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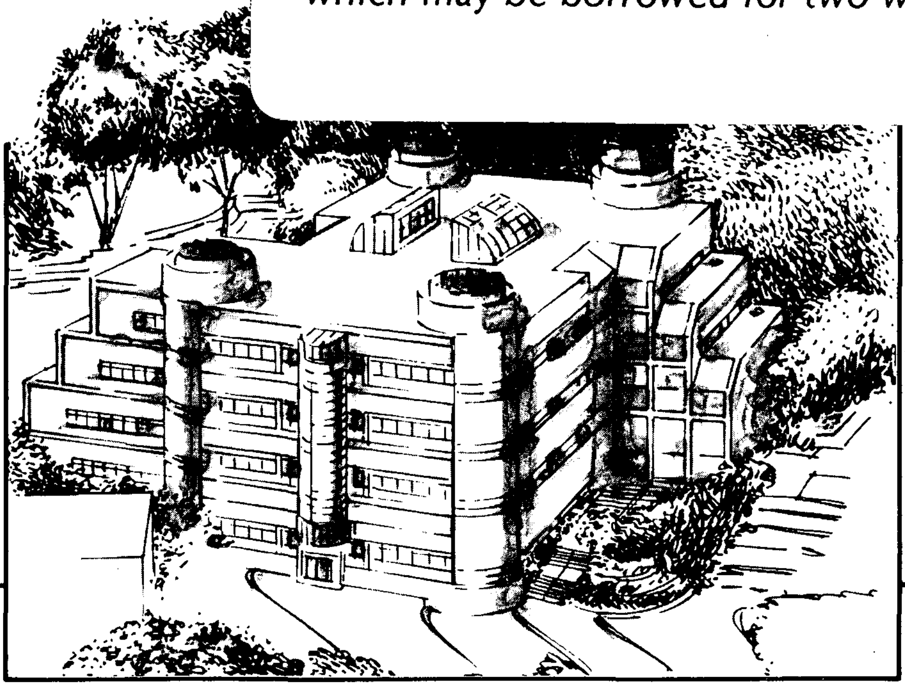

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The Identity of our Profession

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Introduction

We have been hearing a great deal in recent years about the changing nature of chemical engineering. The emphasis on new fields of research has created the appearance of a fragmented profession, comprised of specialized research communities with little inclination to interact. New hiring and career patterns in the industries that have traditionally employed chemical engineers, and the emergence of career opportunities in non-traditional industries, have helped to focus attention on the fundamental issue of the very identity of chemical engineering and how that identity may be changing. The National Research Council's report on "Frontiers in Chemical Engineering" (the *Amundson Report*) [N1] provides a convenient frame of reference for discussion of this issue, because of its emphasis on new directions in the profession.

Chemical engineering, according to "Frontiers in Chemical Engineering," will be governed by a new paradigm. This new paradigm (which is never clearly defined in the text) is introduced with a table of "enduring" versus "emerging characteristics" and a description of changing social and economic pressures; the paradigm appears to be associated with a change from a focus on macroscale processes to those occuring on a microscale. A paradigm is a profession's intellectual frame of reference; "[it is] what the members of a scientific community, and they alone, share." [K2][1] A new paradigm suggests revolutionary change, with far-reaching implications regarding education, research, and the practice of the profession.

I do not believe that chemical engineering has been undergoing revolutionary change. Our profession has been experiencing gradual and predictable evolutionary change for four decades, and differs little today from chemical engineering as it has been traditionally practiced in North America since the Second World War. Recognition of this continuity is important if we are to respond effectively to the current pressures on the profession and to meet the societal needs so clearly enunciated in the "Frontiers" report.

What is the paradigm?

Chemical engineering has traditionally been viewed as the engineering profession that deals with applications in which physical and chemical rate processes are limiting. (*I submit that this is the unchanging paradigm.*) The introduction of the concept of the unit operation, which has provided a major thread of continuity through seven decades of practice, focused attention on physical rate processes; chemical rate processes were ironically to await another three decades for introduction into the core of chemical engineering education, research, and practice, until driven by the necessities of the Second World War[2]. This essential absence of applied chemistry from chemical engineering has been noted in a perceptive essay by Howard Rase [R1], and the change is graphically illustrated by comparison of the contents of the *Transactions of the American Institute of Chemical Engineers* from the late-1930's to 1946. In fact, Arthur D. Little himself drew a sharp distinction between chemical engineering and industrial chemistry along a unit operations-based boundary[3]. Chemical engineering as we know it today thus developed during the Second World War with the integration of industrial chemistry (in the form of the developing specialty of chemical reaction engineering) and unit operations. It is perhaps significant in terms of our current concerns regarding the growing diversity of the profession that the integration of biochemistry into chemical engineering practice, and the birth of the specialty of biochemical engineering, also began at that time. (Like conventional chemical processing, the industrial roots of modern biochemical engineering can be traced to much earlier dates, at least to the World War I Weizmann process for the large-scale production of acetone).

The perception that chemical engineering has undergone major changes has caused several institutions to re-examine their undergraduate curricula to ensure that they remain relevant to modern practice. As far as I know, the conclusions reached by my colleagues at Berkeley after a year of study are typical of the results of such introspection. It was clear to us that the specific content of a number of courses needed modification, generally in the form of examples of applications to new fields of opportunity for chemical engineers. Only a few major structural changes were seen as necessary, however, and none would support the notion of a major change in paradigm. The separations course was seen as being too narrow, and plans are now underway to fashion a course that is philosophically closer to the reaction engineering course in bringing together fundamental concepts and addressing broad issues of separations. Specialized minors, comprising a small number of related courses inside and outside the department, are to be introduced in order to focus students' selections of electives. Finally, an overall plan to integrate computer use throughout the curriculum has been developed. This is all very important, but hardly revolutionary.

Chemical engineering practice in the post-war era has been closely tied to advances in the disciplines on which the modern industrial base is built: chemistry, physics, and molecular biology. Whether the major advances in these fields have been "science-pushed" or "technology-pulled" is irrelevant from our professional point of view; any changes in chemical engineering practice have been externally driven by scientific advances. The growth of industrial practice in materials fields at the microscale is a result of advances in chemistry and physics, particularly of the solid state; the traditional skills of the chemical engineer were readily adapted, because they required "only" the addition of new scientific knowledge. Similarly, biochemical engineering grew with the advances in molecular biology. Chemical engineering research does now consider to an increasing extent phenomena at a "micro" level, using sophisticated instrumentation that was unavailable only a few years ago. These research tools have widened the scope of potential applications, as required by the demands of the modern science-based technologies; they have required no change in the basic disciplinary matrix[4] of transport and reaction rate control.

The technical problems being studied by practitioners of the "systems" aspects of modern chemical engineering have been much less influenced by advances in science; indeed, much current research is concerned with problems that were defined forty to fifty years ago. The optimization of configurations for mass or energy exchange as an area of study dates to the early quantitative descriptions of unit operations; optimization of flowsheets, which has been one area of major interest in recent years, is a straightforward extension of 1930's textbook material, requiring only the availability of more powerful computers and (in some cases) the World War II-driven growth of the mathematical foundations of operations research. The quantification of methods of process control was similarly a logical outgrowth of the wartime development of servomechanism theory and post-war generalizations to aerospace applications. Indeed, one of the common themes of critics of chemical process control research during the 1960's and 70's was the inapplicability of much of the available theory to the peculiar dynamics of industrial processes, and it is only during the most recent decade that control as practiced by chemical engineers has taken on any unique characteristics.

What are the implications?

Let us now proceed on the premise that there is a single, identifiable profession of chemical engineering, with a common disciplinary matrix, or paradigm: the analysis and design of systems governed by physical and chemical rate processes. Despite interest in specialty areas, chemical engineers share an enduring common culture that provides the opportunity for easy exchange of ideas between sub-disciplines, and unparalleled opportunities for movement into new problem areas. Why, then, do we appear to be fragmented and uncertain about our future as a profession?

The question was anticipated by Rase in his 1961 essay [R1]: "Now it appears that the engineer stands waiting for new developments in science, and as in most waiting games the waiter is the loser. It is because of our hesitation that research in chemical engineering has been relegated to improving the ideas of pure science and doing some of the necessary jobs pure science now finds dull or repititious." This is a proposition that we take hold of our own destiny and define the new scientific directions ourselves, rather than continuing in the reactive mode that has been our tradition. Some of the current discomfort is undoubtedly associated with an attempt to do precisely this, accompanied by a sense that a departure from our traditional role is of necessity a departure from a tradition-bound profession as well.

One strength of chemical engineering as a discipline has been its problem orientation, in which familiarity with physical and chemical rate processes has enabled the chemical engineer to use whatever tools were available to attack a wide range of physico-chemical problems. Chemistry and physics (if I may be allowed a broad brush) have been much more technique oriented, with the instrumentation enabling the scientist to seek out problems that *could* be solved. This distinction has always been a profitable one for chemical engineers willing to play the "waiting game," and I disagree with Rase that they have been losers.

Chemical engineers do need to be more aggressive in seeking a leadership role in bringing about advances in technology. Their absence is particularly noteworthy in many areas of "materials science," where the problems are closely related to traditional chemical engineering, but are rarely studied by people who identify themselves as chemical engineers. This leadership role can be achieved, however, without abandoning the problem-oriented approach that has been so successful in the past. It will require a continuing awareness of instrumental advances, and perhaps collaboration with those specialists whose skills are needed for particular applications. Such collaborations can be synergistic; the engineer has much to offer the scientist, and need not feel a junior partner. True collaborative research is unfortunately unusual in U.S. universities today, as Alan Michaels [M1] has noted in an important essay that deserves widespread attention.

Some chemical engineers have been taking a leadership role in the science, as well as the technology, in a number of important areas: catalysis, surface science, and polymer and colloid science are among the easiest to identify. With this involvement has come a natural tendency to identify with the the area of chemistry or physics in which the advances (and much of the initial excitement) are occuring. This identification has led in many cases to a narrow, outward focus, with accompanying perceptions of uniqueness relative to the core of chemical engineering. The outward focus is reinforced by attendence at specialized scientific meetings and the existence of a specialized literature; the chemical engineering "connection" seems secondary. This tendency is reinforced by our system of evaluation for tenure in universities, and the equivalent evaluation system in major research laboratories. Young chemical engineers perceive the necessity of making a mark within the specialized community with which they interact in research, for these are the peers who will evaluate them for their chemical engineering colleagues after five or six years.

The first generation of chemical engineers moving into an area of basic science undoubtedly retains an engineering problem orientation; it appears to me, however, that quite often this outlook is not passed on to the students, who acquire the viewpoint of the natural scientist. I have found in discussions during the preparation of this article that this proposition is a controversial one. Colleagues have argued that graduate student research can be as science-oriented as we may wish; the core graduate educational program in chemical engineering will ensure that the graduate remains a problem-oriented *engineering* scientist, despite working on a dissertation problem that is basic chemistry, physics, or biology. Thus, they argue, we can have all that we might wish if we become more aggressive and seek out the most challenging areas of the natural sciences as they relate to our technological interests. I cannot agree. It has been my observation that many of the best students of science-focused chemical engineering faculty take industrial positions in laboratories where they are indistinguishable from chemists and physicists, and they are effectively lost from the profession.[5] Perhaps the problem is that in some cases the chemical engineering departments that have been most aggressive in seeking new *scientific* directions are those least likely to offer a graduate chemical engineering core.

Some suggestions.

Communication within the chemical engineering profession has been a casualty of the research-driven fragmentation of recent years, and I believe that reestablishment of effective communication is one of our most pressing needs. I have previously commented on the mutual advantages of communication to the specialists and the broader profession, as follows [D1]: " ... some of this research [in new areas] is so strongly based on traditional chemical engineering concepts that it will interest and excite traditional chemical engineers, and help them and the profession to move in new directions. Nor is it to suggest that altruism is the motivation ... ; communication involves the flow of ideas in both directions, and the skills and interests of experienced chemical engineers can often be crucial to the solution of problems in new areas about which they would not otherwise be informed." (Consider how often the effectiveness factor has been rediscovered!)

Our professional societies have been major culprits in creating fragmentation. In my own area of research, the slow response of the AIChE to the growing interest of chemical engineers in polymers was one of the major factors in the formation of still another society, the Polymer Processing Society; most of the North American principals in this new organization are chemical engineers, and the current activities of the Society are within the programming responsibilities of the AIChE. The proliferation of specialized societies probably cannot be stopped, but better integration of meetings of these societies with meetings of AIChE and ACS could minimize the damage and enable mutually-beneficial interaction with the broad chemical engineering community. The 1987 Conference on Emerging Technologies in Materials is a flawed model; the co-sponsorship by twelve other societies was in name only, since they still held their own regular meetings, and the use of a hotel different from the simultaneous AIChE meeting segregated the "materials people" from the rest of the community. Still, it is a better model than the simultaneous 1988 meetings *in different cities* of AIChE, ASME, and the Materials Research Society, all with overlapping materials programming.

The implementation of the tenure system in universities is another factor in fragmentation. I have already noted the research pressure on young faculty that causes them to isolate themselves from the chemical engineering community. There is an educational loss as well. The young faculty are usually the ones who are most involved with research in new areas, and they are the people who must lead the way in integrating the new areas into the core curriculum. Preparing textual materials that can be used by others is very time-consuming, and bears little relation to the time required to prepare one's own lectures. (The closest analogy is probably between writing a computer program for personal use and preparing a "user-friendly" program for distribution. Most of the real work goes into the user-friendly front end.) Young faculty should be encouraged to develop textual material, because it is what the profession needs. Our system of evaluation for tenure needs to be revised to encourage impact on the core profession, both through the preparation of teaching materials intended to broaden the exposure of students in basic chemical engineering courses and through research publications aimed at the entire chemical engineering community.

Finally, it seems obvious that chemical engineering education needs to be built around a core at the graduate as well as the undergraduate level. The core should emphasize the disciplinary matrix: the analysis of chemical and physical rate processes. Whatever new directions are being taken in research, whether oriented towards a traditional engineering outlook or towards basic science, the universality of the profession should be a major focus when these areas are integrated into the course of study.

NOTES

[1] See also the second edition of Kuhn's *The Structure of Scientific Revolutions* [K1]. Kuhn popularized the concept of paradigms for scientific communities, and the term is usually understood in the context of his writings about "scientific revolutions;" I expect that this will be the case for most readers of the "Frontiers" report, although the authors may not intend that to be their meaning. A reading of Kuhn's critics is important to recognize that paradigmatic change need not entail a radical overthrow of established methods and principles; see, for example, Toulmin [T1], pp.96ff.

[2] Arthur D. Little's original 1915 concept of "unit operation" did not necessarily exclude chemical rate-determined operations, but it was in practice restricted to physical processes; chemistry entered only in equilibrium-based situations in the standard textbooks. Consider Little's list of examples in his widely-quoted letter to the president of MIT: "pulverizing, dyeing, roasting, crystallizing, filtering, evaporation, electrolyzing, and so on." A definition of the profession in 1922 was thus a defensive one, "Chemical engineering ... is not a composite of chemistry and mechanical and civil engineering, but a science of itself, the basis of which is those unit operations which in their proper sequence and coordination constitute a chemical process as conducted on the industrial scale." (Report of the Committe on Chemical Engineering Education of the American Institute of Chemical Engineers, 1922, quoted in [R2].) The contrast with the current definition in the AIChE Constitution and Bylaws (Article III) is interesting: "Chemical engineering is the profession in which a knowledge of mathematics, chemistry and other natural sciences

gained by study, experience and practice is applied with judgment to develop economic ways of using materials and energy for the benefit of mankind."

[3] "... there should always be kept in mind the definite line of demarkation between industrial chemistry, which is concerned with individual processes as entities in themselves, and chemical engineering, which focuses attention upon those unit operations common to many processes and the proper grouping of these unit operations for the production of the desired product as efficiently and cheaply as the ruling conditions permit." [L1]

[4] This is a term Kuhn [K2] would use to replace one of his meanings of "paridigm."

[5] I am constantly seeking new reviewers for *AIChE Journal* papers. One of my most important sources of addresses when I have identified potential reviewers is the AIChE membership list. The number of young Ph.D. chemical engineers, including university faculty, who are not AIChE members is shockingly large.

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