A lecture in the Phillips Petroleum Company
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Striking a Balance in Teaching Today's Students to Solve Tomorrow's Problems

All of us have been part of discussions about what should be taught and how material should be presented in chemical engineering courses. For example, the coverage of transport phenomena and associated transport operations always stimulates much discussion. Some say that is better to cover the microscopic perspective first, and then show how models derived from shell balances and appropriate expressions for momentum, heat, and mass transfer can be used to describe the macroscopic behavior of a well-defined system. Others say it is better to discuss how a specific operation works, and then relate that operation to a model that is sufficient to design or rate the given equipment. Only then is the model linked to microscopic phenomena.

I think this is an interesting debate, but readily concede that either of the approaches can be the basis of perfectly fine courses resulting in superbly educated students. Therefore, instead of talking about how material should be taught, I want us to use this time to reflect on what we should teach if Chemical Engineering is to be a discipline of the future. My concern, indeed what should be the concern of all of us, is the intellectual prowess and related abilities that come from completion of a chemical engineering curriculum. Put simply, I believe it imperative that we set and then meet the expectations industries, societies, and governments have of us (*i.e.*, of our discipline). As chemical engineering educators, it is not our duty to preserve the historical domain of our discipline, but to expand it. The issues now are where our discipline is headed and what we can do to be sure that current graduates are prepared for such opportunities.

To highlight this point, consider the statistics from the annual survey of careers entered by chemical engineering graduates.[1] They show that recipients of undergraduate degrees predominantly are entering fields traditional to the discipline: roughly 42 to 45% in chemicals, energy, and engineering services. However, the percentage joining electronics companies has more than doubled from 7% to 16% over the last three years. Interestingly, biotechnology and related pharmaceutical industries have hardly changed, remaining at about 5 to 7% of the graduates. One of the surprises in the numbers is that food and consumer industries have steadily employed, over a number of years, about 10 to 12% of those completing undergraduate degrees in Chemical Engineering. I suspect the role played by chemical engineering graduates in such industries is often overlooked.

Put simply, the large majority of those receiving undergraduate degrees in Chemical Engineering enter the workforce with an organization seeking talent that can be applied in the manufacture of goods: commodity and specialty chemicals, pharmaceuticals, pulp and paper, textiles, oil, gas, microelectronics, plastics, and soaps, detergents and other consumer products.

Consider now the employment of those completing M.S. or Ph.D. degrees in Chemical Engineering. Again, chemicals, energy, and engineering services attracted about 40% of these graduates. However, electronics was the choice of 28% of M.S. and 19% of Ph.D. graduates, doubling in the three-year period for M.S. graduates and tripling for the Ph.D.s. Biotechnology and related industries attracted about 15% of the graduates, more than twice the undergraduate percentage, probably reflecting the growing importance of biology in the manufacturing sector. On the other hand, it is interesting that the percentage of M.S. and Ph.D. graduates entering the food and consumer industries was half that for B.S. graduates.

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[1] http://www.aiche.org/careerservices/trends/placement.htm

What do these numbers tell us? For one thing, they confirm that the breadth of opportunity for chemical engineering graduates is as great as we had thought. They also validate predictions of expansion into many of these areas forecast in the Amundsen Report of more than a decade ago.[2]

My concern with these numbers, however, is that the changes they reflect may be occurring without active involvement of chemical engineering educators. For example, our courses tend to emphasize continuous, steady-state processing of gases and liquids, while many of the growing industrial sectors rely on batch operations, or manufacture products in discrete units, or produce or handle solids. So, that being said, we have the question: Why do our graduates remain highly sought?

I believe it is because our students develop a skill that allows them to transcend the nature of specific problems they face in their careers. That skill is to break a problem into parts, to identify boundary conditions and the applicable fundamental principles, to recognize the key elements affecting the solution, to apply the most appropriate methodologies in obtaining an answer or answers, to visualize how the solution may be impacted by poorly controlled variables, and to do all of this with an appreciation of the entire system in which the problem was formulated. This perspective is supported by results of a survey Felder[3] conducted of a special group of students. They reported that problem-solving and time-management skills were the two most important aspects of their education, and that they had acquired these skills by working on so many long and difficult assignments. These students also believed they had derived a variety of benefits from working in teams on homework. We will reflect on the teamwork issue later in our discussion.

Hearing the above might give the listener an impression that I think the material actually taught in chemical engineering curricula is irrelevant. Furthermore, some may argue that since our current graduates already are being sought by new and growing industrial sectors, we need not concern ourselves with them in formulating our curricula.

I believe such thinking is detrimental to the future of our discipline. The overwhelming majority of chemical engineering graduates will use specific principles taught during their studies. An understanding of and confidence in those principles will give graduates the ability to produce results immediately in their new employment. If we do not provide our students with the edge that comes from such education, either other disciplines will, or new disciplines will be born to meet such needs. In that regard, we must do a better job of teaching our students the relevance of their education, and I offer the following challenge: the next time you have a chance to meet with a group of graduating students, ask them why their future employers have offered them the salaries far in excess of what they would earn without their expected degree. My experience tells me that a few will think of the salaries as rewards for having completed such a demanding curriculum, while others will venture that it has something to do with their being certified as chemical engineering graduates. I would be astounded if any gave the real reason: our graduates are expected to *earn* their salaries; in other words, their activities must return some multiple of what they are paid to their employers. And so, it is important for new graduates to produce ... and the sooner the better.

Establishing New Curricula

In some sense, it is unfortunate that safety nets that existed in curricula of earlier times have been removed. If you would allow me to engage in a little hyperbole, those earlier prescribed sets of courses sought to cover every topic of potential importance. Most of us now

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[2] *Frontiers in Chemical Engineering: Research Needs and Opportunities,* National Academy Press, Washington, D. C., 1988.

[3] R. M. Felder, "The Alumni Speak," *Chemical Engineering Education,* 34(3), 238–239 (2000).

recognize that such curricula are too expensive, and many universities have imposed severe constraints on the total number of hours permitted for a degree. We must deal with these circumstances creatively. In the discussions leading to a recently revised chemical engineering curriculum at Georgia Tech, for example, we sought to focus efforts on what we believed to be *essential,* not just important. The results included reductions in credits in a number of areas, including courses from Chemical Engineering and Chemistry, but they also included *an increase in the responsibility placed on students to choose wisely among an expanded list of electives.* It was clear in our discussions that the faculty also must work harder to integrate material, at the very least among chemical engineering courses. It is inefficient and, worse, pedagogically flawed to separate teaching thermodynamics from separations and computer-aided computations from almost everything else in the curriculum.

Integrating material is not easy, especially in a large program with a large fraction of the students participating in co-op activities. For that reason, integration has to begin with faculty members talking to their colleagues, debating the relative merits of coverage of this or that topic, and reaching consensus on the *essentials.* This should be an exciting prospect in which faculties become engaged again in all aspects of curricula. More experienced faculty members can learn new techniques from their junior colleagues and gain perspectives ourside of their scope of experiences. At the same time, junior faculty members can benefit from the experiences, and in some cases wisdom, their senior colleagues have gained from interacting with generations of students. This may sound utopian, but it's very likely something we would all appreciate: intense, learned discussions with respectful colleagues.

Essentials In A Chemical Engineering Curriculum

In 1915, A. D. Little formulated the concept of unit operations, saying "Any chemical process, on whatever scale conducted, may be resolved into a coordinate series of what may be termed 'unit operations,' as pulverizing, dyeing, roasting, crystallizing, filtering, evaporation, electrolyzing, and so on. The number of these basic unit operations is not large and relatively few of them are involved in any particular process. The complexity of chemical engineering results from the variety of conditions as to temperature, pressure, etc., under which the unit operations must be carried out in different processes, and from the limitations as to material of construction and design of apparatus imposed by the physical and chemical character of the reacting substances."[4] Why reflect on this? It is to highlight the need for continued testing of what is important in our instruction; pulverizing may have been central to the discipline in 1915, but it is not now. Instead, our unit operations include chemical vapor deposition, crystal growth, perhaps genetic engineering, chromatography, and a long list of new separation techniques.

We all recognize the essential nature of thermodynamics, and I think almost all chemical engineering curricula include some form of transport phenomena, unit operations, reaction engineering, and process design, so I will not directly address those topics here. Instead, I would like to provide a rationale for a few often-overlooked courses and leaven this with some topics that may be spread across several courses.

Chemical Process Principles. It might reasonably be assumed that this is one of the obvious essentials in a chemical engineering curriculum, and therefore doesn't

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[4] http://www.pafko.com/history/ citation of T. S. Reynolds, "75 Years of Progress; A History of the American Institute of Chemical Engineers 1908-1983. American Institute of Chemical Engineers, New York, 1983.

belong in this list. But some curricula do not include such a course, and others may not take full advantage of what it has to offer. In my opinion, it is where our students begin their development of the problem-solving skills mentioned earlier. Moreover, it is here that illustrations can bring in fields such as microelectronics processing, bioprocess technology, environmental issues, and advanced materials. Done properly, this course should demonstrate the breadth of chemical engineering early in students' studies, rather than having it eek out as an afterthought.

The title of this section corresponds to that of one of the early textbooks used in the course,[5] and appropriately describes the breadth of material found in current courses. Indeed, when Rich Felder and I were looking for a title for the text we hoped would match the excellence of that early book and its dominant successor,[6] we chose to include those very words.[7] Furthermore, Felder and I designed our book with the determination to link processes and fundamental principles explicitly: first, by trying to put almost every problem in context (there are few "A goes to B" examples); second, by emphasizing the properties of different compounds (which make them unique and give meaning to the chemical nature of materials being processed); and, third, by integrating unit operations, unit processes, and complete facilities in a series of realistic case studies.

In the Felder survey cited earlier (footnote 3), a course covering mass and energy balances was the only one cited as being important by more than 2 of 50 respondents. I truly believe that this course provides the foundation for all that follows in any chemical engineering curriculum.

Process Safety. Whose responsibility is it to insure the safety of those working on a process or living near a petroleum refinery, or a microelectronics fab site, or a pharmaceutical formulating facility? As you ponder that question, consider two others: Whom does the public think is responsible? Do the answers differ? I suspect the public will hold the Chief Executive Officer, or the Chief Corporate Council, or perhaps the plant manager responsible. You, on the other hand, are likely to recognize the complexity of the question. It could be the design engineer, the process engineer, or any of a myriad of individuals and organizations involved. But one thing is sure—there is no room for a weak link in the chain of responsibilities, for that is surely the place where a sophisticated system will fail.

Our curricula cannot cover items of safety specific to every process, but we can teach students to think of safety by including it in problem assignments, tests, and instructional materials supporting other courses. We need to start this in the first course, continue it throughout the curriculum, and certainly emphasize it in process control and design courses. This can be done with several "what if" exercises in each course. Consider, for example, the following end-of-chapter problem:[8]

> *A 20,000-liter storage tank was taken out of service to repair and reattach a damaged feed line. The tank was drained and then opened several days later for a welder to enter and perform the required work. No one realized, however, that 15 liters of liquid nonane remained in a collection sump at the bottom of the tank. Nonane has a lower explosion limit of 0.80 mole% and an upper explosion limit of 2.9 mole%.*[9] *Assume any liquid nonane that evaporates spreads*

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[5] O. A. Hougen, H. Ragatz, (and K. Watson), *Chemical Process Principles. Part I. Material and Energy Balances,* 1st (and 2nd) eds., John Wiley and Sons, Inc., New York, 1943 (and 1954).

[6] D. M. Himmelblau, *Basic Principles and Calculations in Chemical Engineering,* Prentice Hall, Englewood Cliffs, 1962, and subsequent editions.

[7] R. M. Felder and R. W. Rousseau, *Elementary Principles of Chemical Processes,* 1st-3rd eds., John Wiley and Sons, Inc., New York, 1979, 1986, 2000.

[8] R. M. Felder and R. W. Rousseau, ibid.

[9] N. I. Sax and R. J. Lewis, Hazardous Chemicals Desk Reference, Van Nostrand Reinhold, New York, 1987, p. 681.

> *uniformly throughout the tank. Is it possible for the average gas-phase composition in the tank to be within the explosion limits? Even if the average composition falls outside the limits, why is an explosion still a possibility?*

In this problem, a student is asked to apply concepts associated with phase equilibrium (Raoult's law), to make an assumption regarding the temperature of the system, to understand the meaning of explosion limits, and to consider the implications associated with the assumption of perfect mixing of the gas phase. Just as importantly, however, we conclude the problem with an additional exercise:

> *Company policy requiring that the tank be purged with steam after being drained had been violated. What is the purpose of this requirement? What other precautions should be taken to be sure that the welder, other personnel, and the facility are in no danger?*

Here we ask the student to think critically about the rationale for using steam, which again reinforces aspects of phase equilibrium, and to think through what could be done to make this necessary activity as safe as possible. The purpose of this problem is two-fold: to teach the technical concepts and fundamental principles, and to emphasize safety and the responsibilities to be faced by chemical engineering graduates.

The AIChE has made significant progress through the Safety and Chemical Engineering Education (SACHE)[10] program in distributing educational materials for use in teaching aspects of process safety. Most of the chemical engineering programs in the United States are subscribers to SACHE, and I hope they are putting these materials to good use.

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[10] http://www.aiche.org/sache/

Process Analysis and Control. A very large number of our graduates have been or will be employed as process engineers. Seldom will these professionals design a heat exchanger, a distillation column, or a chemical reactor; but they will be responsible for making sure that product flows as prescribed from a process that may include these unit operations. It is important that they know what makes things work—this means the principles of chemical engineering—if they are going to identify and solve potential problems with or squeeze extra capacity from such equipment. Such knowledge must range from the elegance involved in linking process units creatively to understanding the practicalities that may limit implementation of that creativity.

Rakesh Agrawal of Air Products recently published an excellent pair of manuscripts[11,12] reviewing aspects of thermally coupling distillation columns that bear reading, not just from the perspective of energy minimization but as a link to reality for chemical engineering students. Using Agrawal's work as a guide, here's an example of what I mean.

A three-component mixture, A, B, and C, is to be distilled into the pure components. Furthermore, the relative volatilities decrease from A to C; i.e., $\alpha_A > \alpha_B > \alpha_C$. The three non-coupled schemes for carrying out this distillation are shown in Figure 1. They are the direct, indirect, and prefractionator configurations. Notice that there is no direct utilization of the heat input to one column used in the operation of another.

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[11] R. Agrawal, "Thermally Coupled Distillation with Reduced Number of Intercolumn Vapor Transfers," *AIChE Journal*, 46, 2198(2000).

[12] R. Agrawal, "Multieffect Distillation for Thermally Coupled Con figurations," *AIChE Journal*, 46, 2211 (2000).

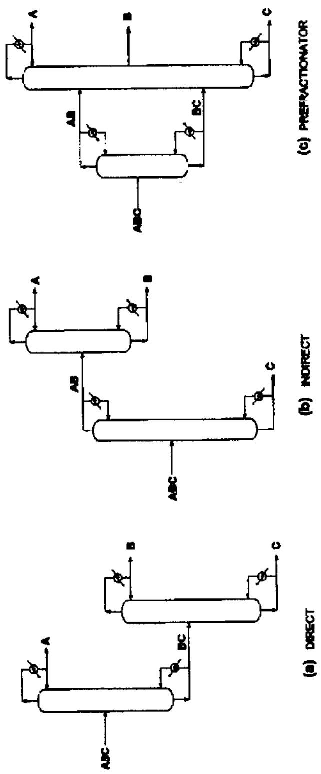

Figure 1. Ternary Distillations Without Thermal Coupling (footnote 11) Reproduced with permission of the American Institute of Chemical Engineers. Copyright © 2000 AIChE

A number of thermally coupled column configurations can be formulated, and the one known as fully coupled is shown in Figure 2. Notice that the first column has neither a heat sink nor a heat source, so this means one less condenser and one less reboiler than any of the uncoupled systems. Moreover, heat is only withdrawn from a condensing vapor at the lowest possible temperature and added to a vaporizing liquid at the highest possible temperature. The system can therefore operate with a higher thermal efficiency than any of the non-coupled schemes.

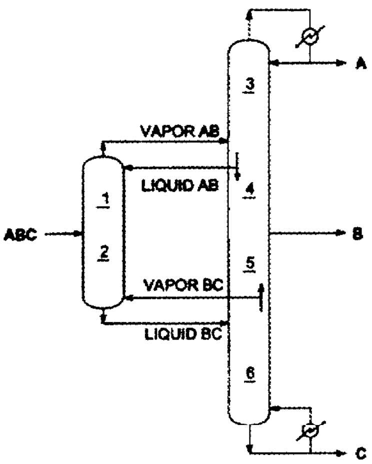

Figure 2. Fully Coupled Distillation Columns (footnote 11) Reproduced with permission of the American Institute of Chemical Engineers. Copyright © 2000 AIChE

However, what about the operability of the column? Agrawal calls attention to the fact that there are two vapor-transfer lines between the columns—one from the top of the first column to the second column, and another from the second column to the bottom of the first column. There are, of course, also two liquid-transfer lines. But how do the fluids move through the lines? If one of the columns is at a pressure different from that of the other, then flow will occur from the column at higher pressure to the column at lower pressure without assistance. However, as shown in Figure 2, there are a vapor and a liquid stream flowing into each column from the other column. Liquids can easily be pumped from a lower pressure to a higher pressure, but how is the vapor to be moved from the column at a lower pressure to the one at the higher pressure? Compressors raise the pressure of a vapor, but they are much larger and more expensive than a pump. The elegant, fully coupled system loses out over a simple thing like trying to pump a vapor. It is interesting to note that with a clever bit of engineering, facilitated by an understanding of the principles of cascades, Agrawal shows (Figure 3) how an alternative coupling of the columns can be rearranged to provide some of the same advantages without problems in operability.

Among the additional important lessons to be reinforced by the example just discussed is that there usually are numerous solutions to a given problem. Remember, the objective was to separate a mixture of three compounds into essentially pure components. In the Agrawal references, he shows 20 different column configurations that will meet this objective. If the two columns are arranged in a double-effect fashion, another 15 or so configurations are possible.

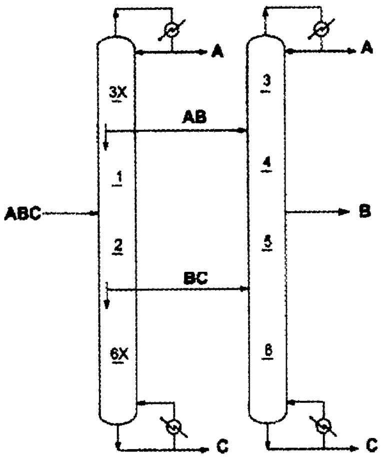

Figure 3. Equivalent Fully Coupled Columns Without Vapor Transfer (footnote 11) Reproduced with permission of the American Institute of Chemical Engineers. Copyright © 2000 AIChE

For decades, I have heard about the importance of considering the control of a process an important factor in its design. However, I am not sure that we yet correctly link these two important parts of process engineering.

To illustrate how control and design should be coupled, let us consider the familiar distillation column as an allegory for all processes; similar points could be illustrated in the production of a specific hydrocarbon fraction, a complex new pharmaceutical compound, or a microelectronics wafer. However, we make the point with the well-known relationship between reflux ratio and the purity of a specific chemical species in the overhead product of a distillation column. All chemical engineers know that the most economical approach to operation of an existing column is to run at the lowest possible reflux ratio, which requires the lowest heat input to the reboiler. However, suppose your job is to produce a product with a specified purity and that you must be 99.9% sure that the purity is achieved. Are you going to run at the lowest possible reflux ratio? Not likely. In fact, without balanced instruction in process control, our graduates may think that the column described above or any other system of interest can be controlled perfectly. What does that mean? Perfect sensors and either no lag in feedback control systems or a perfect model for feedforward control systems are essential. Once the requirements for perfection are realized, and today's graduates should understand these, a proper emphasis can be placed on where advancements in process reliability can have an impact.

Environment and Sustainability. Which engineering discipline should be concerned with the environment and the impact of technology on our surroundings? My answer is—all of them. Should any discipline have exclusive domain when it comes to serving the ideals of environmental stewardship? I think not and I tell prospective students that all of us (meaning all of Engineering, but especially Chemical Engineering) do environmental engineering.

There are academic programs, mainly housed in civil engineering departments, bearing the name of environmental engineering. Let me try to explain why this creates significant problems among students and, perhaps most importantly, the public. Students who want to study a discipline that will enable them to impact the environment are quite naturally misled into believing they need to major in "Environmental Engineering." Of course, the public makes the same sort of connection. So, research programs and, often other environmental initiatives with tangible intellectual and financial resources are directed towards the academic unit bearing the name. This shortchanges all involved because chemical engineers bring both hard science and a sense of economic reality to environmental problems; they are singularly positioned to produce solutions that can be implemented.

We must become more explicit about the roles chemical engineers play in insuring that the growth of technology provides us with a sustainable society. Many thought of as environmental engineers have earned their appellation by cleaning up environmental messes created by oil spills, waste dumps, years of neglectful discharge of toxic materials, and so forth. These are important tasks and those who do them are to be congratulated, but I think most of these problems would have been better addressed by the kind of foresight and planning today's chemical engineering graduates should be able to bring to their careers. Which is better environmental engineering: to design a process that is environmentally benign or to devise a process that cleans up the consequences of one that is not? The Technology for a Sustainable Environment program[13] co-sponsored by the National Science Foundation and the Environmental Protection Agency is an excellent concept that seeks to recognize the latter approach to environmentalism.

To emphasize my point, the most important positive impact of technology on the environment will be through modifying existing processes or in the development of new processes that are environmentally benign. The impact will come through reducing the amount of waste generated in chemical and other processes and/or by separating (and destroying) undesired species from process effluents before these streams are dispersed to the environment. The first of these clearly is preferable, but it is also more difficult to accomplish; an entirely new set of processes will need to be developed and there are no generic approaches to the problems. That is, a single technology will not solve all problems with waste generation. This reality has stymied the success of many university research programs on environmental topics. Likewise, separation of undesired species from effluent streams will present a variety of system-specific problems with the only broad categorization being whether the effluent is dispersed in air or water or as a solid.

The recycling of various products has been made possible through the use of separation technologies to remove contaminants, fillers, or other undesired species from the products of interest. Recycled paper and aluminum are examples of such successes. New separation processes, many of which should be described to our students, are unfolding that will permit the recycling of various kinds of plastics, solvents, lubricating oils, and other products. Furthermore, there are numerous opportunities throughout chemical engineering curricula to integrate fundamentals with applications affecting the environment. These range from using principles from thermodynamics and transport to quantify emissions of volatile species to illustrating how varying a design variable, such as reactor temperature, affects the synthesis of noxious byproducts. Additionally, we should take every opportunity to publicize the roles of chemical engineers in maintaining environmental quality and developing processes and products that lead to a sustainable economy.

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[13] http://www.nsf.gov/search97cgi/vtopic

Teamwork. For a variety of good reasons, employers, advisory groups, and colleagues have implored us to teach our students the elements of teamwork. We struggle to comply, but I think this may be one of those areas where we are only partially successful. Furthermore, I am concerned that our efforts actually may be limiting the development of true teamwork skills in our students. This apparent contradiction results from what I think is a misunderstanding of the meaning and values of teamwork.

I have seen countless descriptions of efforts to teach teamwork in laboratory courses. This is an excellent idea, but upon further analysis, it almost always turns out to be little more than an updated version of getting a group of people to divide up the elements of the total task and having each independently complete a fraction of the work. Again, the result is exactly the sum of the individual efforts. This is a valuable experience for students, if for no other reason than for them to learn that there will be people who will not live up to the responsibilities of even such simply defined tasks. It can also sharpen organizational skills; for example, there may be an issue of timing the completion of the individual tasks, which might require sequential, rather than parallel, effort by the team members. Finally, communication of the results of the individual efforts among the team members and bringing these together in a cohesive report can refine communication skills. So, the effort I initially disparaged is not a complete loss.

But what else should our teaching of teamwork include? It should by no means result in a loss of individuality or sense of responsibility within the individual. But at the very least, it should lead students to appreciate the power of a team that works in a way to produce an outcome that is greater than the participants could produce working independently. I am concerned that our students are missing that element in the way we talk about and use teamwork in many of our undergraduate laboratory courses. This can be corrected in a number of ways: (1) use of cooperative learning techniques in the classroom, including brainstorming exercises; (2) involvement in research programs that have active interactions among all participants; and (3) formulation of design projects that require interactions among team members in order to isolate key problem areas and determine methods of solution.

Leadership. It is important that we foster within our students a sense of what it takes to be a leader: discipline, hard work, an appreciation of the efforts of others (see the earlier comments on teamwork), knowledge, and vision. We must help our students build a knowledge base in the technical aspects of chemical engineering, but we should provide them with other knowledge as well. Our graduates should have at least an elementary understanding of the business world, the time value of money, cash-flow issues, and key aspects of economics. This will become even more important with the continued growth in entrepreneurial activities among our graduates.

Communications skills are recognized to be vitally important to leadership. In recognition of that, almost all chemical engineering programs have some effort underway to improve these skills among our student population. This is a good thing, and I can certainly see good presentation skills among most of our students. On the other hand, writing skills seem to be getting worse. We need to work harder with our students by including assignments in our courses that require more than putting down the numerical solutions to problems. Some of these should require an explanation of what was done and why.

All organizations, whether governmental, academic, or industrial need and value leadership, and many of our students have great leadership potential. We expect our graduates to become leaders. Clearly, then, we have the responsibility to teach skills that our students can use as they are called upon to lead. Leadership requires the intellectual strength to evaluate a situation as competently as possible; hence, we teach our disciplines with rigor and effectiveness, and expect our graduates to be able to handle the toughest of technical problems. We all know that an ability to communicate is an essential characteristic of good leaders, and most chemical engineering programs have now invested substantially in activities designed to develop such skills in their students. In addition, leadership cannot be exercised without an awareness of context; hence, we insist upon our engineering students having courses in the humanities. But context includes more than history, sociology, religion, and philosophy; it must involve ethics.

Can ethics be taught? I doubt it, but what we can teach is the importance of measuring our professional (and personal) activities against an ethical yardstick whose units were put in place with the help of numerous influences, but which must survive with our own internal sense of what is right.

The loss of confidence of the general public in corporations and especially the leaders of such organizations is another reason I believe it important to link leadership and ethics. For example, in a Gallup poll (August 1985) on the ethical standards and honesty of various professions in the United States, the following rankings emerged:[14]

1. Clergymen 67%
2. Druggists/pharmacists 65%
3. Medical doctors 58%
4. Dentists 56%
5. College teachers 54%
6. Engineers 53%
7. Policemen 47%
8. Bankers 37%
9. TV reporters/commentators 33%
10. Journalists 31%
11. Newspaper reporters 29%
12. Lawyers 27%
13. Executives 23%

It may also be that things have changed dramatically since 1985, and we might draw some confidence from the relatively high ranking of college teachers and engineers. However, many future executives will come from our student ranks, and I think we have an opportunity and responsibility to put ethics in the lineup of material addressed in our curricula. Indeed, it is interesting to consider how many of the safety and environmental issues mentioned earlier might come down to a question of ethics.

The School of Chemical Engineering at Georgia Tech has had the good fortune to be the recipient of funding from the Phillips Petroleum Foundation for the Phillips Petroleum/C. J. "Pete" Silas Program in Ethics and Leadership. Pete Silas is a Georgia Tech chemical engineering graduate and was for a number of years the Chairman and Chief Executive Officer of Phillips Petroleum Company (coincidently, the company sponsoring this lectureship). The program was begun with his initiative, and I believe his record as CEO is an example of how leadership exercised ethically can lead to successful careers and successful companies. With the Phillips/Silas program we have asked recognized leaders such as Pete, Ray Gilmartin (CEO of Merck and Company) and Robert Galvin (Chairman of the Board of Motorola) to share their insights and experiences as leaders of major industrial organizations. Their presentations have provided our students and faculty with valuable lessons for *yet-to-be-made* decisions and judgments.

As part of this program, an attempt is made to introduce ethics throughout the curriculum. Here for example is a discussion topic in a course given by Mark Prausnitz.[15]

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[14] from http://www.foundation.novartis.com/business_corporate_ethics.htm#corporate_ethics which provided the source: T. M. Jones and F. H. Gautschi, "Will the Ethics of Business Change? A Survey of Future Executives," *Journal of Business Ethics*, 7, 231(1988).

[15] adapted from the Discussion Guide for Gilbane Gold, a video dramatization on engineering ethics, produced by the National Institute for Engineering Ethics of the National Society of Professional Engineers.

Gilbane Gold is the name given to dried sludge from the Gilbane wastewater treatment plant. It is sold to farmers as a commercial fertilizer. The annual revenue generated saves the average family about $300 a year in taxes. Several years ago the city of Gilbane established limits on the discharge of heavy metals to the sewers in order to protect Gilbane Gold from the build-up of toxic materials that could end up in the farmer's soil. These limits are ten times more restrictive than Federal limits. However, the limits are based on the concentration of the discharge with no restrictions on total weight of material discharged.

Z CORP is a computer components manufacturer which discharges wastewater containing small amounts of lead and arsenic into the city sewer system. By the current city test standards, the discharge usually meets the allowable levels for heavy metals. However, a newer test, known only to Z CORP environmental people, shows the discharge exceeds the city test standards. An ethical dilemma arises within Z CORP concerning whether to advise the city of the newer test. Acceptance of the newer test would require additional investment in clean-up equipment. Tom Richards is a Z CORP environmental engineering consultant who was fired for advocating the new test. Thereafter, David Jackson, an engineer working for Z CORP, "goes public" with his views. A television media investigation results.

Complicating the situation is the fact that Z CORP has just received a contract for five times as many computer modules as they presently produce, albeit at a very thin profit margin. The increased production means five times as much waste will be produced. The discharge concentration can be kept the same by adding five times the amount of water, thus still meeting the existing city standards. The result, however, is that Gilbane Gold has five times the amount of heavy metals in it as before. The Z CORP vice president is opposed to changing the test standards because that would require additional investment in wastewater treatment equipment. This could cause Z CORP to lose money on the new contract. The vice president contends that Z CORP's responsibility is to provide jobs and a payroll and that the city should worry about the environment.

As homework before discussing the Gilbane Gold situation, Dr. Prausnitz's class was given the National Society of Professional Engineer's "Code of Ethics for Engineers"[16] to read. Then, just before viewing the 24-minute video that presents the Gilbane Gold dramatization, the class briefly summarized and discussed the Code of Ethics to provide one possible moral framework for evaluating ethical quandaries. After viewing the video, the class was asked to identify the views held by the characters in the presentation and to critique the strengths and weaknesses of their positions. After considering the many possible attitudes toward corporate responsibility, the class was then asked to suggest courses of action that the engineer, David Jackson, could take. The class was also asked to identify to whom and to what the engineer has moral obligations—his employer, his career, the city, professional engineering integrity. Possible solutions to the ethical dilemma were evaluated in terms of which of these obligations were best met and what compromises were required to implement them.

Each of us may approach the example problem from a different perspective that leads us to different solutions. The real error, however, would be to miss that it is a problem with ethical dimensions, and we must teach students to recognize such situations.

Product Design. Process design has been the traditional capstone design course for chemical engineering curricula. Recently, however, other approaches have been touted as providing an equally good experience and, at the same time, providing students with a background that may be more appropriate for their career

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[16] available at the web site http://www.nspe.org/ethics/eh1-code.asp

interests. One of these is product design. In the 2000 Warren K. Lewis Lectureship in Chemical Engineering at MIT, James Wei referred to Product Engineering as the Third Paradigm of Chemical Engineering. Numerous chemical engineering programs have some activity in this area, and the description of one such course at Cambridge University is given below.

> *Product Design introduces a new approach to materials, processes and design. Rather than considering how big something should be, which is the focus of traditional chemical engineering design, Product Design introduces the vitally important mode of design where the attributes of the final product dictate the selection of the process route or technology, i.e. "what should we make?" This more open-ended approach is extremely important in the industries that employ chemical engineers working alongside other scientists and technologists-in commodities, pharmaceuticals, food and drink, for example-and reflects the interdisciplinary nature of many modern companies. This [course] draws on the creativity (and fun) that underpins innovation, idea generation and start-up companies.*[17]

Cussler has written of his experiences in developing that course with Moggeridge of Cambridge.[18] He states that 25 years ago, 75% of our graduates went into the chemical process industries; now, only 20% do. In contrast, few went into businesses 25 years ago that stressed products; now, about half do.

Clearly these are strong arguments for doing something different with our design courses. I suspect that we will see considerable effort to provide something in the product design arena as an alternative to process design. However, in my opinion, this is something that should be approached slowly in order to insure that such courses are pedagogically sound, and that they have the proper intellectual content and infrastructure (such as textbooks).

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[17] http://www.cheng.cam.ac.uk ugbro_course2 .html

[18] E. L. Cussler, personal communication, 1999

Curriculum Flexibility

Earlier, I commented upon additional flexibility that should be added to today's chemical engineering curricula. The breadth of our discipline and the concomitant opportunities provided to our graduates require us to give students an opportunity to enhance their capabilities in areas that may vary from student to student. This means more electives and, to reiterate, it places increased responsibility on students to choose wisely among electives. This has been done at Georgia Tech by providing students lists of courses that allow them to specialize in areas such as the following:

- Preparation for the Professional Engineering License
- Polymers
- Microelectronics and Electrochemical Engineering
- Preparation for Graduate School in Chemical Engineering
- Bioengineering
- Leadership and Management
- Pulp and Paper Engineering

Students are not required to pick one area and may, instead, formulate a set of courses in another area. The additional flexibility provided by a larger number of electives increases the responsibilities on both students and faculty members; students must make efforts to plan their own curriculum and faculty must provide improved advising.

Summary and Conclusion

There are a few items to summarize with respect to the education of future chemical engineers:

1. The practice of chemical engineering is changing. Although historically important employers of chemical engineers continue to employ the largest fraction of graduates, there is now much greater diversity in job opportunities.
2. Curricula must reflect changes in the practice of chemical engineering. Contributions by a new chemical engineering graduate are enhanced by knowledge of the industry in which the graduate is employed.
3. Curricula must emphasize the development of both skill and knowledge. Knowledge by itself is not sufficient; chemical engineering graduates must be able to *apply* knowledge. Therefore, the most important attribute that can be cultivated in our graduates is the skill to solve problems, to communicate those solutions, and to adapt to changing circumstances.
4. New curricula place additional responsibilities on students. Because the flexibility built into curricula can be squandered without the exercise of good judgment, students must choose wisely among a greater variety of courses.

If we recognize the importance of these factors and formulate what may be program-specific methods of dealing them, there is no doubt in my mind that today's chemical engineering students will solve tomorrow's problems.