applicable for the chemical industry but may not be representative of other industries that employ chemists and chemical engineers.

DISCUSSION

Discussion arose out of Thomas Connelly's presentation dealing with such issues as DuPont's globalization, including the transition from a competence base to a team base, the opening of a laboratory in Shanghai, further discussions with China, safety programs, and relocation and compensation of DuPont employees. Discussion was also continued from previous presentations about diversity and education and training of employees from the perspective of DuPont.

Transition from a Competence Base to a Team Base

Douglas Selman, of ExxonMobil, asked for an elaboration of DuPont's motivation for reorganizing corporate research from a competence base to a team base.

Connelly responded that the decision was made about 4 years ago to reorganize the central laboratories. Companies take different approaches, but Connelly's belief is that a central laboratory has to be relevant to what is going on in the company, or it will risk destroying value and its own existence. For about 20 years in DuPont, the central research mission was to do world-class science or other activities relevant to DuPont business. Researchers today have the advantage of being able to do both.

Connelly continued that a competence-based laboratory is good at perpetuating competence, but it does not necessarily point out gaps. DuPont has moved away from being a competency-based organization.

With project teams, if someone who knows about a particular subject is needed but is not on the team, the company knows that it has to hire people with relevant backgrounds. When DuPont went to this setup, there was talk about focusing on problems, but now there is work on the subset of problems that represents opportunities. It is called the apex research effort, and DuPont has pushed ahead with the transition. Although there was debate, Connelly believes that no one would want to go back to the old base.

DuPont's Shanghai Laboratory

A second question posed by Selman was about the major risks that were associated with the opening of DuPont's research center in Shanghai.

Connelly stated that the mission of the Shanghai laboratory is going to be development work and product tailoring. It will provide a training center and ultimately may move on to a research mission, but that is not yet envisioned.

Discussions with China

Paul Anastas, of the Office of Science and Technology Policy, had an interesting experience in 2002 in renegotiating the science and technology treaty with China. He wondered about discussions with regard to engagement in industrial development in China between DuPont and the government and other sectors.

Connelly replied that he or his counterparts meet fairly regularly. He takes two to three trips a year to Asia and probably at least two to China. China is obviously still very interested in attracting investment. In the emphasis on more high-technology investment, DuPont is considered a partner. In the week after this workshop, a delegation would be coming to DuPont to talk about some specific projects. A list of 20 to 30 projects came out of a series of prior discussions.

Most of the discussions involve new directions and are not just to establish business. For instance, biobased materials will be discussed. The Chinese are interested, at the government level, in greener processes and nonpolluting processes. Their expectations for a foreign firm coming into China are much higher than they would be for a state-run enterprise with respect to environmental performance.

Safety Programs

William Koch, of the National Institute of Standards and Technology, noted that DuPont is recognized for its enhanced safety programs, both on the job and in personal lives. Is this accepted and recognized in other parts of the world?

Connelly stated that his company began to globalize the safety program about five years ago and wondered whether it would be of the same value around the world. Connelly has been impressed by the acceptance. The company has had good interactions with leaders of businesses in developing parts of the world that previously had too many deaths.

Relocation of Employees

Steven Buelow, of Los Alamos National Laboratory, asked whether DuPont has a governing policy for compensation for life work and how it handles problems associated with moving workers from one location to another.

Connelly believes that *global* means putting people in the right roles, regardless of where they came from. Many of DuPont's policies have to become more flexible with regard to moving people around. The company is making progress. Some of the policies may have been conceived when a transnational move meant relocating someone from the United States to another part of the world. Now more movements from other parts of the world to the United States or from region B to region C are being seen.

DuPont has worked to reduce the costs associated with some of its policies. There is no question that people who work outside their home country create a significant expense for the company. There is always economic pressure to keep down the totals.

Compensation

Buelow asked whether any social problems are encountered when members from different parts of the world work on the same team but receive different compensation.

Connelly said that there are surprisingly few problems, probably because people do not discuss their salaries. There is also an understanding that if one's children have to go to an international school, this presents an expense that one would not have in one's home country. In China, there is little potential for problems, because it is well known that the cost of an expatriate working in China is many times that of a local employee. As more and more capable and well-trained local employees are found in China, there is a tendency to hire a local employee of another company and pay that person at a rate midway between the transferee price and the local price. Per capita income in China is less than $1,000 a year, but an English-speaking electrical engineer working in Shanghai for an international company knows what he or she is worth.

Diversity

Tyrone Mitchell, of the National Science Foundation (NSF), pointed out how DuPont is thought of as a company of chemists. He wanted to know DuPont's views of nonchemists with respect to recognition and promotions.

Connelly said that historically there have been a lot of chemists. When a team needs, for instance, a physicist, the physicist is valued. DuPont does not have too many problems with inclusiveness; there are chemists, physicists, and biologists.

Mitchell also asked about the statistics given that 40 percent of the people hired by DuPont in the United States are non-white, but that most of those are foreign born. He said that these statistics suggest DuPont is not doing a very aggressive job of trying to recruit among underrepresented minorities.

Connelly responded that most of the people hired are not foreign born and that most of the Asians hired are not American born. He believes that DuPont is attracting more than its fair share of members of underrepresented minorities. However, he said the company does have problems, particularly at the Ph.D. level, with the total number of African Americans and Hispanics because the pool of these graduates is small.

Education and Training

Marshall Lih, of NSF, asked whether DuPont provides summer jobs or internship opportunities for U.S. students in science and engineering in which they are assigned internationally or globally oriented projects rather than typical chemical operations projects. If so, how are they advertised?

Connelly replied that there are summer projects, but there is plenty of room for improvement. DuPont gets into collaborative research programs, and some of the students will show up for a few months in the laboratories. He said that the next phase of the project is up to the principal investigators. Little thought is given to an international orientation to this work. When Connelly ran the laboratory in Geneva, there was a more formal system in Europe. The idea was that as part of the degree, most technical students, even as undergraduates, needed to spend time in industry. The industry is set up for that system. In the European region, DuPont is transnational, but in the United States, there are no student experiences outside the United States. More could be done.

Michael Rogers, of the National Institutes of Health, reflected on the previous question in a different discussion about how U.S. graduates and Ph.D.s could be trained to make them more appealing to the global environment.

Connelly has had some good experiences with a lot of universities. Some faculty members send large numbers of their students to DuPont because they seem to understand and fit into the program. DuPont certainly has principal investigators who have spent time teaching at universities. More interchange might help.

Karin Bartels, of Degussa, then asked whether more research can be encouraged at the undergraduate level of university education where the higher-order skills can be communicated. She wondered whether Connelly thought more could be accomplished if research started at the undergraduate level.

Connelly became involved in some research programs as an undergraduate, and he believes that is the best recruiting technique to get people to continue in graduate school. He probably would have chosen another career if he had not enjoyed his undergraduate experience. On a number of levels, it is worth doing, but the experience must be meaningful.

The Academic Perspective

5

Does the U.S. Style of Chemical Engineering Education Serve the Nation Well?

Matthew V. Tirrell
University of California, Santa Barbara

In thinking about how well chemical engineering departments in the United States perform in preparing chemical engineers for a global workforce, the key issue is a larger dilemma in engineering education. The challenges to a global workforce from the engineering point of view involve how engineers are educated, regardless of engineering discipline. There is no quick fix to the global part of this. Instead, some overall issues in engineering education must be addressed.

U.S. COMPETITIVE STATUS IN THE GLOBAL ECONOMY

A report to the Government-University-Industry Research Roundtable (GUIRR) in 2003, led by Shirley Jackson, president of Rensselaer Polytechnic Institute, begins by documenting evidence that the U.S. competitive status in the global economy is eroding (GUIRR, 2003). In fact, the worldwide competition is picking up in excellence, training, and entrepreneurial activities; even the status quo would represent a declining share in these areas for the United States. Not enough students are choosing majors in science, mathematics, engineering, and technology to maintain the current levels, let alone to sustain the U.S. leadership in these fields. There are certainly concerns expressed in the GUIRR report about the level of technical and mathematical competence of U.S. students and about the production of Ph.D.s. The role of international scientists and engineers in developing many important technologies in this country cannot be overestimated, with the United States relying to a large extent on importing talent when it has been difficult to find this at home.

The data and trends are supported by citations in the report and form the basis of its proposal aimed at augmenting the number of people entering the U.S. science and engineering workforce. The report addresses one major global issue that chemists and chemical engineers face: the diminished capacity to compete in science and engineering. Many of the points are directed at educational institutions, particularly with respect to the students that are choosing majors, the caliber of preparation, and U.S. production of scientists and engineers.

Some of the trends outlined in the GUIRR report that can be viewed as weaknesses from a purely U.S. perspective could be turned into strengths from a global perspective. For example, with the proper exploitation and development, the importation of international talent could be turned into a strength in the international world.

There are obstacles and limitations, however, to what can be achieved by the importation of talent from outside the United States. First of all, the ability to recruit from abroad may be limited by immigration restrictions driven by, for example, security or economic concerns or policy decisions. Second, comparable opportunities are becoming available to students in their native countries. Countries that once supplied major fractions of the U.S. international science and engineering workforce are now providing first-world kinds of opportunities themselves. South Korea is a good example, and India and China have been mentioned earlier in the meeting. They are far behind, but one can see where things are going.

In fact, the "stay rates" of foreign scientists and engineers who study in the United States cannot rise much further, so not much growth of this kind can be expected. However, there is some hope in changing the absolute numbers.

This is an edited transcript of speaker and discussion remarks at the workshop. The discussions were edited and organized around major themes to provide a more readable summary.

They have been stable and high for a long time. In science and engineering, historically about 63 percent of foreign students who study in the United States stay here. In the physical sciences, the stay rate is 73 percent, and in electrical engineering and computer science, it is 81 percent. The stay rate does have a limit (GUIRR, 2003). However, keeping the high rate of foreign participation, at least by the highest-quality students, may be a challenge in the future.

HEALTH OF U.S. CHEMICAL ENGINEERING PROGRAMS

There are positive and negative signs in the health of U.S. chemical engineering programs. On the positive side, starting salaries for various degree levels for chemical engineering graduates have stayed reasonably high, comparable with the highest in engineering. This generally reflects the technical versatility of chemical engineers, who are often able to work not only in the chemical industry, but in the biotechnology, electronics, and food industries, for example. The diversity of fields in which chemical engineers work is very great.

At the same time, there have been declines in both chemistry and chemical engineering graduate student enrollments over the last decade that are cause for some concern. In chemistry, enrollment dropped from 17,204 in 1993 to 15,707 in 2000; in chemical engineering, it dropped from 6,079 in 1993 to 5,865 in 2000 (RAND, 2002). However, there is strong competition in academic chemical engineering right now because of the rapid growth in bioengineering programs; many chemical engineering departments may be unduly worried.

Universities are responding in some reflexive rather than strategic ways to opportunities represented by biology as it intersects with engineering. In particular, universities are starting new undergraduate departments in biomedical engineering rather than making room for biology in every engineering curriculum. The trend of starting biomedical engineering departments does not imply a pervasive influence of biology across the engineering curriculum, but in some sectors it is a tendency to specialize narrowly at too early a stage. It certainly does drive some of the enrollments because students, no doubt, are interested in biology. The current state of concern in chemical engineering over the role of bioengineering embodies an issue that is crucial to the future of engineering in general.

CONSTRAINTS

Thinking about the overall goal of engineering education leads to the question of what engineers are actually being trained for. Academic engineers have not studied this or expressed it clearly among themselves enough. It is difficult to say what engineering is. So what do engineers do?

William Wulf, president of the National Academy of Engineering (NAE), defined simply what engineering does: engineering embodies design under constraints. What are some of the constraints? Some are economic, and some are temporal. Sometimes a job is done to the best extent possible in the available time. Engineers accept conditions and constraints when they do their jobs. Social and cultural constraints may include human factors, such as understanding what gets individual human beings to adopt particular products. There are ethical constraints: just because something can be done does not mean that it should be done. There is also a lack of knowledge of fundamental science, a constraint that current modern chemical engineering focuses on a lot. In other words, there is a kind of reinterpretation of chemical engineering as applied or basic chemical science necessary for particular achievements, and there is not as much focus on some of the other constraints.

By focusing on the other constraints of engineers, one can address some of the issues related to globalization. There is a fundamental challenge to address the other constraints well in engineering education. It is a fundamental challenge that strongly affects U.S. effectiveness in preparing a global workforce: there is an insufficient focus on preparing students for what engineers do. The constraints together reflect engineers' effectiveness in the workforce and their impact on society and the world.

Academic chemical engineering probably does not adequately appreciate engineering as a profession. Some of the issues discussed in this workshop could be addressed more effectively if engineering in universities were thought of more as a profession than as a major. Engineering is not exactly parallel to the other majors.

The current emphasis on biology, biological engineering, and biomedical engineering is occurring because of the enormous opportunities—the ability of the new science generated to become applied science, and the potential for that to have a favorable effect on the economy, society, and the quality of human life. This area of applied biological science and applied science in general is not synonymous with engineering. That is where the applied-science view of engineering comes in.

Lack of knowledge of basic science is sometimes, but not usually, the most important constraint on an engineer in the workforce. More often, the others—economic, political, and social—dominate. For example, it is not mainly lack of a science base among engineers that inhibits the introduction of expensive new biomedical technology into health care. It has more to do with regulatory affairs and the willingness of insurance companies to pay for it. It is not mainly lack of a science base among engineers and scientists that inhibits the introduction of genetically modified foods in countries where they could conceivably bring economic or social benefit or that limits the wider use or exploitation of stem-cell technology or cloning. Other constraints are involved.

There may be a lack of a science base in society that keeps people from appreciating engineers more. However, this is not the most important issue here. More important is what scientists and engineers can do themselves to understand the economic, political, and social constraints to prepare for the global workforce better. This is not to suggest that biomedical technology, genetically modified foods, or cloning should be adopted, but rather it is the lack of understanding the constraints other than the technical ones that are keeping that from happening.

LOW RETENTION RATES

U.S. engineering education is not well equipped to deal with the matters just discussed. One problem is in attracting the right people into engineering.

A bigger problem than the slightly declining enrollment figures cited earlier is the relatively low retention, from their initial declaration of interest in a major all the way through to a degree, of students who initially choose engineering studies. According to Bill Wulf, speaking at the 2003 NAE annual meeting, only about half the students that initially indicate interest in an engineering degree follow through to the actual attainment of that degree. For example, the University of California, Santa Barbara (UCSB), has a freshman seminar course in which for 10 weeks students get a 1-hour introduction per week to what chemical engineers do. In recent years, there have been about 65-70 students per class. Over the same period, UCSB has graduated between 35 and 40 majors in chemical engineering. Where do those who do not continue go?

It may be that the weaker students drop out or transfer to other majors. Perhaps they do not see early enough in their education that engineering is design under constraint for the benefit of society and the economy. That may go all the way back into elementary and secondary education: they do not see engineering as consistent with their goal in life, which is to do good in the world. Some interesting programs are designed to counteract this, at least at the university level. Northwestern has a program called Engineering First that makes a serious attempt to engage engineering students in the design aspects of engineering very early in their education. That is where the principal point about the need for more professional orientation in engineering education comes in.

Pedagogy in academic engineering is divorced from industrial practice. There is no industry to hire undergraduate bioengineering majors. About 75 percent of the students from the biggest producers of undergraduate degrees in biomedical engineering, such as Johns Hopkins and Duke, go to medical school, and a large fraction of the rest go to graduate school. This is not necessarily a bad thing, and not everyone has to do everything the same way, but those undergraduate programs are definitely not preparing students at that level for a need that is seen in industry.

ADDITIONS TO THE ENGINEERING CURRICULUM

There is concern that students are not going to be fully functional unless they are given a good view of and exposure to an increasing science base. Many people would argue that it is not possible to do some of the things that have been discussed here, because programs are already overconstrained, and students need a strong grounding in fundamentals.

There is certainly merit to that argument. The increasing set of fundamentals is rooted historically in engineering science, physics, and continuous mathematics and now in biology, information technology (not just programming, but discrete mathematics, and integrated aspects), scientific computation, and so on. It would be ideal for students to have grounding in all of these, but it is not feasible.

The net effect is that major elements of a liberal education are being squeezed out—the same elements that are often tied to the higher-order skills that industrial colleagues say are needed. Languages and a lot of electives involving history and studies of other cultures have been squeezed out. This is also true of the study of business, management, and economics, which might be a bit more palatable or acceptable as a logical extension or diversification of engineering education.

Efforts must be made to provide students with understanding in the fields that are being squeezed out by a largely exclusive emphasis in current engineering education on the constraints under which engineers operate. More room has to be found for this, and not only because companies that operate in a global workforce need people who are more adept at the skills associated with the other conditions under which engineers operate. It is fundamentally important to attract the best students into the field. How engineers function in society and affect society has to be highlighted more to attract the best students.

ADDITIONAL EXPERIENCES

Three practical elements are worth considering in moving toward a more professional education for students: management exposure, faculty development, and internship and cooperative experiences.

Management Exposure

Engineering students need to get exposure to the management side of industry during their professional education. Technology management programs in engineering can be effective adjuncts to engaging students in engineering education. UCSB is launching the Center for Entrepreneurship and Engineering Management that was built around extracurricular activities and now is moving into the curriculum with the hiring of faculty. The program was driven by student demands, and the course, which involves a mixture of undergraduates and graduate students, is a basic course on business and management taught in a technology management context. The coursework is oversubscribed. One of the best features is that about half of the students (of the 50 student limit per course) come from elsewhere on campus.

Faculty Development

Some thought must also be given to faculty careers: development or management and involvement with industry. In engineering, engaging in consulting, technological startups, and other kinds of deep involvement with industry should be viewed in the most favorable light possible that is consistent with academic standards and other practices. This fits with the idea of starting to treat engineering as a profession.

Universities are not likely to hire artists that have not produced art or music, and doctors and lawyers are trained through a professional experience that goes beyond a basic undergraduate degree. Nothing less should be expected of an engineer. It is not clear how to do this, but it needs to be different from having universities hire experienced industrial people at a senior level in their careers. This approach works well many times, but more often, it produces situations in which war stories are told that are difficult to relate to the rest of an engineering education. As an alternative, universities must determine how to value professional involvement and the practice of engineering in a faculty member's career development, even if he or she starts out as an assistant professor with no industrial experience.

Internship and Cooperative Experiences

Internships and cooperative programs may be the best prospects for students for both the experience and the possibilities that they provide students. These kinds of opportunity, with the right kind of relationships with multinational corporations, can be enlarged to produce the global exposure and awareness that are desired.

THE FOUR-YEAR ENGINEERING DEGREE

In many cases, the four-year engineering degree limits what can be accomplished. Doctors and other professionals are not trained in four years. Fundamentals cannot be sacrificed, so the only variable that can be played with is time.

Without prescribing the exact solution, I find it evident that engineering should be treated more as a profession than as a major. This means expanding the four-year engineering degree into a five-year program. The expansion should probably offer some compensating benefits or advantages, at least to induce students to engage in it—perhaps a master's degree or some other kind of credential.

There are some risks, of course. If a university required that the engineering degree take five years, the result might be an even more dramatic impact on enrollments than the overall trends already seen. Either a highly recognized leader in education—a private or major public school that offers engineering—or some adventurous maverick would have to be willing to take some risks for a possible high reward.

The view presented here is admittedly a very personal one and offers this proposition: The way to approach some of the needs that have been expressed here and to attract the best people into chemical engineering to address global needs is to redefine an engineering degree as a professional degree.

REFERENCES

Government-University-Industry Research Roundtable (GUIRR). 2003. *Envisioning a 21st Century Science and Engineering Workforce for the U.S.: Tasks for University, Industry and Government,* Washington, DC: The National Academies Press.

Halford, B. 2004 CHEMICAL ENGINEERING EDUCATION IN FLUX: Mindful of declining enrollments, educators emphasize the field's evolution, new directions. *Chem. & Eng. News,* 82 (10), 34-36.

National Science Foundation, Division of Science Resources Statistics, *Science and Engineering Degrees: 1966-2000*, NSF 02-327, Author, Susan T. Hill (Arlington, VA 2002).

RAND Science and Technology Policy Institute. *Federal Investment in R&D,* E. Eiseman, K. Koizumi, and D. Fossum. 2002. Arlington, VA, (Table 17), p. 99.

DISCUSSION

Matthew Tirrell's presentation on the education of chemical engineers prompted dialogue on such topics as generating interest early in the educational curriculum and alternative programs, such as the five-year degree. Summer study and study abroad were also discussed.

Generating Interest in Science and Engineering

B.J. Evans, of the University of Michigan (retired), stated that globalization is not new and will take place. The focus of this workshop is to see that globalization takes place in such a way that there are some benefits to the country and that dislocations do not result from it. He pointed out that Tom Connelly distinguished between education and training. Companies can train and coach their employees to do the kinds of things they want. Education belongs in places where education is optimized. Only universities are optimized for the interactions between a younger person and an older person. The purpose of the university is to educate, not to make a profit; if that job is done well, the university has succeeded.

Engineers and chemists who start their curricula do not really know what their field is about. Things are taught that have nothing to do with chemistry. If chemistry were taught as the global enterprise that it is, there would be many more students of different orientations from those currently electing to do chemistry. The first year of chemistry should enable students to make informed decisions as to whether they want to continue to study the discipline. Once that decision has been made, the motivation to learn may be instilled. Once education is handled this way, there will be a difference in the orientation of students for learning languages, as well as their need to know how to use their higher-order skills.

Alternative Career Paths

Tyrone Mitchell, of the National Science Foundation (NSF), noted that many chemical engineers opt to go into marketing or management. He was not sure whether the chemical engineering profession sells itself very well with respect to what a person ought to do over a lifetime in chemical engineering. He also questioned whether undergraduate chemical engineering students get much research experience.

Tirrell thinks that chemical engineers may not explain potential career paths very well. At his institution, they try to do a lot of undergraduate research. It is attractive in engaging students. He said that at UCSB, about 30 percent of engineering graduates engage in research.

Changing Degree Programs

Ned Heindel, of Lehigh University, suggested following the model of the American Pharmaceutical Association and the American Association of Colleges of Pharmacy in choosing not to use the bachelor's degree as a gateway to becoming a pharmacist but instead implementing a doctorate in pharmacy. The transition was not easy; a number of universities tried to opt out and stay with a bachelor's degree.

Steven Buelow, of Los Alamos National Laboratory, mentioned that the Department of Chemistry at Northeastern University had decided to move aggressively to implement a five-year program. With participation in a cooperative program with industry, undergraduate chemistry majors already take five years to get their degree. With the possibility of an advanced degree or a professional master's, the degree would be much more attractive to undergraduate chemistry majors.

Karin Bartels, of Degussa, stated that Germany is determining whether to move in the opposite direction. Germany offers a five-year program but is leaning toward reducing it so that there will be master's and more bachelor's degrees. Germany feels that the degree takes too long but would like to include business management aspects and regulatory affairs in the chemical engineering degree or process engineering degree.

Mitchell brought up "3-2", or dual degree, programs. The first three years provide a liberal arts degree, and the final two years provide the engineering education. Many of the students went on to get Ph.D.s. Mitchell recruited some of those young people for internships and found them to be very well spoken with good people skills. He questioned whether the five-year program mentioned in the presentation would have more mathematics and engineering courses or more liberal arts education where students become more well rounded.

Tirrell responded that the program he is proposing would cover more science courses. His point about five-year degrees was that it would solve the problem of not being able to fit courses into a four-year degree.

Bartels added that the "3-2" program is essentially a community-college track over three years, where industry experience is coordinated with coursework.

James Martin, of North Carolina State University, asked whether, if globalization is such an issue, there should be so much advocating for interdisciplinary centers. He said that often when a center gets created, such topics as bioengineering and nanotechnology get taken out of the core curriculum and placed in the center, creating a new discipline. When new ideas are encouraged in the core, there is probably more interdisciplinary education, which probably is better for globalization. Sometimes, the quest for centers has created a subdiscipline, such as bioengineering or nanotechnology. The new ideas have been taken out of the core and put into their own situation. From a global perspective of education, these ideas are needed, but they should somehow be dispersed into the core. However, Martin said that centers do provide more opportunities for internships, partnerships, and collaboration.

Tirrell agreed that establishing narrow specializations is dangerous, especially at the undergraduate level. He said, however, that centers aimed at interdisciplinary research may not have some of the same adverse influences as specialized departments.

Using Summertime

Robert Powell, of the University of California, Davis, asked whether the summer could be used with the existing curriculum to achieve the goals apparent from the workshop.

Tirrell felt that some changes would not be too difficult or revolutionary. Some require changing a mind-set or using current resources such as summertime. He said that the University of California is looking into year-round education, and he has been very enthusiastic about it, because he thinks it could provide some opportunities, so that the summer could be better used and the co-ops and internships could be staggered throughout the year. Simply investing the resources to make sure that engineering students have profitable professional summers would be a good idea.

Robert Grathwol, of the Alexander von Humboldt Foundation, reminded the participants that many students spend their summers earning money to pay for school the next fall. He said that if summer programs are instituted and are to succeed, the experience must be profitable.

Study Abroad

Donald Burland, of NSF, stated that if chemistry and chemical engineering are to be treated as professions, the whole person needs to be developed. The topic here is globalization, which implies that some time will be spent overseas during education. Most universities have a semester-abroad program for undergraduates, but frequently scientists cannot participate because they have laboratory courses and other constraints. He asked whether anyone knew of instances in which it is possible for a scientist or engineer to spend a semester abroad.

Thomas Chapman, of NSF, noted some examples of engineering schools' attempts to facilitate study abroad and international experience. NSF has at least two research experiences for undergraduate sites that have been funded in the last year.

6

The Itinerant Chemist—Where Will the Jobs Be in 2020?

Alvin L. Kwiram
University of Washington

> This commitment to the promotion of human resources *and their mobility* is based on the idea that because of the increasing complexity and interdependence of modern science, scientists will increasingly need a strong international component as part of their scientific pedigree. There is no good reason to believe that such a high level of scientific pedigree can only be obtained in the United States. Investing into the development of human resources in science and for science by promoting their mobility is insofar an essential contribution to the European Research Area [emphasis added].
> —The European Commission, Research Directorate General, Sixth Framework Program

WORKFORCE

This statement, both a vision and a challenge, bears directly on the topic of this workshop. It will be touched on again later, but first the larger context of workforce is addressed.

Workforce requirements are a perennial topic, and rightly so. Most workshop participants are involved in one way or another in producing students in the university or hiring them in industry, government, or academia. Understanding future needs for graduates in the sciences in general and in chemistry and chemical engineering in particular is very important. There are several dimensions to the workforce problem:

- the ability of industry to hire the people it needs to remain competitive;
- the importance of maintaining some balance in supply and demand:

  —employers want a large supply in order to have the best choices,
  —producers want a large supply because this feeds their programs, and
  —employees want a small supply because that drives up wages;

- the importance of giving students a realistic sense of job opportunities and career paths (it is generally agreed that academe does not do a good job in this);
- the importance of adjusting academic curricula to adapt to changing societal needs (industry is not impressed with academe's record here); and
- the importance at the federal level of funding directions and policy decisions.

During the last two decades, there have been three major flare-ups on the topic of workforce needs and what the nature of workforce training should be. There was extensive coverage and discussion in the late 1980s of the huge impending shortage of scientists and engineers (Atkinson, 1990; Bowen and Sosa, 1989; NSF, 1989). It was most visible in the National Science Foundation (NSF) report predicting a shortage of a half-million or more science and engineering employees within the decade. Some were skeptical and questioned the feasibility of adequately predicting future workforce needs.

These reports soon gave workforce prediction studies a bad name even though there were some good data in them. In part, the analysis just reflected the "groupthink" of the community at that time, coupled with typical linear extrapolations about the future.

This is an edited transcript of speaker and discussion remarks at the workshop. The discussions were edited and organized around major themes to provide a more readable summary.

Things quieted down in the early 1990s until physicists began to notice a serious problem with employment opportunities for their graduates after the end of the Cold War. They also saw evidence, to their chagrin, that their decades-long hegemony in the science policy arena might not go on forever. David Goodstein, of the California Institute of Technology, did the community a great service by pointing out that unrestrained production of Ph.D. physicists who all wanted to be faculty at "Research I" universities would lead to serious disappointment (Goodstein, 1994). Unfortunately, academic pundits made wild extrapolations from his analyses and groupthink went overboard in the opposite direction.

There was an American Association for the Advancement of Science symposium titled "Whither Research Intensive Universities" in 1996 when this topic was actively being discussed. Most of the speakers at that symposium were in favor of seriously reducing Ph.D. production. However, others (including me) argued that reducing Ph.D. production should be viewed with caution. One of the points was that in the future there could be a reverse brain drain as the developing economies picked up steam and began to import scientific talent to be competitive in the modern knowledge-based economy. That trend is now beginning. It was also argued that to understand long-term trends in workforce requirements, one had to consider historical context.

During World War II, the United States and its allies prevailed, and the rest of the world's economic base was essentially destroyed. In the boom years after the war, the United States was in an almost monopolistic position to benefit from the enormous demands for new products and materials to help the rest of the world rebuild. Consequently, there was enormous growth in the economy, and many in the United States began to believe that this growth occurred because of the country's great business sense, work ethic, special intellectual horsepower, and entrepreneurial spirit. In fact, all of these things were important, but success was in large part an artifact of the world situation.

Today, that world is changing with surprising speed. Look at what Japan has achieved in the automobile industry, what Japan and Korea have achieved in the semiconductor industry, and what China is doing in the manufacturing sector. Indeed, even this country's pride and joy, research, is increasingly farmed out to other countries. The best-known example is the software industry: India has become a major supplier to U.S. corporations. Equally well known is the work in chemical synthesis that is increasingly shipped off to Eastern Europe, Russia, and other nations. As recently as a year ago, a representative of Hewlett Packard (HP) essentially said that it is too hard to work with U.S. universities and HP would simply go overseas to get its research done because it could control the intellectual property, pay after the work was done and only if it liked the results, and pay very little for the service. This strategy might seem somewhat unpalatable to U.S. observers, but it suggests that the nature of the trends has to be better understood especially in terms of what they mean for the national economy and the academic enterprise.

Another more recent example of the workforce discussion centered on the information technology (IT) explosion in the late 1990s, which was exacerbated by the Y2K problem. Projections during this period suggested the need for nearly one million new IT workers in the next five years. Needless to say, the year 2000 came and went, and today programmers are having a hard time finding work. Nonetheless, IT jobs will continue to grow, and the need for people with this expertise seems to have no end in sight. In other words, we have to keep a balanced perspective when projecting workforce needs.

OBSERVABLE EMPLOYMENT TRENDS

Some long-term observable trends should concern us: the decline of strategic research in industry (the most notable example is the dismantling of the formerly superb Bell Labs), the decline of the traditional chemical industry in the United States, the decline of manufacturing jobs in general in the United States, the growing trend of shipping even R&D offshore, and the growing competition internationally.

It is clear that companies have a hard time justifying fundamental research to their shareholders — in part because it is difficult to demonstrate convincingly that the "curiosity-driven" discoveries that scientists make are going to lead to new products. That factor, combined with other forces, influenced companies to jettison not only fundamental research but also, inexplicably, strategic research. It is hard to see how in the long run a company can be competitive without a reasonable strategic research arm. If for no other reason, it seems that in-house expertise would be needed to recognize when an important new discovery is relevant to the future of the enterprise.

When Bill Gates announced the creation of a strategic research arm of Microsoft a few years ago, which is now funded at about $500 million a year, he felt compelled to argue (as reported in the *New York Times*) that this was a justified and prudent investment by the company. The fact is that the Microsoft strategy was recognized as an anomaly on the U.S. industrial landscape. The present de-emphasis on corporate research is neither wise nor constructive for the U.S. economy, but there might not be any substantial reversal in this behavior. If there is not, it can be expected that employment opportunities, especially for Ph.D. chemists, will continue to decline (except in the biosciences; see below).

There is an equally worrisome challenge: the gradual loss of the traditional chemical enterprises in the United States. For many years the United States was one of the top exporters of chemicals, with trade surpluses of $15 billion or more. In 2000, the balance of trade in chemicals dropped to essentially zero. Estimates for 2003 show a trade deficit of about $8.9 billion, and there is no evidence to suggest that will ever get back to its former levels (Storck, 2004).

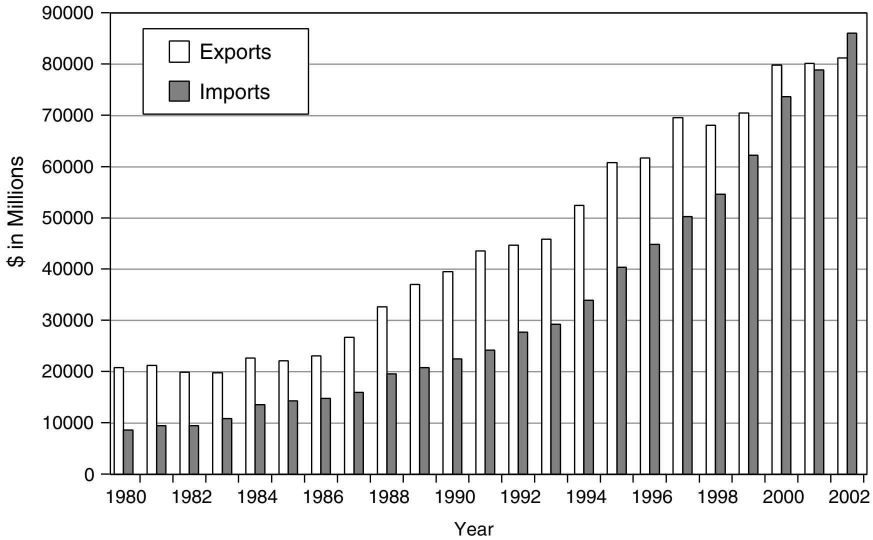

FIGURE 6.1 U.S. imports and exports over time. SOURCE: American Chemistry Council.

It may be worth examining this situation in a bit more detail on the basis of data generously provided by Kevin Swift, of the American Chemistry Council. Exports have not dropped dramatically, as seen in Figure 6.1. On the contrary, they have continued to grow. However, imports have grown more.

The purchasing of basic chemicals, basic industrial chemicals, fertilizers, and consumer products has remained more or less flat after factoring in inflation, despite the strongest economic growth in several decades. Why have exports grown at all? Specialty chemicals and life sciences have roughly tripled in the last 15 years or so, as seen in Figure 6.2. The contrast with the traditional chemicals sector is striking.

Even though traditional commodity chemical production will continue to decline in the United States, there is a good chance that the United States will remain strong in the biosciences arena for the foreseeable future. However, if this is the trend, it seems to suggest that the emphasis in undergraduate and graduate programs and faculty appointments in chemistry departments should all be reevaluated. Nevertheless, just as the rest of the world has caught up with the United States in the traditional fields (physical sciences, engineering, etc.) it will not be long until they are serious competitors in the biosciences. Other countries are making huge investments and are committed to being serious competitors in these sectors in 10 to 20 years. Obviously, not all will succeed, but this determined onslaught should not be ignored.

Unless substantial steps are taken to bolster the U.S. position scientifically and economically, there will continue to be a relative decline in employment of chemists (except in

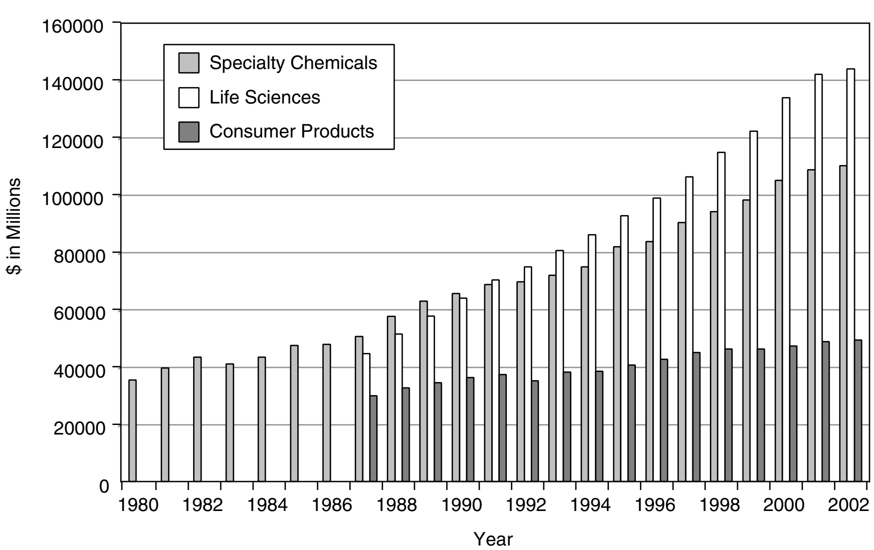

FIGURE 6.2 Purchase of chemicals. SOURCE: American Chemistry Council.

the biosciences). Of course, it might not be a serious problem inasmuch as fewer of the best and brightest are choosing to make the Ph.D. journey in the physical sciences in any case, and a large fraction of Ph.D. students in the sciences and engineering are foreign born. If those students return to their own countries or do not come to the United States in the first place, the problem may be conveniently solved.

EDUCATION REFORM

The size of the workforce is one of the major issues in graduate education; a second is the nature of graduate education and its character. The Carnegie Foundation recently launched a major program called the Carnegie Initiative on the Doctorate. It has chosen six disciplines in which it hopes to encourage serious experimentation in reforming the doctoral program. In each field, two or three persons have been asked to write a provocative white paper to help to catalyze a conversation and stimulate the thinking of the participating institutions. In chemistry, the three invited white papers were written by Ron Breslow, Angelica Stacy, and me. My recommendations fall into two broad categories: functional reform and structural reform.

Functional Improvements

Functional improvements, or "enhancements," essentially represent the development of a more-complete repertoire of professional skills. Here is a list of elements that may be appropriate for our graduate students' training:

- more training in patent law;
- improved communication skills, both written and oral;
- early introduction to the nature of a career in industry;
- learning to work in teams;
- counteracting the tendency toward increasingly narrow training;
- developing an appreciation for economic factors in an industry setting;
- greater emphasis on safety training;
- the need for instruction on human behavior and personal interactions;
- an emphasis on strategies for research planning; and
- greater faculty attention to their mentoring role.

This list may look familiar; it was compiled from a 1947 American Chemical Society study based on Committee on Professional Relations surveys of chemistry department chairs, recent graduates who had taken jobs in industry, and directors of research in industry. The concerns identified more than 50 years ago have a striking similarity to those identified in the most recent discussions of problems with the chemistry Ph.D.

No one would dispute that these are worthy topics, but the likelihood that any departments will take action to include such instruction is very low, not only because there is little time or interest to give these matters serious attention, but especially because it would distract from so-called "more-important" endeavors.

Structural Improvements

The second category is structural, and it in turn has two parts. First, the time needed to get a Ph.D. has gotten far too long. In 2001, the median number of years between award of bachelor's and award of doctoral to doctoral degree was 7.0 years in the physical sciences, 8.1 years in the biological sciences, and 8.4 years in engineering (National Science Board, 2004). The situation has several adverse features. It tends to discourage some bright students from entering the program because of the long delay in obtaining a degree. It also reduces the "window of creativity" because students often do not become independent scientists until their mid-30s. It sometimes constitutes an exploitation of the student for the benefit of the program. It reduces opportunity for other students, both in access to programs and in access to financial resources. Other avenues will develop to train people for the workforce, as evidenced by the growth in certification programs and the renewed interest in the professional master's degree. At a time when there is a systematic and long-term decline in the number of U.S. citizens entering doctoral programs in the sciences, it is imperative that programs be reexamined. It is more and more difficult to be competitive for the best and brightest who perceive that the time to degree (and even time to career) in medicine, law, and business is much more predictable, and shorter, and the outcome financially more rewarding.

Some will argue that science today is complicated and that students therefore need more time to have a chance to make an original contribution. In that case, U.S. science must be much more complex than European science—the Ph.D. is a three-year degree in the United Kingdom and it is only slightly longer in Germany. (One has to recognize, of course, that undergraduate training in Europe is more focused on the discipline, and this is one factor in the shorter time to degree.) There is no good excuse for the long time it takes to obtain a Ph.D. in this country. In part, the lengthening time to degree is driven by increasing competitive pressures and the nature of the funding structure at the federal level.

The second part of the structural category is less global because it is limited to those who are going to seek academic jobs. Our doctoral programs have inexcusably failed to provide those aspiring to university teaching and research careers with the tools that they need for these roles. Indeed, it should be considered an outrage that someone starting as an assistant professor has had virtually no systematic preparation for the job. The entire period of seven to ten years of postbaccalaureate training is essentially an intensive research-focused activity. Then, suddenly, the newly minted Ph.D. is expected to take on major responsibilities in an academic setting. There are many responsibilities beyond carrying out research that many Ph.D. graduates are not prepared for.

INTERNATIONAL EXPERIENCE

A broader international outlook and experience are especially relevant in view of the earlier discussion on trends in workforce needs in the United States. If there are going to be fewer job opportunities of the traditional variety in industry in the United States in the coming decades, graduates may have to be prepared to look elsewhere. In a discipline in which nearly two-thirds of the bachelor's graduates and roughly one-third of the doctoral candidates have historically gone on to work in industry, this trend deserves serious attention.

What might it mean for students? It would not be surprising, 25 years from now, to find many U.S. Ph.D. graduates working in other countries (whether for U.S. or foreign companies or for research institutions). The flow of talent from other lands to the United States could very well reverse, and the best and brightest from the United States will be hired by major corporations and academic institutions abroad or at least be expected to spend considerable time abroad. They will become itinerant chemists. Other nations have awakened to the fact that the economy of the future is the knowledge-based economy and that brains and education are the raw material, for that economy.

Students in the United States, especially at the Ph.D. level, need to be prepared to become part of the global workforce and be better prepared to seek their fortune in foreign settings, at least for part of their career. This, of course, will not always be comfortable or easy. U.S. students often take for granted what others who are foreign born struggle with daily. They do not have nearly enough sympathy for foreign students and the challenges they face. More time and energy should be spent in educating U.S.-born students about these challenges. Our guests have taken huge risks and made major sacrifices to come here to study and to contribute to this society. They should be treated with the respect and the support that one day U.S. students will, I hope, be accorded when they are in a strange culture trying to make their way economically and culturally. There is nothing so debilitating as the inability to be articulate on topics of interest in another country because of a language barrier. No matter how smart someone might be, without the proper language skills it is easy to be seen as limited in capacity.

Even if everyone agrees that doctoral students should be given a more international outlook, how can this be achieved? One obvious answer is to encourage them to take an international postdoctoral position. That is not always seen as an attractive option. There are language barriers, family considerations, questions about how it might affect competitiveness for a U.S.-based job, lack of information about the opportunities, and questions about the quality. Consequently, not many students choose to take advantage of such opportunities; they should be encouraged.

For the last few years, the University of Washington has been involved in an initiative to try to address the problem at a very modest level by participation in the Worldwide University Network (WUN). This initiative was spearheaded by the vice chancellors of four U.K. universities: Sheffield, York, Southampton, and Leeds. The key idea was to create a worldwide network of major research institutions to promote research collaboration, e-learning, and graduate student and researcher exchanges. The initial idea was to have five institutions on each of the major continents of the world serve as the core administrative group. The hope was that corporate interest in the potential intellectual property and the e-learning resources might be the source of financing for this effort. Unfortunately, that was not realistic and has not panned out. However, after three years, there is a surprising amount of activity.

Initially, several broad fields were selected to try to identify potential opportunities for collaboration: geography of the new economy, public policy and management, materials science and nanotechnology, and biomedical informatics. Others areas have begun to emerge, including wireless communication, nursing, marine and ocean sciences, and fuel cells.

E-learning has had the most visible activity. The United Kingdom has been motivated to be an active participant in the anticipated worldwide explosion of the e-learning business. Hence, the e-university program was launched by the U.K. government, which earmarked 100 million pounds (as of 5-10-04, 1 British pound was equal to 1.77 U.S. dollars) to promote the development of a wide array of e-learning modules. The WUN was ideally positioned to respond to that funding opportunity and promptly won a $1 million award for a public policy and management program at the master's degree level and another $1 million for a bioinformatics master's.

In each case U.S. partner institutions have been participants. Because all of the funding was from the United Kingdom and because the U.K. government put fairly tight intellectual property constraints on the products, this has not been as effective as it might have been. Had there been comparable funding from the United States, it might have been possible to ensure that these courses and later courses yet to be developed could be made widely available and used broadly by individual institutions in their own branded degree programs. There is still a chance to move in that direction, but the lack of any U.S. funding is a serious impediment.

With respect to research and student exchanges, the results are a bit more mixed, in part because of national and institutional "silos." It takes effort and time to build relationships, and money is required. The only source of support is the individual institutions that feel that this is an important investment. To make such collaboration truly attractive, there has to be some incentive, such as more financial support for the research. Again, there are virtually no mechanisms for this. A prime example of the problem in the United States is the failure to achieve serious collaboration between national laboratories and universities because there are no funding sources to support it. Likewise, although many thoughtful observers might argue that international collaboration is important—and indeed the National Science Board (NSB) declared so for NSF—there are hardly any formal programs (apart from modest grant supplement or travel programs) whereby investigators can seek such funding.

There are a few exceptions. The National Institutes of Health (NIH) Fogarty program is a venerable example. NSF has recently sponsored a joint effort with the U.K. Joint Information Systems Committee (JISC) program. NSF was urged to expand the Integrative Graduate Education and Research Traineeship (IGERT) Program by providing supplements to encourage international exchange of students, and it is now doing this. More recently, the European Union (EU) has launched Framework VI. In this new 5-year plan, the European Union provides an opportunity for the first time to fund researchers in the United States who participate with EU partners. Indeed, there are excellent opportunities for graduate students, postdoctoral scientists, and faculty to receive funding to work in the European Union on collaborative projects. It may be worth while, as a part of the NSB directive, for NSF to work constructively with the United Kingdom and the European Union to find appropriate programs whereby joint research efforts could yield important benefits, but a separate pot of money has to be earmarked for international collaboration or it may not work. The overhead for the individual principal investigator (PI) is just too high to try to do this on a shoestring, especially because PIs are already too stressed out.

The student exchange program has also been active. In just over two years, about 150 students have spent a couple of months on the average at an international site. The University of Washington has the largest number of U.K. students visiting in the United States, but it has been the least successful in sending students to the United Kingdom.

COLLABORATION

People and policy makers are beginning to look at the issue of international collaboration with new interest and to talk about implementing new initiatives. There is, however, an unspoken underlying concern that tends to weaken the commitment: Is collaboration a good idea? Maybe the best ideas will be stolen, maybe this will just help to develop the competition more quickly, or maybe it is less efficient than simply focusing on local programs. The inverse is also true in each case. Very good science is going on around the world, and although at a macroscopic scale there is significant advantage in the United States, at the level of an individual research group the advantage often disappears or even goes over to the other side.

A far more fundamental issue has to be thought about in new ways, especially in view of the fact that the United States is entering a period of severe financial difficulty, given the explosive deficits and long-term problems with the economy. Global challenges of huge dimensions require a more concerted and aggressive approach. It is not acceptable for us to fumble around erratically with piecemeal approaches, because the security and survival of the country are at stake. Even with the most effective worldwide collaboration imaginable, the United States will be severely tested to meet the challenges of global health, sustainable energy resources, protection of the environment, and global climate change in a timely manner.

In a recent talk in Seattle, the former head of the National Cancer Institute and now global health director for the Gates Foundation, Richard Klausner, pointed out that 90 percent of the health resources are spent on 10 percent of the world's population. What is even worse is that people in the United States can afford to be complacent and sloppy in medical methods because there is the wealth to do follow-up tests and have repeat visits to physicians' offices. He argued that this should not be tolerated. Demands should be made for the kinds of tests that can be done once and with a high degree of definitiveness. Thinking about how to address the needs of Third World countries, where tests have to be cheap and accurate, may improve health care in the United States.

A serious public conversation concerning our ambivalence about cooperation is long overdue. This issue needs to be deliberated at the highest levels of government because there are policies currently that are not conducive to collaboration. Should there be collaboration or isolation? If it is believed that the United States is well in the lead and can dominate the rest of the world in science as well as defense, maybe the country can afford to work alone.

CONCLUSION

In conclusion, there is a serious decline in manufacturing activity in the United States. Every state has experienced it. It is argued that manufacturing is being displaced by a service industry, which is expected in a knowledge-based economy. However, the assumptions that underlie that argument should be questioned seriously. Much of current U.S. trade policy focuses on reducing trade barriers and tariffs. This is of great importance to major corporations. It also means that it is easier for them to send production and R&D offshore. Is this trend in the national interest? If it is not, who is minding the store? What is the long-term prospect for the U.S. economy, to say nothing of defense, if most of the major manufacturing sectors shrivel up in the United States? Maybe it can be tolerated in textiles and even automobiles, but how about semiconductors, telecom, IT, and aerospace? If manufacturing and then R&D continue to decline, what will the service industries service? This nation is going to be in for some difficult times unless there is a much more public and spirited debate about the future of the economy. It is not enough just to mention the platitudes about how the classic market works and how this should be expected in a knowledge-based economy.

It is highly likely that the chemical industry will also experience continued pressure and relative decline with the rest of the manufacturing economy and that jobs in general will become less abundant in relative terms. Thus, it is necessary to take a serious look at how this country positions itself and its students to become members of a global community, because that is where a goodly number of them will be working in the latter half of this century. If this premise is correct, there has to be substantially more public debate at the national level on what the trends mean for the future of this nation.

REFERENCES

Atkinson, R. 1990. Supply and demand for scientists and engineers: A national crisis in the making., *Science* April 27: 425.

Bowen, W.A. and J.A. Sosa. 1989. *Prospects for Faculty in the Arts and Sciences: A Study of Factors Affecting Demand and Supply.* Princeton, NJ: Princeton University Press.

Goodstein, D. 1994. The Big Crunch, NCAR48 Symposium, Portland, OR. September 19.

National Science Board. 2004. *Science and Engineering Indicators 2004* (NSB 04-01). Arlington, VA: National Science Foundation.

National Science Foundation. 1989. *The State of Academic Science and Engineering*, Arlington, VA: National Science Foundation.

Storck, W.J. 2004 World Chemical Outlook. *Chem. Eng. News* 82(2), 18-20.

DISCUSSION

Much conversation arose out of Alvin Kwiram's presentation. Particular attention was given to the many opportunities for U.S. students to broaden their international experience.

Graduate Student Funding

Paul Hopkins, of the University of Washington, requested a comment on how funding agencies could possibly change to take some corrective steps on some of the items mentioned in the presentation.

Kwiram responded that he is not prepared to provide piecemeal solutions off the cuff but thinks that the intensive pressure that all researchers face at institutions today, the way graduate students are funded, and the reluctance to fund technician support mean that research groups have to be extremely productive to remain competitive for grants. It is attractive to keep graduate students around longer because their later years are when they most productive. Initiating serious discussions on these factors should have high priority. The pressure has to be reduced somehow.

Art Ellis, of NSF, stated that NSF is trying to provide longer-duration grants in the hope of relieving some of the stress for a principal investigator and has started making some four-year awards based on peer review. He said that NSF is also open to ideas from the academic community about mechanisms to address these very important points.

An unidentified participant stated that the United States is probably the only country that provides an academic investigator with the funds to support personnel. In other countries, funding is done by various relationships that depend on national need. In Europe, personnel support is not associated with the funding necessary for a particular grant program, except in the large grants and consortium grants. The speaker asked Kwiram whether he would recommend that the personnel element be dissociated from the research grant award process in U.S. federal agencies.

Kwiram responded that it was an important question. In the United Kingdom, the government provides all of the funding for graduate students; the funding is not in connection with the research grant but as a block fund to the university. There is some reluctance to go that route in this country for a number of reasons, including the nature of private and public institutions in this country. Again, it is a complex issue that would benefit from a broadly informed conversation in this country. Obviously, there is a strong motivation in the United Kingdom to finish in three to three-and-a-half years because funding ends after that period. However, to craft the right mechanism for the United States and one that is politically realistic would require a lot of serious thought and discussion.

James Martin, of North Carolina State University, claimed that the United States does not have to come up with different ways to think about funding. He said that the United States has a competitive edge in education because of its history of openness. These competitive edges should be looked at more carefully and leveraged in a market sense. He questioned how funding could be achieved by taking advantage of the competitive edge.

Steven Buelow, of Los Alamos National Laboratory, had found that a reason for the lack of an even flow of students in and out of the country is that the United States is funding most of the foreign students directly from laboratory grants, but it is not getting the same reciprocity abroad.

Martin added that many foreign countries have strict rules that do not allow students from other countries to be paid.

Education of International Students

Hopkins asked whether we should be educating more or fewer international students in the United States than we are now. Clearly, legislators want more students from their home state (rather than foreign students) educated and deans and presidents are concerned about the language skills of international students who would be teaching assistants. Yet the faculty would like the very best students, and this is important for the nation.

Kwiram replied that the growth in international students in U.S. universities in the last 25 years has been healthy and important, but it is unfortunate that there are not more U.S. students going overseas for their Ph.D.s. The number of domestic students in engineering is too low, and efforts should be made to balance that proportion.

If there is a continuing decline of U.S. citizens in particular fields of science and if the decline is only partially made up by international students, we risk not having the human resources that the nation needs. It is much easier to work in one's native culture and language, so it is not surprising that foreign students are increasingly returning to their home countries.

Hiring Students with International Experience

Karin Bartels, of Degussa, asked why more U.S. graduate students are not doing work abroad, such as postdoctoral work in Europe and in Asia. One of the main reasons may be that students think that they do not increase their chances of finding jobs in industry when they return. There needs to be different thinking about this and greater effort to increase their international experience. She thinks that family issues and language are not the big obstacles but that employment opportunities are not as good as they would be if the students had stayed in the United States. Kwiram believes that family, language, and cultural issues do represent important obstacles to international engagement.

Miles Drake, of Air Products and Chemicals, Inc., believes that someone who has worked overseas for some time in an academic institution and is coming to his or her first position in a company is going to be very popular because of an assumption of increased breadth.

B.J. Evans, of the University of Michigan (retired), reminded the audience of the difficulties in our educational process in instilling international perspectives and an understanding of the global nature of chemistry in students. It appears to him that the difficulty is in training students appropriately so that they will have experience in another language; educated people should know another language.

Kwiram thinks that problems reach back into high school. He recommends looking at German high-school education to get a different insight into the problem

Douglas Selman, of ExxonMobil, said his company hires students who have an international perspective because it needs access to the academic and government research institutions around the world. A lot of Europeans with Ph.D.s are hired because they have access to Europe. They are expected to work collaboratively across international boundaries. With skill and training, people can accomplish this.

E-Learning

Ned Heindel, of Lehigh University, addressed the e-learning issue. In 1991, Lehigh got a Department of Education grant to buy a transmitter and begin distance education broadcasting in materials chemistry. It had four partner companies: Exxon, Air Products and Chemicals, DuPont, and 3M. Twenty students started, and Merck provided $450,000 for Lehigh to create a master's degree in pharmaceutical sciences taught by industrial scientists. Now, there are 1,500 students in 72 companies, including students in Canada. The market for e-learning is not in chemistry but in pharmaceuticals. Some 87 percent of the enrollment is in pharmaceutical companies, and the rest is scattered over government laboratories and the chemical industry. More programs are being added.

Drivers for Chemical Industry Relocation

Selman believes that the chemical industry is being driven offshore, particularly for the commodity end of businesses, by raw materials pricing and access. The trend is also promoted by markets, and the big market growth is in Asia. He thinks that the trend will continue, at least for commodity chemicals, and the import and export balance will probably continue in this direction. If the United States has opportunities, they would be more in the specialty end, where we bring special skills that are not necessarily as driven by raw materials pricing and market access to large-volume commodity products.

Interface of Government Laboratories and Universities

Esin Gulari, of NSF, asked whether there are many unique facilities that researchers in the universities can access at the government laboratory-university interface.

Kwiram believes that the national laboratories are superb resources for scientist-to-scientist collaboration. Laboratories and universities have complementary capabilities and resources, but there is negligible cooperation overall compared with what should and could be achieved.

Similar Trends in Agriculture

Heindel's experience in agriculture mirrors the discussions in the workshop. Agriculture has experienced a decline for at least twice as long in numbers of people coming into programs. He made two observations. First, the agriculture schools are reinventing themselves constantly. Second, despite external pressures, the universities continue to push internationalization. He predicts that the trend will continue in chemistry as well.

7

Attracting and Preparing Chemists and Chemical Engineers for a Global Workforce

Mostafa A. El-Sayed
Georgia Institute of Technology

INTRODUCTION

In today's world, scientists and engineers need to prepare to be part of a workforce that is global in perspective. At the same time the serious potential decrease in the workforce of scientists and engineers in the United States does not bode well. This presentation addresses the preparation of chemists and chemical engineers for a global workforce, with emphasis on changes in undergraduate and graduate education that can meet the chemical industry's needs.

U.S. Supply of Scientists and Engineers

According to data from the National Science Board, the fraction of science and engineering doctoral students in the United States who are U.S. citizens has dropped from 70 percent to 56 percent in the last 25 years; the average enrollment dropped steadily from 118,000 in 1992 to about 100,000 in 1998. Reversing these trends will be difficult, and the consequences of not doing something, potentially damaging. According to the Department of Labor, 60 percent of future jobs require skills only 20 percent of Americans have.

International students have typically been attracted to the United States by the standard of living and the great opportunities to carry out science and engineering research. This has been of great benefit to the U.S. science and engineering workforce. In the United States, 10 percent of holders of bachelor's degrees, 20 percent of master's degrees, and 25 percent of doctorates in science and engineering were born in other countries. This trend might not continue in the future. In fact, some countries other than the United States are trying to counteract it as competition for scientists and engineers increases. For instance, China now has special programs with funds for Chinese citizens that want to return to China and start up laboratories. Recently in the European Union (EU), 1.9 million high-technology jobs were made available to non-EU applicants.

The percentage of students going into science and engineering outside the United States is increasing rapidly but the percentage of U.S. students going into science and engineering remains very low (a few percent each year). If that continues, the United States will become less competitive. We should continue to focus on improving the quantity and quality of U.S. students so that there is no need to worry about the supply coming in from other countries or about foreign students returning home.

Attracting More U.S. Students to Science

One possible solution to the potential shortfall in scientists and engineers in the future is to work on making science more attractive to young people in the United States. Improving the teaching of science in elementary and high school is critical. There have to be more programs that bring scientists and engineers into schools to talk to students about science and give high-school teachers opportunities to develop exciting demonstrations and make the laboratory more attractive to students. Money also needs to be invested in improving laboratory facilities at those levels. Summer research fellowships for senior high-school students to do research in neighboring junior or 4-year colleges could offer incentives for young students to see what research is like.

One way to improve recruitment at the college level is

This is an edited transcript of speaker and discussion remarks at the workshop. The discussions were edited and organized around major themes to provide a more readable summary.

to pay undergraduates to do research, much as graduate students are paid. Some bright students are unable, for economic reasons, to follow their desired vocation. Also, many undergraduates do not know that graduate students get paid; if they did, it might make science careers more attractive.

SOME THOUGHTS FROM CHEMRAWN X

In 2000, workshops were held as part of the Tenth Chemical Research Applied to World Needs (CHEMRAWN X) workshop and focused on the topic "The Globalization of Chemical Education—Preparing Chemical Scientists and Engineers for Transnational Industries." Potential solutions to the global workforce challenges discussed earlier are presented below relative to ideas presented at those workshops.

Alternative Degree Programs

The University of Texas (UT) at Dallas has said that in a global economy there is a need for chemists with doctoral level skills, practical attitudes, and the ability to work with teams of engineers. The school has designed a doctorate of chemistry (D.Chem.) to prepare students for such careers. In the third year, every student works for 9-12 months at an industrial site. The technical managers that the group works with become a voting member of the students' advisory committees. During the year, students learn how to work with a variety of people within the company, which provides them with insight into the U.S. industrial world. It seems that this kind of exposure has to occur for students before going globally. So far, industries seem to view the program positively, as do most of the students, who thus far have had no problems in locating jobs after completing the program.

The International Experience

Most European countries have enthusiastically embraced the idea and practice of providing international students and teachers with exchange opportunities. The exchange networks that have developed in Europe, such as the European Chemistry Thematic Network (ECTN), have led to various activities, including exchanging curricula, development of short courses, and multinational-multilingual tests. Expanded exchange programs help students get to know about other countries, languages, and cultures, and this helps in the global aspects of the profession.

Multinational Chemical Employment

As Mary Good pointed out at CHEMRAWN X, chemistry at the undergraduate level is taught as a disciplinary subject in the expectation that students will either go to graduate school or work for a chemically focused industry. Graduate students are expected to find academic positions or research positions in industrial laboratories. No thought is given to the fact that most of the chemical and pharmaceutical companies are multinational. People who aspire to become leaders in those companies are usually expected to have some non-U.S. experiences, but students are not introduced to the chemical industry and its complexities. She has sought ways to include industrially relevant material from the multinational perspective throughout the curriculum.

PROPOSED CHANGES IN EDUCATION

Where do students go after graduation? Of the 11 million science and engineering degree holders in 1999, business and industry employed 78 percent of bachelor's degree holders, 70 percent of master's degree holders, and 40 percent of doctorate holders (these values are 73, 62, and 31 percent, respectively, for companies in the private, for-profit sector).[1] The academic sector was the second-largest employer of scientists and engineers, but the largest employer of doctorate holders.

It is not clear why such a distribution occurs. Why are more Ph.D. holders not going into industry, and does this constitute a problem? The distribution has something to do with the current educational system at both the undergraduate and the graduate levels. A complete overhaul of education might not be necessary, but some things might be done to enhance science and engineering education to prepare students better for global industrial jobs.

At the undergraduate level, changes in coursework could help to broaden education. Some schools are requiring biology for chemistry majors. Such electives as computer science, management, political science, and languages, would also be helpful. As discussed earlier, requiring a research thesis and encouraging industrial research experience (cooperative) would also attract students to science and engineering while potentially fostering a global perspective.

Collaborative research between students and laboratories in different countries also fosters a global perspective. In fact, the international division at the National Science Foundation (NSF) sponsors a program that has allowed students (including mine) to spend short periods working in an overseas laboratory. In return, students from those countries spend time working at the U.S. school. This kind of exchange has proved to be wonderful. The funds for such programs, however, are not abundant, and it is not certain how long they will continue, but it is a great start and should be enlarged.

There also has to be increased attendance at international scientific meetings by U.S. students and scientists in general. In the past, a large fraction of audiences at these

[1] National Science Foundation. 1990. Division of Science Resources Statistics (NSF/SRS), Scientists and Engineers Statistical Data System (SESTAT).

meetings was from the United States. This is not the case now, possibly because the U.S. research experience is becoming less international or funding in that direction is not as it was before. It is important that American scientists and engineers attend meetings in other countries.

Making changes in graduate education is not as straightforward. For those going into industry, learning more about the business aspects of chemistry is important. There is also the idea of having two types of degrees at the graduate level: a Ph.D. degree and a doctor of chemistry degree like the one given at UT-Dallas. The present degree could be refined to make it more global. One way might be to reinstate the foreign language requirement.

At the same time, students must still be able to take more of the fundamental courses that they want and gain deep understanding of different subjects. The greatest challenge is in balancing all the requirements that will at the end make this country competitive and prosperous for a long time to come.

A great example of the need for fundamental understanding of science and engineering is the success of Bell Labs. If it were not for the number of laboratories there performing fundamental work in solid-state physics, computers today would still be using vacuum tubes instead of chips, and the landscape of the world economy would probably be drastically different. Bell Labs has since changed, but the fundamentals will always be essential for continued exploration of new frontiers in science and engineering and for the global future.

DISCUSSION

After the presentation, there were many comments and a few questions from the audience. People had strong opinions on such issues as education at all levels, including a new program called the doctorate of chemistry.

Existing Programs

Donald Burland, of NSF, agreed that a lot of existing programs could solve some international questions, but people are not aware of them. He believes that in existing NSF programs, and potentially National Institutes of Health (NIH) and Department of Energy programs, virtually anything worth doing can be done. For example, Discovery Corps, recently announced in the NSF Chemistry Division, allows a postdoctoral student or a senior faculty member to conduct an activity other than research, such as developing a program with a less developed country or working with a school board to establish relationships with industries. Another example is funding that exists for undergraduate research centers, where freshmen and sophomores are encouraged to begin research. Burland stated that these years are targeted because most losses of chemistry students in universities occur then.

Michael Rogers, of NIH, echoed Burland's thoughts on the ability to make use of current funding mechanisms. NIH supports postdoctoral fellowships, and trainees can select foreign sites. It is rare for one postdoctoral fellows to propose training at a foreign site, but if they do, it must be justified. If the study section feels that equivalent training could be obtained in the United States, it can grade the application down accordingly. Part of the job is to convince colleagues that international training is important; if this happens, not only will it be possible to consider new funding programs, but there will be better use of existing programs.

William Koch, of the National Institute of Standards and Technology (NIST), highlighted other funding opportunities that have proved successful. Models all over the country are working, and he is not sure that a national solution and more laws are going to fix the problems being discussed. At NIST, students from high school to graduate school are brought in during the summer in a special program in collaboration with NSF. NIST also has a grant fellow program. He said that more of the best practices can and should be shared.

Working in Developing Countries

Burland pointed out that there are many efforts to work with European and more-developed Asian countries, but very little work is done with the developing world. He wondered about the problems and potential solutions for this situation.

Mostafa El-Sayed commented that developing countries have a lot of problems to which chemistry and engineering can be applied and be helpful. For example, in Mexico City, pollution is a huge problem that could benefit from the help of U.S. scientists in analyzing it, determining its sources, and making recommendations to reduce it. This is probably being done to some extent, but there must also be student involvement. In exchange, students from the United States could learn from the experience and acquire publishable work. It would help if people were aware of NSF funds available for such projects.

K-12 Education

George Lorimer, of the University of Maryland, pointed out that students at his university typically attend for two semesters a year, totaling 28 weeks. High schools typically teach 30 to 35 weeks of the year. Industry does not operate only part-time in such a manner. He noted that the current schedule reflects the agrarian past, when long summer breaks existed so that children could work on the farm, but does not reflect our industrialized nation. He suggested a revolution that would involve extending the high-school year to 45 weeks, which would allow students to take additional courses that could teach the higher-order skills that have been discussed. To fund the effort, Lorimer suggested that there be a graduate tax. Undergraduate education could be much less expensive than it is now, but a tax could be imposed on the graduates who will most likely make more money as a result of the education they received at taxpayer expense. The added benefit of all this is that information would not be lost by students over the summer.

Douglas Selman, of ExxonMobil Chemical, commented that he has a son taking chemistry and questioned whether his son is learning any of the value that chemistry brings to our world. Children today are motivated to find jobs in which they think they can have a satisfying career and contribute to the world. Selman thinks that this motivation has to come in part through K-12 education.

Doctorate of Chemistry Program

Tyrone Mitchell, of NSF, does not like the doctorate of chemistry program that El-Sayed discussed because he thinks that getting a Ph.D. is an intellectual pursuit that teaches one how to think creatively independently. He has worked with people who have gotten the doctorate in chemistry, and he thinks that industry does not teach them how to think independently and be marketable throughout their whole career. He spent many years with General Electric and avoided company courses because they would have trained him only about General Electric when he wanted to learn more about chemistry in the global perspective. In addition, training people to go into industry helps only industry, so industry should not be participating in the educational process. There have to be more ways for Ph.D.s to gain experience that makes them more global. This involves developing Ph.D.s who can think independently and take on intellectual challenges no matter where they are in the world.

Selman prefers the doctor of chemistry idea because of the prospect of embodying the higher-level skills described earlier. ExxonMobil struggles to find people who have a balance of the breadth of skills to be a manager and the depth of technological understanding to manage technology and R&D. Selman also believes that the general interface between academe and industry must be strengthened rather than separated, because it is relevant to couple the science that can be developed from academic and graduate research programs with the application of that science. The more both sides understand each other and the more collaboration they have, the easier the transfer of technology will be.

Collaborations with Russia

Selman noted that in the late 1990s, the United States started going to Russia to solicit contracts with Russian research institutes. An environment was found in which there were a huge number of scientists and highly technically oriented people with nothing to do. He wondered why the U.S. government did not jump in aggressively to acquire this pool of people. Previously, there were many challenges to working in Russia, but now, U.S. companies have many opportunities to develop business ties and investments in Russia. The development of collaborations between the two countries could lead to more positive relations on the global scene in business and more broadly.

Attracting Students into Chemistry

B.J. Evans, of the University of Michigan (retired), believes that the will to include an international aspect in students' training is not present in the United States. He became a chemist because it was the best discipline on his campus and because he wanted a good life. Today, we must attract students to chemistry by taking them to American Chemical Society meetings and discussing with them the life available through a chemistry career. Because of the industry connection, chemistry can do things that other disciplines cannot do.

Regionalization of Financial Resources

Michael Doyle, of the University of Maryland, observed that 30 years ago, various nations had resources that they were willing to give to undergraduate students to spend time in the United States to learn something in another laboratory and experience the culture. Funds and resources were available in many countries, but they were minimal in the United States, because the United States liked to be the recipient of the largesse and held out the standard of excellence in science education.

Today, there is regionalization of these efforts. It is much more difficult to attract students from the European Community to the United States because the resources are not available. He asked whether regionalization of globalization is occurring because an international operation that previously favored the United States is now a regional operation that does not favor the United States.

El-Sayed thinks that the reason for this problem may be that those countries now have technical knowledge and do not need to learn from the United States as much as they used to. Very few foreign people now attend conferences in the United States. The United States may now be able to learn something from them. They may have something that this country does not, or they may be developing a product in a different way.

The International Perspective

8

Seeing the World Through a Different Window

Robert P. Grathwol
Alexander von Humboldt Foundation

Preparing chemists and chemical engineers for a global workforce involves two intertwined problems: creativity and competitiveness. It is important to maintain or to stimulate creativity in research. It is also vital to ensure that American-trained researchers have the tools to compete in an increasingly global environment.

Both problems and tasks are subsumed in the metaphor chosen as the title of this presentation, "Seeing the World Through a Different Window." This phrase comes from James Buchanan, Nobel laureate in economics. Buchanan used to tell his graduate students that if they sought original, creative insights, they needed to "see the world through a different window." For purposes of this presentation, the phrase is taken to mean that forcing oneself outside of a comfort zone provokes creativity.

Placing oneself in another culture by undertaking research abroad enhances the likelihood of gaining a view through a different window. Even if everyone with whom you are working is exploring the same research problems, your collaborators will bring a different cultural filter to the research and to their thinking. This increases the chances of learning to see things in a new way.

In addition, learning how to work in another culture hones your abilities to interact with others in the global marketplace of talent and labor that now characterizes the world economy. Thus, on both a creative level and a practical level, a research sojourn abroad makes sense—even dollars and cents—as a long-term investment.

Three topics were offered that expand on this assertion: What are others doing to find that different window? What are we Americans doing or not doing in response to the challenge of the global marketplace? How do we change the trend?

WHAT ARE OTHERS DOING?

The European Level

Under the programs associated with the European Commission's (EC's) Sixth Framework (see *http://europa.eu.int/comm/research/fp6/index-en.html*), the European Union (EU) has budgeted 17.5 billion euros for the period 2002-2006 to support a series of research programs designed to enhance the international exposure of European scholars. The programs bear the titles "Marie Curie Actions" and "Human Resources and Mobility Actions." In general, they broaden existing research funding to include researchers of any nationality to undertake research within the EU and to increase the "mobility" of researchers within member countries. The EU is rapidly expanding to cover the entire continent from the Atlantic to the Urals—and even beyond.

In this context, *mobility* supports movement both in a geographic sense and between economic sectors and scholarly disciplines. Thus, the programs fund movement of researchers between the private sector (industry) and state-supported research installations (academe) and between disciplines or research concentrations.

The EU has focused all this effort as an "essential element of the strategy proposed by the Commission . . . [to] relieve the tension in the research labour market . . . fundamental to the achievement of 3 percent GDP [gross domestic product] investment in research in Europe."

The Sixth Framework also makes funds available to

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"facilitate professional integration of researchers" *after* they have spent a period of research abroad. The commitment to reintegrate researchers underscores that the community as a whole values foreign research experience and is willing to put its money where its mouth is. The same reality is reflected in the framework's commitment of funding to long-term cooperation in research between universities and the private sector. More information about these programs can be found in an EC bulletin on community research *A Rough Guide to the Marie Curie Actions*, published in January 2003 (e-mail contact: *rtd-mariecurie-actions@cec.eu.int*).

The Alexander Von Humboldt Foundation

The Alexander von Humboldt Foundation's contribution to preparation for a global workforce is a side effect of its primary focus—the commitment to the ideal, embodied in the life of its namesake, Alexander von Humboldt, that international collaboration in research fosters both better and more-creative research and international understanding. Traditional Humboldt programs have supported about 23,000 non-German scholars since 1953, creating a network of highly accomplished people spread out across more than 130 countries, all of whom have the common experience of an extended stay pursuing their intellectual interests in Germany.

The Alexander von Humboldt Foundation, a European-based organization, has spent the equivalent of about 1 billion euros since 1953 to fund non-German researchers during extended research stays in Germany, an investment that the foundation continues to believe is worthwhile.

The foundation's continuing commitment to the ideal is evident in its assumption of a leading role in the organization of new facets of the mobility programs at the European level. In the coming year, the foundation will open "mobility centers" in Germany that act as a form of clearinghouse for information about research opportunities open to non-Germans.

The foundation continues its support for its traditional programs. Five programs have the most relevance for American-based researchers. One is the **Humboldt Research Fellowship**, which is open to persons in any field and of any nationality for a research stay in Germany and aimed at scholars under 40 years old who have a Ph.D. or equivalent degree and internationally recognized publications. The foundation has recently raised the stipend attached to this program and introduced variations in the length of the stay in Germany (for details, see *http://www.humboldt-foundation.de/en/programme/stip_aus/stp.htm*).

Another program, the **Feodor Lynen Research Fellowship,** has requirements identical to those of the Humboldt Research Fellowship, but it sends German scholars under 38 years old abroad to work with former Humboldtians in their home institutions. The foundation's expectation is that this opportunity for German researchers in foreign lands will extend professional and intellectual ties across national boundaries and across generational and disciplinary lines (for details, see *http://www.humboldt-foundation.de/en/programme/stip_deu/flf.htm*).

A third program, **TransCoop** (Transatlantic Cooperation in Research), seeks to provide seed money to promote new collaboration between German scholars and scholars from the United States and Canada. It has no age requirement. It focuses on disciplines in the humanities and social sciences (for details, see *http://www.humboldt-foundation.de/en/programme/stip_aus/transcoop.htm*).

A fourth program, the **German Chancellor Scholarship Program,** is unlike any of the other Humboldt grants in that it does not require a Ph.D. and focuses more on professional development than on research. Created in 1990 as a means of strengthening ties between Germany and the United States, the program awards 10 scholarships a year to U.S. citizens under 35 years to spend a self-defined year-long project in Germany. The program's successes emboldened the foundation to expand it in 2002 to include citizens of the Russian Federation. Thus, henceforth 10 young American professionals and 10 counterparts from the Russian Federation will spend a year together in Germany—a gratifying opportunity to realize the foundation's goal of promoting international understanding through intellectual exchange. The German Chancellor Scholarship Program might have particular appeal to those in the private sector who have bright young people making a name for themselves in corporations who might profit from a year of professional exposure in Germany (for details, see *http://www.humboldt-foundation.de/en/programme/stip_aus/buka.htm*).

The fifth program is the **Humboldt Research Award.** In contrast with the others one cannot apply for this grant. Eminent German scholars may nominate candidates of any nationality and in any discipline at any time. Nomination is in recognition of a candidate's internationally recognized contributions to research. Nominees are reviewed for selection by the Humboldt Foundation (for details, see *http://www.humboldt-foundation.de/en/programme/preise/pt.htm*).

Those and the many other, more specifically focused programs supported by the Humboldt Foundation account for about 800 new awards each year.

HOW DO AMERICANS COMPARE?

The Sixth Framework programs and the research grants supported by the Humboldt Foundation typify the initiatives undertaken by colleagues abroad to encourage research on an international and intercultural level. How do Americans compare?

At least by available measures, the answer is not very advantageously. From 1993 to 2000, applications by American researchers for fellowships abroad declined sharply. This was true for American applications for the Humboldt Research Fellowships, for National Science Foundation (NSF) fellowships to Japan, and for Fulbright Senior Scholar Awards. Three other statistics illustrate an American reluctance to undertake educational travel abroad.

- Only 1 percent of U.S. students in American colleges and universities travel abroad to study, the vast majority in programs that last for less than 8 weeks.
- When asked in how many months during the preceding 3 years they had traveled abroad, 65 percent of faculty members said none.
- About 80 percent of U.S. faculty members have never collaborated with foreign scholars.

Add the assertion that fewer than half the members of Congress have passports, and one must conclude that overseas experience is not a particularly strong value in our society. What accounts for American reluctance or resistance? Nine explanatory factors are offered.

The Curse of Our Preeminence, or Why Should We Worry?

One fundamental difference between the United States and other countries is that for many reasons, numerous scholars and researchers from abroad are drawn to the United States. The quality and reputation of our system of higher education and research and its very size exert an attraction. The United States has 3,600 nonprofit colleges and universities and another 3,000 proprietary schools. Working in the United States is economically attractive. Our educational system and our professions are relatively open. Our country has enjoyed a certain political prestige since the middle of the twentieth century. Finally, English has become the universal language of science and commerce; Art Buchwald would probably take great delight in the description of English as a lingua franca, literally the tongue of the Franks. All of these elements conspire to promote a sense of contentedness with things as they are.

We in the United States attract the best. The Humboldt Foundation is proud that 35 Nobel laureates also held Humboldt grants, and more than 20 of them reside in the United States. Nineteen American Nobelists received their Humboldt grants before their Nobel Prizes, and 10 of the 24 U.S. Nobel awardees have been chemists.

Given these factors, it is perhaps understandable that to attract researchers, other countries have to be much more active. So why worry? The answer is that a static state is not a natural condition in human affairs. Moreover, others are developing strategies to overcome the advantages that the United States has enjoyed over the last 50 years.

The Level of Our Arrogance, or Why Should We Bother?

The dampening effect of this attitude is displayed in a comment on improving the lot of postdoctoral scholars at a symposium sponsored by the National Academy of Sciences' Committee on Science, Engineering, and Public Policy on March 2, 2001 (for more information see h*ttp://www7.nationalacademies.org/postdoc/agenda.html*). In response to a suggestion made during discussion that money was available to support advanced research outside the United States, a participant voiced the following comment: "When advising my best postdocs about grants, I always tell them to go where the best science is." The responder's meaning clearly was not abroad. Mentors are the most influential elements in the career paths of Ph.D. researchers, and an attitude such as that comment conveyed will not expand our international experience or our preparedness for a global talent marketplace.

- *The booming economy*. The booming economy of the 1990s is a factor in the decline of interest in stays abroad for research. That factor has changed in the last 3 years and may be changing again.
- *A substantial lack of awareness*. A substantial lack of international awareness faces many of us who try to promote research opportunities abroad. Many researchers in this country and the administrators who are responsible for encouraging grant applications know little or nothing about the Alexander von Humboldt Foundation or other similar opportunities
- *Money.* The Humboldt Foundation has to maintain the financial and logistic attractiveness of its sponsoring programs. That support is now roughly $29,000-41,000 a year—a handsome stipend for many researchers around the world, but substantially less than a postdoctoral scholar in chemistry or chemical engineering might command in the United States. It is generally adequate in Germany, however, especially when supplemented by travel funds, family allowances, and other considerations, which the foundation provides.
- *Difficulties with career paths.* A research sojourn abroad can disrupt career advancement, especially for those who are not yet tenured. Thus, time abroad can be seen not as just without value but with negative value in career terms.
- *Reintegration*. There is a lack of support for returning researchers.
- *Two-career couples*. A Humboldt Foundation fellowship awarded to one member of a two-career family can disrupt coordination of career objectives. The foundation *does* pay for language instruction for spouses and seeks informal ways to integrate spouses into the life at German host institutions and into the German community. Such efforts do not replace a spouse's income or assure a spouse of a professionally enhancing experience.
- *Special situation of women*. The career paths of women have a different tempo from the paths traditionally followed by men. The Humboldt Foundation allows women

some leeway regarding the age limit, but this is a minor factor in perceptions of the competition.

CHANGING THE TREND, OR WHAT CAN YOU DO?

Given the many factors that work against research ventures abroad, what can we do to ameliorate the situation?

The impediments to greater international experience fall into two categories: things that we cannot control and elements in which our actions have at least some hope of success. We cannot control the economy or its cycles. We cannot solve all the problems posed by two-career families, although we may be able to address some of the concerns that this situation raises. However, we can change knowledge about overseas programs. The Humboldt Foundation, particularly the U.S. Liaison Office in Washington, D.C., has increased its paid advertising of the programs sketched earlier. This may account for the recent increase in applications from the United States for the Humboldt Research Fellowship, the TransCoop program, and the German Chancellor Scholarship. It is too early to tell whether this upswing will be an enduring trend.

Because its promotional budget is limited, the foundation could benefit from outside help. Mentors have a profound influence as researchers chart their career paths. Word-of-mouth advertising, announcements of success when the foundation awards grants, and professional newsletters and journals can be used to expand awareness of the programs. If you are a Humboldtian, wear your Humboldt tie or scarf and mention the foundation's support when making a professional presentation; the foundation can provide a PowerPoint slide to do this.

The support offered to those who take advantage of research sojourns abroad can also be changed. Deans and heads of research teams can assure successful applicants that they will have money available for scholars when they return from abroad; this is a way to overcome the reality that time outside the United States leaves the researcher out of touch and thus works against career advancement.

Furthermore, we can all think creatively about the programs that offer support for overseas research. One of the new options allows an applicant to request a minimal stay of 3 months in 3 successive years rather than the traditional minimal stay of 6 months—less time away from the home institution, but guaranteed travel and research support for 3 successive years. Similarly, a candidate may opt for 24 consecutive months of research support. Details of these options are available at *http://www.humboldt-foundation.de/en/programme/stip_aus/tshp2.htm* and *http://www.humboldt-foundation.de/en/programme/stip_aus/tshp1.htm,* respectively.

The TransCoop program, mentioned earlier, offers another set of opportunities to initiate collaboration with a German scholar or research team.

The Humboldt Foundation and the National Research Council have also worked out terms to link research grants offered independently by each organization. The linked program allows scholar successful in both competitions to take the grants sequentially. The idea is to make reintegration easier when a scholar returns from Germany. You can do something similar if, when your postdoctoral scholar or young colleague goes abroad, you assure him or her of a place in your program on return. Such provision for reintegration into the American scene might increase willingness to take advantage of overseas opportunities at the same time that it facilitates career development.

In all of this, people can help the foundation by:

- becoming familiar with its programs;
- distributing widely the information outlined here;
- putting postdoctoral scholars in touch with it at the U.S. Liaison Office or the web site, *www.humboldt-foundation.de*;
- establishing their own contacts with overseas researchers and perhaps exploring the Lynen Program or becoming a Humboldt research awardee;
- putting the foundation in touch with their professional organizations, journals, and newsletters, especially the latter, where announcements about the grants can be placed; and
- if they themselves are Humboldtians, acknowledging the foundation's support when they make presentations, placing articles in alumni newsletters that mention their research and the Humboldt Foundation's support of it, and making the Humboldt opportunities known to those at their institutions who have an interest in research.

The foundation is happy to help you help it. Contact Robert P. Grathwol directly at

Alexander von Humboldt Foundation
U.S. Liaison Office
1012 14th St. N.W., Suite 1015
202 783-1907
e-mail: *avh@bellatlantic.net*

Or contact the foundation in Bad Godesberg, Germany, at

Alexander von Humboldt Foundation
Jean-Paul Strasse 12
D-53173 Bonn
Federal Republic of Germany
Tel: 011 49 (0)228 833 199
e-mail: *post@avh.de*
web—*www.humboldt-foundation.de*

Finally, it possible to foster a more positive attitude toward research abroad. Perhaps the comment quoted earlier ought now to come from your mouth as follows: **"I tell my**

best students to explore a research stay abroad, because that may give them their greatest opportunity to look at the world through a different window."

DISCUSSION

The discussion centered on the Humboldt Foundation and included such topics as dual careers, opportunities for undergraduates and women, and the funding structure. Programs available through the NSF were also considered.

Humboldt Recipients

Several recipients of Humboldt awards spoke about their experiences. Although each experience was unique, the recipients discussed their favorable experiences and excitement about the programs. Many have maintained their contacts, and the past opportunity profoundly affects their current outlooks and careers.

NSF Funding Programs

Larry Weber, of NSF, pointed out that NSF has many programs that support students to go to foreign laboratories. One is called the East Asia and Pacific Summer Institutes; each summer, NSF sends about 150 U.S. graduate students to Asian laboratories for 2 months. Weber encouraged professors and corporate leaders to encourage graduate students to participate in this.

James Martin, of North Carolina State University, brought up another NSF program called Long and Medium Stays at Foreign Centers of Excellence. He went to France through the program and believes that it is worthwhile.

Dual Careers

Martin was glad that the issue of dual careers was addressed. When he went to France, his wife followed and was fortunate to find a laboratory in Paris where she could continue predoctoral work, but they had to live on one stipend. Funding is a major consideration for expanding opportunities. As faculty members now, he and his wife would love to go on a sabbatical overseas again, but the problem is staggered schedules. It is important for some foundations to look at dual-career situations and see whether they can come up with some creative ideas to make that possible.

Robert Grathwol suggested that Martin consider the "3 × 3" option (a minimal stay of 3 months in 3 successive years). Martin responded that the option helps, but it is still difficult to participate when one is running a graduate program. Being away every summer is not optimal; this is when many professors are in the laboratory working with students and not spending as much time writing grant proposals, getting money, and writing papers. Grathwol agreed that there need to be ways to detach from the sort of rigidity that bureaucratic structures impose.

U.S. Students Going Abroad

Weber mentioned that there is a curse of having been at the top, that there is arrogance in the United States, where people disregard the fact that in some cases the best science is in other laboratories. He added that by combining U.S. and foreign expertise, in fact, it is possible to find something better than what can be done separately.

With reference to the Fulbright statistics suggesting that only 1 percent of U.S. students go abroad, Weber assumed that the statistic was pulled from the Institute for International Education's *Open Door* publication, which indicates that the number is about 150,000. The other important point is that 500,000 foreign students who come to the United States are getting degrees, and many of them are in science and engineering. In contrast, the 1 percent of U.S. students that go abroad are going for a week or at most a semester. Almost no U.S. students take degrees from foreign institutions. The experience is very different.

Martin agreed that there is a problem but that it needs to be thought about in different contexts. For instance, if it is looked at as a total fraction of the population as opposed to total fraction of students, the statistics may be slightly different. In the United States, students tend to be a larger population set than is typically the case in most foreign settings. There is a preselection process. Therefore, if one looks at the issue as a percentage of the total, the perspective will be slightly different.

Martin also noted that many students have not been out of a region of the country, much less abroad. For many students educated in the United States, going out of state is a multicultural experience, very much like going from one country to another in Europe. This situation must be considered as well.

Funding for Undergraduate Research

Karin Bartels, of Degussa Corporation, suggested that funding could be extended a bit to include people that are involved in undergraduate research at four-year colleges and universities, some of which may also have master's programs. The Humboldt Foundation could make a special program for encouraging undergraduate research.

Grathwol replied that DAAD, the German Academic Exchange Service, would be the appropriate organization responsible for dealing with undergraduates and graduate students. However, the German Chancellor Scholarship Program does not require a doctorate degree and tries to identify young Americans. The minimal degree requirement is a B.A., but an advanced degree is allowed. The ideal candidate probably is five to eight years beyond the B.A., has some professional experience, is starting to make a name for himself or herself in the profession, and is willing to take the time off. It is a great program.

Humboldt Funding Structure

Guangyu Sun, of the National Cancer Institute, commented that the distinction of the Humboldt structure is that the funding is attached to the fellow instead of the principal investigator (PI). He wondered whether this kind of funding structure is also available to German domestic postdoctoral fellows. What do U.S. funding agencies think about the structure? Perhaps more than 90 percent of the funding in the United States goes to the PI.

Grathwol could not answer about U.S. funding agencies but stated the Humboldt Foundation is committed to the idea of funding people, not projects, and therefore it would not fund a PI for the project cost. It would fund the person for that research project that the person designs. It is advantageous for a postdoctoral scholar to get the money for himself or herself rather than having it filtered through someone else; there might not be a connection to the larger research project.

The Theodore Noonan Fellowship is one program in which the foundation is allowed to fund German postdoctoral fellows, but they must be under 38 years old and a fellow must apply at an institution where a Humboldtian can serve as his or her host. The host arrangement does not have to be with someone who is intimately involved with the research for the Noonan who comes to the United States, but there has to be a Humboldtian on-site to act as host. In a corporate setting, there might not be any Humboldtians, but someone at a local university could act as a nominal host, and a Noonan fellow could then work in a research setting.

In addition, Germans are fundable as long as they are not in Germany. A German has to be out of Germany for some period, and this creates the anomalous situation in which young Germans who have done all their graduate work in the United States apply as research fellows and the Humboldt Foundation considers them Americans, whether they have American citizenship or not. The foundation is not authorized to fund Germans for careers in Germany.

Opportunities for Women

Jack Gill, of Texas Woman's University, requested additional comments on the varied opportunities for women.

Grathwol answered that a woman can identify someone in Germany who can nominate her because she has an eminent record of research and publication, or if she is at an earlier point in her career, she would be eligible for the research fellowship. The requirements are a Ph.D., international publication, and age under 40 years. Because the career patterns for women are different, the foundation makes an allowance for that 40-year level.

Grathwol taught with a woman at Washington State University who did not get her Ph.D. until she was 50 but had 20 years in community colleges before then. She was a young professional with respect to the Ph.D., but she was no longer eligible for the grant because of her age. Grathwol would like to see the foundation redefine the requirements to, say, age 40 or some number of years after the Ph.D., but that change is not likely to happen soon.

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Expanding Boundaries to Advance Medical Research—Lessons Learned at the National Institutes of Health and Ways Forward

Sharon Hrynkow
Fogarty International Center, National Institutes of Health

INTRODUCTION

Geographic boundaries no longer pose the challenge to scientists who wish to work internationally that they did even 10 years ago. International partnerships and collaborations in medical research are rising steadily and rapidly. This presentation explores models of international collaboration in medical research and training and new approaches to bringing scientists in a variety of disciplines together to address common challenges. Breaking down geographic and disciplinary borders provides new opportunities for support of research and is crucial as the chemical science community takes an increasingly global outlook. Potential subjects of joint pursuit between the chemical sciences and the life sciences are discussed, particularly as related to global health challenges and possibilities for enhancing international training and cross-training.

A LOOK AT NATIONAL INSTITUTES OF HEALTH INTERNATIONAL ACTIVITIES: THE GEOGRAPHIC LENS

As a backdrop for this discussion, a word on the international initiatives supported by the National Institutes of Health (NIH) may be useful. NIH's very roots are international. Begun as a one-room laboratory on Staten Island, New York, as the Laboratory of Hygiene, NIH had as its mission in 1887 identification of disease—cholera in particular—on ships entering port to prevent their spread to the broader population. Joseph Kinyoun, the first NIH director, had benefited from training abroad in the laboratories of the leading microbiologists of the day, Koch and Pasteur. From that humble beginning, NIH has grown into the lead agency in the U.S. government for support of biomedical and behavioral research, spanning 27 component institutes and centers and supporting a vibrant intramural research program. Today, NIH extramural and intramural activities involve substantial levels of partnership with foreign scientists.

On the extramural side, NIH supports a variety of research grants, contracts, and training programs involving foreign scientists. Research topics cover the full array of medical research pursuits, from basic research on cell signaling, protein production and degradation, imaging technologies, and underlying mechanisms of disease establishment and progression to behavioral research, disease pathogenesis, and more applied work in vaccine development and clinical research. As with support of domestic research projects, scientific rigor must be demonstrated before any award is made to a foreign scientist. Additional specific criteria are used to assess foreign applications.

Many NIH extramural programs are dedicated to advancing medical research through international cooperation. These include the programs and initiatives of the Fogarty International Center (FIC) whose mission is "to reduce disparities in global health through international cooperation." Thus, FIC works entirely on global health issues and supports partnerships between U.S. scientists and counterparts abroad as an integral component of its work. Fogarty's 30 extramural research and training programs address critical challenges and training needs related to AIDS; emerging infectious diseases, including malaria and tuberculosis; maternal and child health issues; and the human health effects posed by environmental pollution. Research programs support studies to understand the causes and consequences of being stigmatized by an illness or disease, the linkages between health of populations and economic development, and

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interventions for brain disorders and mental illness, a growing burden of disease in resource-poor nations.

Fogarty's well-established training programs are dedicated to building expertise and scientific infrastructure in resource-poor nations, whereas newer programs have been developed to provide the next generation of U.S. researchers and physicians with international training experience. Over time, the success of the programs aimed at enhancing science in poor countries has become clear. For example, the AIDS research training program, developed and supported in conjunction with multiple NIH institutes, has contributed to the development of leading AIDS researchers and policy makers in countries most heavily affected by this dreadful disease. Leaders in Uganda, Haiti, Senegal, Brazil, and Thailand, for example, have all received training through the Fogarty program and have made important contributions to reducing the spread of AIDS in their home countries. This new generation of AIDS leaders trained by Fogarty competes successfully for NIH grant support and for support on a competitive basis from other international sources, including the Global Fund to Combat AIDS, TB and Malaria; the Elizabeth Glaser Pediatric AIDS Foundation, and the Bill and Melinda Gates Foundation. Thus, this cadre of scientists and health policy makers serves as the linchpins for tackling AIDS in their home countries, and they do so with a firm foundation of scientific knowledge and understanding of evidence-based medicine.

In addition to its long-term approach, Fogarty training programs are characterized by the following:

- Close linkage between research and training efforts in individual awards
- Flexibility to allow scientific collaborators to determine what kind of training is most needed to advance critical research areas (Ph.D., master's, postdoctoral fellows, and allied health professionals)
- Networking among researchers and trainees across programs
- Long-term mentoring
- Empowerment and mutual respect
- Response to local needs and priorities
- Individual and institutional partnerships and commitments
- Support for trainees on their return home on a competitive basis

In addition to the targeted programs of the FIC, specific international programs are supported by other NIH centers and institutes. They include major programs supported by the National Institute of Allergy and Infectious Diseases aimed at development and testing of HIV intervention technologies (such as the Comprehensive International Program for Research on AIDS and HIV vaccine and prevention networks), by the National Institute of Child Health and Human Development aimed at identification of effective strategies to reduce maternal and infant morbidity and mortality (such as the Global Development Network), and by the National Heart, Lung, and Blood Institute to improve detection and treatment of hypertension (the Pan American Hypertension Initiative).

On the intramural side, the NIH visiting program supports training of about 2,500 foreign scientists per year in the NIH laboratories in Bethesda, Maryland, of a total of about 6,000 scientists. Foreign scientists are an integral component of the intramural efforts of NIH. Entry into the NIH visiting program depends on scientific matching between the laboratory chief and prospective trainee.

Over the last few years, NIH support of international partnerships and programs has risen dramatically. In FY 1996, for example, NIH spent about $157 million in support of international cooperation, including about $32 million for research projects for foreign investigators, about $40 million for collaborative research projects for U.S.-foreign teams, and about $67 million for training of foreign scientists on the NIH campus. In comparison, in FY 2002, overall spending was around $400 million, including $90 million in support of direct awards to foreign scientists, $200 million for partnerships between U.S. and foreign counterparts, and more than $90 million for training of foreign scientists in the NIH intramural program.

NATIONAL INSTITUTES OF HEALTH INTERNATIONAL PARTNERSHIPS ARE LIKELY TO CONTINUE TO EXPAND

Several conditions make it likely that international partnerships in medical research, including those supported by NIH, will continue to expand. First is the growing recognition that international scientific partnerships will lead to more rapid understanding of specific diseases or conditions and to development of interventions for critical problems, including AIDS, cancer, and other chronic diseases. The scientific community will respond with increasing numbers of applications, many of them internationally oriented. The World Health Organization (WHO) projects that the global burden of disease in 2020 will reflect an increasing burden because of noncommunicable diseases. This epidemiologic shift from the current pattern, in which communicable diseases are most important, will open new opportunities and rationale for scientists around the world to work together in new ways.

Second, ease of communication with scientists anywhere in the world fosters the development and strengthening of partnerships. The Internet and low-cost air travel will continue to be critical as scientists meet and exchange ideas by whatever means available.

Third, new partners and funding sources, including the Bill and Melinda Gates Foundation and the Civilian Research and Development Foundation, provide new opportunities for international teams of scientists to exchange information and ideas and to partner on projects of joint interest. As awareness grows that health of populations leads to wealth of populations, some governments have begun to make increased investments in health and health research, again increasing the possibilities for research support and potential partnerships.

Fourth, as a global culture of science takes hold—to include shared understanding of values on peer review, bioethics, communication of science and health advances to the public, and public involvement in the scientific enterprise—scientists around the world will find themselves on a more level playing field, which will pave the way for increased international cooperation.

WHAT IS HAPPENING ON THE INDIVIDUAL LEVEL?

U.S. scientists do not travel abroad for postdoctoral experiences, nor do U.S. senior scientists travel abroad for sabbatical experiences at the same rate as counterparts in Europe and much of the rest of the world. The numbers are stark. For example, of the 7,000 National Research Service Awards (postdoctoral support from NIH) provided in 2 successive years, 1998 and 1999, fewer than 20 people elected to take their postdoctoral fellowship outside the United States. Reasons for electing to remain in the United States during the formative period are many and varied. Some report that fear of being out of the U.S. scientific mainstream is the overriding factor. Some new programs (Fogarty-supported, those of the Human Frontier Science Program [HFSP], and the von Humboldt Foundation—see Chapter 8 of this report—and others) provide a "safety net" on return home in the form of salary support for a permanent position, at least for a couple of years. These awards are made on a competitive basis, and early experience with the programs shows that they are working. Fogarty, for example, now supports 20 postdoctoral fellows in developing-country laboratories—this after 3 years of the program. With the appropriate safety nets and with support and encouragement from mentors and department heads, more junior U.S. scientists will take advantage of opportunities to train overseas during the early stages of their careers. In 10 years, we hope to be able to tell a different story with respect to overall numbers than the one being told today.

MODELS AND CHALLENGES FOR SUCCESSFUL INTERNATIONAL PARTNERSHIPS

Lessons learned from the medical research community on international partnerships, formal and informal, may be instructive to others who are planning to engage in international research initiatives. Among the effective model programs and the features that contribute to their success are the following:

- *Human Genome Project*. This public-private project brought U.S. scientists together with foreign scientists, particularly those in the United Kingdom, to conduct the largest sequencing project ever. Among the features that allowed this venture to succeed were adequate funding, common vision, clear leadership, an agreed-upon work program, and regular communication among the partners.
- *Multilateral Initiative on Malaria (MIM*). This international initiative, launched in 1997, brought together science funding agencies from around the world with scientists from Africa, WHO, the World Bank, and others to develop an action plan in malaria research and training to implement it. Since that time, the United Kingdom, the United States (NIH), and now a Swedish consortium have led the MIM, and support for its efforts has grown. New resources for malaria have resulted. No formal agreement among partners was signed to launch and implement this initiative. African scientists' participation in all aspects of the MIM has ensured its success and relevance. In addition, the MIM adopted a transparent operating mechanism and voting mechanism to engage all stakeholders in identifying future MIM lead agencies.
- *Fogarty International Center research training programs*. As described above, these programs are flexible, meet local needs, are scientifically rooted and rigorous, and are long term. Fogarty works in partnership with many other NIH centers and institutes, with the Centers for Disease Control and Prevention and other Department of Health and Human Services agencies, with foreign science funding agencies, and with private groups to develop and support its programs, which work through U.S. universities and counterparts abroad. The result is enhanced scientific infrastructure and leadership in low- and middle-income nations that translates into evidence-based decision making and improvements in individual, family, and community health.

CHALLENGES AND REALITIES IN WORKING INTERNATIONALLY

An array of challenges must be considered before one enters into negotiations or implementation of a joint international project or effort. All are potentially surmountable with planning and with good information. Some of the major challenges are described below.

Exchange of scientists across borders is increasingly difficult. In the post-9/11 era and with heightened security, travel restrictions for foreign scientists and increased security measures require additional planning and time in development of exchanges and partnerships. Delays in receiving appropriate visa documentation to enter the United States can be substantial. In addition, as foreign scientists working in the United States travel abroad for home visits or to attend scientific conferences, anecdotal data show that delays in reentering the United States can also be substantial. As new visa systems are put in place, U.S. scientists and institutions and their counterparts abroad must become familiar with new travel requirements and be prepared to work within existing frameworks to advance international efforts.

Missions and practices vary across agencies. Working in partnership with other institutions, domestic or foreign, may pose challenges if missions and operational practices differ seriously. Gaining an appreciation of what is likely to be supported by other agencies and practical ways for sharing support for a given project is important early in the planning stages. Not all successful partnerships require transfer of funds from one agency to another, but it is critical to determine early how the partners will support the project and leverage each other's resources.

Expectations as to level of formality of international partnerships may vary. NIH is party to more than 90 formal agreements—some at the government-to-government level as part of broader science and technology agreements, others between NIH or component institutes and centers and counterparts abroad. Still other partnerships occur through informal mechanisms in which no agreement has been signed. Understanding the benefits and costs of both formal and informal agreements is crucial in determining whether a signed agreement would most effectively advance a particular research objective or whether no formal agreement is needed.

EXPANDING BOUNDARIES: THE DISCIPLINARY LENS

Many achievements in medical research can be traced back to advances in chemistry, physics, mathematics, and other disciplines. Whether it is the development of microscopic methods whose application has yielded enormous insight into normal functioning and disease states or the development of rapid gene-sequencing technologies to identify new genes involved in disease or protection from disease, the underpinnings have involved a mix of expertise and the ultimate benefits to human health have been enormous. The 2004 Nobel Prizes in Chemistry and Physiology or Medicine, awarded to long-standing NIH grantees, are indicative of the fluidity between the physical sciences and the life sciences. The major advances recognized by these awards–for enhanced understanding of the structure of ion channels and for the development of high-resolution imaging technologies—have already led to applications in health care and medical research.

Opportunities are on the horizon for even stronger cooperation among scientists across disciplines. With recent advances in genome technology, imaging technology, and other fields, opportunities to propel health research forward through strong ties among disciplines have perhaps never been greater. To bring scientists together in new ways for the improvement of human health, the NIH Director announced (September 2003) a new strategy to accelerate medical research progress, the NIH Roadmap for Medical Research. Achieving progress under this roadmap will require strong participation by the chemical sciences community.

One of the chief aims of the roadmap is to improve the understanding of complex biologic systems. Among the tools to be produced to assist in this effort will be libraries of molecules that can serve as probes of biologic networks, innovative tools for capturing real-time images of molecular and cellular events, improved computational infrastructure for biomedical research, and nanotechnology devices capable of viewing and interacting with basic life processes.

A second emphasis of the roadmap is on encouraging scientists to move beyond traditional disciplinary borders to participate in novel interdisciplinary scientific projects. Through the new teams, involving public-private partnerships as needed, it is expected that more high-risk, high-payoff projects may be pursued. More information on how the roadmap initiative was developed and announcements on roadmap-related requests for applications are available at *www.nihroadmap.nih.gov*.

FILLING THE GAPS: CHALLENGES AND REALITIES

National Science Foundation indicators show that foreign-born scientists make up a substantial proportion of those working in all fields of science in the United States today. This trend is expected to continue in the coming years. As the United States works to strengthen the science pipeline domestically through programs that engage American children and those entering college in science, the reality will remain that key needs will continue to be met through foreign-born scientists. As we look to the future and consider important gaps that that must be adequately filled to advance medical research, including synthetic organic chemistry and radiochemistry, several trends should be kept in mind.

There is an increased competition for highly qualified personnel, particularly at the postdoctoral level. As other Organisation for Economic Co-operation and Development governments develop attractive research environments, anecdotal evidence suggests that European postdoctoral fellows, for example, may opt to train in Europe or Australia rather than in the United States. Several countries now have major repatriation programs to attract young scientists who have traveled abroad for postdoctoral training to come back. Attractive recruitment packages are contributing to increasing repatriation rates in some countries.

There are many favorable effects of this approach on a long-term basis. The short-term effects must be addressed.

As political conditions improve, living standards rise, and scientific infrastructures are strengthened in some countries, junior scientists may opt to remain in their home countries rather than travel abroad during their formative years.

BRINGING THE TWO LENSES TOGETHER: BIFOCALS FOR HEALTH

As the chemical sciences community works to expand its global outlook and outreach, taking into account crossboundary and cross-disciplinary considerations will be useful. Following are perspectives, practical approaches, and questions that could be considered.

Taking a Global Health Approach

Placing international cooperation on a backdrop of global health needs and opportunities adds a dimension to the discussion that may not previously have been considered. As junior scientists set out on a career path, engaging them to tackle issues of global health import should be presented as a worthy endeavor. There are high-profile endeavors and funding streams to assist in engaging the best and brightest scientists on the global health agenda. For example, the Bill and Melinda Gates Foundation and the Foundation for the NIH announced on October 17 the first 14 "grand challenges in global health" as part of a $200 million effort to solve critical challenges that stymie efforts to improve global health. Among the challenges are several directly relevant to the chemical sciences community, including preparing vaccines that do not require refrigeration, development of needle-free delivery systems for vaccines, and development of a chemical strategy to deplete or incapacitate a disease-transmitting insect population. More information on the challenges and application procedures is available at *www.grandchallengesgh.org*. As noted previously, the programs of the Fogarty International Center *(www.fic.nih.gov)* provide additional opportunities for U.S. scientists to work in cooperation with foreign counterparts on issues of global health import.

Raising Awareness in the Global Scientific Community About the National Institutes of Health Roadmap Initiative

Individual initiatives under the broad umbrella of the NIH roadmap should be reviewed carefully to determine the extent to which foreign scientists may participate. Raising awareness priorities among interdisciplinary efforts at NIH may lead other agencies to develop similar programs and approaches.

Increasing Awareness in the Chemical Science Community About National Institutes of Health Mechanisms of Support

In addition to the roadmap initiative, NIH, primarily through its National Institute of General Medical Sciences, supports ongoing programs in research and training for chemists working in medical research. Other medical research funding agencies, including the HFSP, support interdisciplinary efforts that are relevant to the chemical sciences community.

Sharing Lessons Learned

Development of international partnerships between chemical scientists and their institutions (for both research and training purposes) can be informed by lessons learned from both formal and informal efforts involving medical researchers. Many of the principles and lessons learned by the medical research community are directly applicable to other scientific communities.

Preparing the Next Generation—Mentoring Is Key

Encouraging junior scientists to expand disciplinary boundaries and geographic boundaries early in their careers will help to develop the next generation of creative, knowledgeable, and broad thinkers. There is a critical role for mentors in achieving this broad objective and a need for funding agencies to advertise more effectively the programs and opportunities that support junior scientists in venturing beyond geographic and disciplinary borders during formative stages. New kinds of training opportunities should be considered, including short courses in new fields of endeavor and summer programs. Programs involving junior scientists in paired institutions—one in the United States, one abroad—could be considered. New models to identify and support mentors who have international and multidisciplinary experience could be pursued.

Meeting Needs Today and Tomorrow

While efforts continue to strengthen the pipeline of U.S. citizens into the chemical sciences, foreign-born scientists will continue to play an important role in achieving short-term and medium-term objectives. Are existing mechanisms appropriate to meet needs in supporting critical fields, including synthetic organic chemistry and radiochemistry? Could new models be developed to meet critical needs without contributing to brain drain in low- and middle-income nations?

Where Are the Women?

Creating a globally aware workforce will require that we recognize and address issues of underrepresentation, including gender representation at senior levels in academe. At a recent colloquium on "Career Paths for Women in the Health Sciences: A Global Perspective," sponsored jointly by FIC, the Office of Research on Women's Health (ORWH), and the National Institute of Environmental Health Sciences, NIH Director Zerhouni noted that it will increasingly be teams of scientists that propel medical research forward. He called for a change in mind-set to incorporate team approaches as we work to address critical health challenges and encouraged colloquium participants to identify the most effective means to include the best and brightest, including women, in strategies to tackle these challenges. As FIC and the ORWH move ahead with this agenda, collaboration with counterparts in the chemical sciences community is welcomed and encouraged.

DISCUSSION

Diverse topics were taken up after Sharon Hrynkow's presentation, including NIH funding of international research, global health, and diversity in science.

Foreign Scientists on National Institutes of Health Study Panels

David Budil, of Northeastern University, asked to what extent the increase in funding of overseas investigators that Hrynkow documented is mirrored by increased participation of foreign scientists on NIH study panels.

Hrynkow responded that to her knowledge there has been no dramatic increase in foreign participation on study sections over the years. A number of Canadian investigators participate on study sections. The most likely contributors to the rise in foreign funding are scientific opportunities, as recognized by both U.S. and foreign scientists, and mechanisms that foster international collaboration. FIC supports some of the mechanisms, such as the small-grant award that Hrynkow mentioned, and these programs are increasingly advertised to wider audiences. For example, FIC and other components of NIH take advantage of major scientific conferences to raise awareness of international opportunities. Fogarty also supports proposal-writing sessions and provides information about how to access and understand the NIH grant process.

National Institutes of Health Funding of International Research

Alvin Kwiram, of the University of Washington, first asked about the figures on external funding for Canada.

Hrynkow stated that Canada receives around $60 million in NIH support each year. Canadian investigators are the most successful among foreign scientists in receiving NIH awards, including direct awards to Canadian investigators and support of U.S.-Canadian joint research projects.

Kwiram then asked whether NIH "catches flak" from Congress about sending funds overseas and how NIH justifies it. Is the program for joint funding of U.S. scientists working with international scientists a separate program or the regular R01 program?

Hrynkow responded that NIH justifies spending abroad on the basis of good science and scientific opportunity or training efforts. The Fogarty mission is to tackle global health challenges, so it must work in partnership with its colleagues abroad. To make strides in research in such fields as AIDS and emerging infectious diseases, FIC must work with partners abroad. The benefits accrue to both the United States and the global community. The particular mechanism for joint funding is called "foreign components of domestic awards." U.S. scientists may partner with foreign scientists on an NIH grant application. Every component of NIH may use this mechanism to support joint international projects.

Kwiram said that it would be constructive if the participants in the workshop had a mechanism for publicizing the importance of international exchanges and study because there is substantial resistance in institutions and among administrators to spending money this way. Furthermore, if someone published op-ed pieces in various professional magazines, such as *Science*, it would help to convince some of the leadership that international experiences are important. He challenged the group to think about ways to give greater visibility to the issues and present more compelling arguments to make the chemical community be more receptive to these kinds of activities.

Global Health

George Lorimer, of the University of Maryland, inquired about global health and how NIH goes about capturing the enormous intellectual and scientific power that is represented by the U.S. pharmaceutical industry, bearing in mind that many of the health challenges facing the global community involve diseases. Most of the diseases are infectious diseases, which are certainly not being worked on by Western pharmaceutical companies, largely because they affect people who do not have the money to pay for the research involved. In southern Africa for example, Western pharmaceutical companies are reluctant to lower the prices for their drugs even though large parts of sub-Saharan Africa are infected with AIDS, for example. This is enormously damaging for U.S. public relations and global relations. He wondered whether Hrynkow and colleagues are giving any thought to how this politically and scientifically important aspect could be overcome to reflect better on this nation as a whole and its supposed humanitarian behavior.

Hrynkow confirmed that they are looking at that exact issue because as they look at global health and how to improve the health of people around the world, global public good comes into play. Is it the responsibility of NIH, of academic institutions, and of the private sector to see that drugs are developed and moved to people who need them most in poor countries? Market forces, the investments made by pharmaceutical companies to bring drugs to market, and the enormous needs are all being considered. A number of plans and public-private partnerships have been established to accomplish some of the work, and NIH follows them closely.

Diversity in Science

James Martin, of North Carolina State University, directed some comments to the whole meeting about the statistic Hrynkow gave, that about 2,500 of the 6,000 researchers in NIH laboratories in Bethesda, Maryland were foreign. Despite being an extreme advocate of international exchange, Martin asked where the exchange ends. He does not know of any other nation in the world that would accept that statistic in a national laboratory.

He mentioned a comment that he had heard made on more than one occasion by department heads that foreign students are smarter than American students. He has routinely felt this pressure—that because he is domestic, he is not quite as smart as internationals. If this happens to a white American male, what happens to a woman or an African American? He suspected that there were more foreign-born persons in the workshop than women and definitely more than African Americans.

If the participants of the workshop believe in global education and globalization of the workforce, they have to look at their own resources, and Martin does not think that is happening. The statistic mentioned is disturbing, not because of the number but because of the lack of exchange. He believes that we need exchange and we have to develop our policies so that there will be exchange if we are going to make progress.

Hrynkow said the 2,500 figure is based on scientific matching between prospective postdoctoral fellows and laboratory chiefs. People are accepted in laboratories on the basis of their scientific expertise, the match, and the interest. The system is open, and all are encouraged to try to find appropriate laboratories in which to train.

She agreed wholeheartedly that we should do more to encourage and support Americans to go abroad for training and sabbaticals. As she mentioned, she was a postdoctoral fellow in Norway for almost 3 years. It was formative not only professionally but also personally. She used every opportunity to speak to postdoctoral fellows about the value of going abroad early in one's career. She challenged Martin and others in academic settings to have a role as mentors to encourage young scientists to expand their horizons and professional careers beyond the United States.

Martin agreed but was also getting the impression that countless Americans would love to recruit Asians because they are smart. Who is recruiting Americans because they are smart? There is a cultural question, and it is not completely different from getting women and minority groups members into science. We have to get Americans into science.

Hrynkow supported the need for diversity but pointed out that the best minds are recruited and the best grant applications supported. Good science must be the premise.

Inspiring the Next Generation of Global Scientists

Robert Grathwol, of the Alexander von Humboldt Foundation, mentioned one consequence of the German Chancellor Scholarship Program that may be applicable elsewhere. The German Chancellor Scholarship Program has an alumni web site on which people have profiled their own experience with the program. One of them makes it clear that he is prepared to mentor interested people interested in applying; as a result, there is a flood of applications in the environmental field because he is right there saying that he is prepared to talk about the program. Grathwol stated that everyone at the workshop could create a profile of his or her experience and put it on a web site to promote interest.

Hrynkow declared that she looks forward to this and agreed that people and their stories are what capture other people's interest. Compelling personal stories have a big role to play in inspiring the next generation of global scientists.

Appendix A

Workshop Participants

Paul Anastas, Green Chemistry Institute (formerly of the Office of Science and Technology Policy), Washington, DC
Karin Bartels, Degussa Corporation, Parsippany, NJ
Edwin D. Becker, National Institutes of Health, Bethesda, MD
Mary T. Berry, University of South Dakota, Vermillion, SD
David E. Budil, Northeastern University, Boston, MA
Steven Buelow, Los Alamos National Laboratory, Los Alamos, NM
Donald M. Burland, National Science Foundation, Arlington, VA
Lynda T. Carlson, National Science Foundation, Arlington, VA
Thomas W. Chapman, National Science Foundation, Arlington, VA
Sue B. Clark, Washington State University, Pullman, WA
Michael J. Clarke, National Science Foundation, Arlington, VA
Thomas M. Connelly, DuPont Company, Wilmington, DE
David DiBiasio, Worchester Polytechnic Institute, Worchester, MA
Michael P. Doyle, University of Maryland, College Park, MD
Miles P. Drake, Air Products and Chemicals, Inc., Allentown, PA
Art Ellis, National Science Foundation, Arlington, VA
Mostafa A. El-Sayed, Georgia Institute of Technology, Atlanta, GA
B.J. Evans, University of Michigan (retired), Ann Arbor, MI
Christos Georgakis, Polytechnic University, Brooklyn, NY
Jack T. Gill, Texas Woman's University, Denton, TX
Robert P. Grathwol, Alexander von Humboldt Foundation, Washington, DC
Esin Gulari, National Science Foundation, Arlington, VA
Ned D. Heindel, Lehigh University, Bethlehem, PA
D. Michael Heinekey, University of Washington, Seattle, WA
Peter H. Henderson, The National Academies, Washington, DC
Susan H. Hixson, National Science Foundation, Arlington, VA
Paul B. Hopkins, University of Washington, Seattle, WA
Sharon H. Hrynkow, National Institutes of Health, Bethesda, MD
Bruce B. Jablonski, Shell Chemical LP, Houston, TX
Wyn Jennings, National Science Foundation, Arlington, VA
Peter Kilpatrick, North Carolina State University, Raleigh, NC
William F. Koch, National Institute of Standards and Technology, Gaithersburg, MD
Alvin L. Kwiram, University of Washington, Seattle, WA
Marshall M. Lih, National Science Foundation, Arlington, VA
George Lorimer, University of Maryland, College Park, MD
John M. Malin, American Chemical Society, Washington, DC
James D. Martin, North Carolina State University, Raleigh, NC
Bradley D. Miller, American Chemical Society, Washington, DC
Tyrone D. Mitchell, National Science Foundation, Arlington, VA
Francisco Moris, National Science Foundation, Arlington, VA

Susan Morrissey, Chemical & Engineering News, Washington, DC
Hemant P. Pendse, University of Maine, Orono, ME
Robert Louis Powell III, University of California, Davis, CA
Douglas J. Raber, GreenPoint Science, Washington, DC
Michael E. Rogers, National Institutes of Health, Bethesda, MD
Douglas Selman, ExxonMobil, Baytown, TX
C. Frank Shaw III, Illinois State University, Normal, IL
Philip B. Shevlin, National Science Foundation, Arlington, VA
Matthew J. Slaughter, Dartmouth College, Hanover, NH
Mark A. Smith, University of Arizona, Tucson, AZ
Guangyu Sun, National Institutes of Health, Bethesda, MD
Tony Teolis, National Science Foundation, Arlington, VA
Matthew V. Tirrell, University of California, Santa Barbara, CA
Larry H. Weber, National Science Foundation, Arlington, VA
Rosemarie D. Wesson, National Science Foundation, Arlington, VA
Frank Wodarczyk, National Science Foundation, Arlington, VA

Appendix B

Biographical Sketches of Workshop Speakers

Karin Bartels is director of the Intellectual Property Management Department of Degussa Corporation. She has worked for Degussa both in Germany and in the United States for 19 years in various functions, including R&D, applied technology, corporate business planning, and new business development. In her last position as director for corporate innovation management at Degussa's U.S. subsidiary, she was responsible for collaborations with U.S. universities. Bartels is a member of the Council for Chemical Research where she served on its governing board, is a member of the Industrial Research Institute and is active in its external directors technology network, and represents Degussa on the American Chemical Society's Corporation Associates. She holds B.S. and M.S. degrees in chemistry, holds a Ph.D. in organic chemistry from the Technical University of Braunschweig (Germany), and was a postdoctoral fellow at the University of California, Riverside.

Thomas M. Connelly, Jr., is senior vice president and chief science and technology officer, DuPont Company. He joined DuPont in 1977 as a research engineer and has served in a variety of research and plant technical leadership roles in the United States and overseas. Before assuming his current position in September 2000, he held leadership roles in the company's engineering polymers business in Europe and Asia, served as business director in advanced fiber systems, and led the fluoroproducts business unit. He received his bachelor's degree in chemical engineering and economics from Princeton University and his doctorate in chemical engineering from the University of Cambridge (1977).

Miles P. Drake joined Air Products and Chemicals, Inc., in 1986 as technology manager, electronics, for the company's European applied R&D group. He was named European technology director in 1986 and in 1990 relocated to the United States, where he was named director, advanced technology, for the global applications development group. In 1994, Drake was appointed director of the Corporate Science and Technology Center; and in 1998, he was named director, gases and equipment group technology. He assumed his current position in February 2001. He is responsible for all technology companywide. Drake received a B.S. in chemistry from Cambridge University in 1971 and a Ph.D. in surface and colloid chemistry from the University of Bristol in 1975. He is chairman-elect of the Industrial Research Institute, a fellow of the Royal Society of Chemistry, a member of the Advisory Board of the Materials Research Center at Santa Barbara, California, and a member of the American Institute of Chemical Engineers.

Mostafa A. El-Sayed received his B.Sc. from Ain Shams University, Cairo, Egypt, and his Ph.D. from Florida State University. He was appointed to the faculty of the University of California, Los Angeles, in 1961 and in 1994 was named the Julius Brown Chair, Regents' Professor and Director of the Laser Dynamics Laboratory at the School of Chemistry and Biochemistry of the Georgia Institute of Technology. His research involves ultrafast dynamics in molecules, in amorphous and crystalline solid material in the bulk and on the nanometer scale, and in photobiological systems. His studies involve ultrafast time-resolved laser techniques. El-Sayed has received numerous honors and awards and is an elected member of the U.S. National Academy of Sciences and the Third World Academy of Science and an elected fellow of the American Academy of Arts and Sciences, the American Physical Society, and the American Association for the Advancement of Science. From 1980 to 2004, El-Sayed was the editor-in-chief of the *Journal of Physical Chemistry A* and *B*.

Robert P. Grathwol has more than 30 years of experience as a professional historian and publishing scholar, beginning as a university professor and shifting after more than two decades to become an independent researcher and historical consultant. In 1988, he helped to found R & D Associates, a partnership providing historical research and services in organizational development. Since January 1998, Grathwol has served as director of the U.S. Liaison Office of the Alexander von Humboldt Foundation. He has a B.A. from Providence College, an advanced degree (Diplôme Supérieur) from the University of Strasbourg (France), and a Ph.D. from the University of Chicago. He held faculty appointments at several institutions, most recently at Washington State University (1979-1990). Grathwol studied in France from 1961 to 1963 on a Fulbright fellowship and conducted research in Germany as a Humboldt research fellow in 1973-1975. He is fluent in German, French, and Italian.

Sharon H. Hrynkow is the deputy director of the Fogarty International Center (FIC) at the National Institutes of Health (NIH). FIC's more than 20 programs and initiatives are aimed at reducing disparities in health status between rich and poor countries, and Fogarty is the focal point for international activities at NIH. Among Hrynkow's specific fields of focus at FIC are efforts to combat "brain drain" among junior scientists from developing nations who are trained in the United States and initiatives to address gender issues related to global health. A native of Rhode Island, Hrynkow received her Ph.D. in neuroscience from the University of Connecticut. After completing postdoctoral training in brain development at the University of Oslo, she became a science officer at the U.S. Department of State, a position she held for roughly three years. She worked with interagency partners, State Department leadership, nongovernmental organizations, and business leaders to produce the first U.S. International Strategy on HIV/AIDS. Hrynkow was elected to the Council of Foreign Relations in 1996.

Alvin L. Kwiram became vice provost at the University of Washington on January 1, 1987, and vice provost for research in 1990. In 2000, he stepped down as vice provost and returned to the Chemistry Department as professor of chemistry; he has taught since 1970. He serves as executive director of a new National Science Foundation Science and Technology Center in photonics and optoelectronics. His research is in physical chemistry, emphasizing the development of novel magnetic resonance techniques designed to probe the electronic structure of molecular systems in the solid state. Kwiram has received numerous honors and awards and is a fellow of the American Physical Society and the American Association for the Advancement of Science, a member of the Graduate Education Advisory Board of the American Chemical Society (ACS), and a member of the Executive Committee of the ACS Division of Physical Chemistry. He is the U.S. liaison for the Worldwide University Network, a consortium of international research universities. Kwiram received his B.A. in physics and B.S. in chemistry from Walla Walla College in 1958, and he received a Ph.D. in chemistry from the California Institute of Technology in 1962.

Matthew J. Slaughter is associate professor of business administration at the Tuck School of Business at Dartmouth College. He is also a research associate at the National Bureau of Economic Research, a visiting fellow at the Institute for International Economics, and a term member of the Council on Foreign Relations. Slaughter's expertise is in the economics and politics of globalization. Much of his recent work has focused on the global operations of multinational firms, in particular how knowledge is created and shared in these firms and how their cross-border production arrangements are structured. Slaughter joined the Tuck faculty in 2002. Before that, since 1994 he had been an assistant and associate professor of economics at Dartmouth, where in 2001 he received the school-wide John M. Manley Huntington Teaching Award. Slaughter received his bachelor's degree summa cum laude and Phi Beta Kappa from the University of Notre Dame in 1990 and his doctorate from the Massachusetts Institute of Technology in 1994.

Matthew V. Tirrell is dean of the College of Engineering at the University of California, Santa Barbara. He received his undergraduate education in chemical engineering at Northwestern University and his Ph.D. in 1977 in polymer science from the University of Massachusetts. From 1977 to 1999, he was on the faculty of chemical engineering and materials science at the University of Minnesota, and he served as head of that department from 1995 to 1999. His research has been in polymer surface properties, including adsorption, adhesion, surface treatment, friction, lubrication, and biocompatibility. He is coauthor of about 250 papers and one book and has supervised about 60 Ph.D. students. Tirrell has received numerous prestigious awards and is a member of the National Academy of Engineering, a fellow of the American Institute of Medical and Biological Engineers, and a fellow of the American Association for the Advancement of Science. In 2003, he concluded more than two years of service as co-chair of the steering committee for the National Research Council report *Beyond the Molecular Frontier: Challenges for Chemistry and Chemical Engineering*, published in 2003 by the National Academies Press.

Appendix C

Origin of and Information on the Chemical Sciences Roundtable

In April 1994, the American Chemical Society (ACS) held an Interactive Presidential Colloquium entitled "Shaping the Future: The Chemical Research Environment in the Next Century."[1] The report from this colloquium identified several objectives, including the need to ensure communication on key issues among government, industry, and university representatives. The rapidly changing environment in the United States for science and technology has created a number of stresses on the chemical enterprise. The stresses are particularly important with regard to the chemical industry, which is a major segment of U.S. industry; makes a strong, positive contribution to the U.S. balance of trade; and provides major employment opportunities for a technical workforce. A neutral and credible forum for communication among all segments of the enterprise could enhance the future well-being of chemical science and technology.

After the report was issued, a formal request for such a roundtable activity was transmitted to Dr. Bruce M. Alberts, chairman of the National Research Council (NRC), by the Federal Interagency Chemistry Representatives, an informal organization of representatives from the various federal agencies that support chemical research. As part of the NRC, the Board on Chemical Sciences and Technology (BCST) can provide an intellectual focus on issues and fundamentals of science and technology across the broad fields of chemistry and chemical engineering. In the winter of 1996, Dr. Alberts asked BCST to establish the Chemical Sciences Roundtable to provide a mechanism for initiating and maintaining the dialogue envisioned in the ACS report.

The mission of the Chemical Sciences Roundtable is to provide a science-oriented, apolitical forum to enhance understanding of the critical issues in chemical science and technology affecting the government, industrial, and academic sectors. To support this mission, the Chemical Sciences Roundtable will do the following:

- Identify topics of importance to the chemical science and technology community by holding periodic discussions and presentations, and gathering input from the broadest possible set of constituencies involved in chemical science and technology.
- Organize workshops and symposia and publish reports on topics important to the continuing health and advancement of chemical science and technology.
- Disseminate information and knowledge gained in the workshops and reports to the chemical science and technology community through discussions with, presentations to, and engagement of other forums and organizations.
- Bring topics deserving further, in-depth study to the attention of the NRC's Board on Chemical Sciences and Technology. The roundtable itself will not attempt to resolve the issues and problems that it identifies—it will make no recommendations, nor provide any specific guidance. Rather, the goal of the roundtable is to ensure a full and meaningful discussion of the identified topics so that the participants in the workshops and the community as a whole can determine the best courses of action.

[1] *Shaping the Future: The Chemical Research Environment in the Next Century,* American Chemical Society Report from the Interactive Presidential Colloquium, April 7-9, 1994, Washington, D.C.