ChE views and opinions

TOWARD ENCOURAGING CREATIVITY IN STUDENTS

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THE WORD "CREATIVITY" has been much abused because it is difficult to define precisely. In common speech, it is often used for a negative purpose: educators, politicians and administrators are criticized for "not being creative" but, upon further investigation, that criticism often means only that the critic doesn't approve of what the educator, or politician or administrator, is doing. In American society, where we tend to worship whatever is new and where we tend to condemn whatever is old, the word "creative" is a positive adjective, a word of praise, while the more-commonly-used phrase "lack of creativity" is a sign of condemnation.

The dictionary doesn't help much. *Webster's Unabridged Dictionary* refers, on the one hand, to creativity as "making something out of nothing" as in the Bible where God created the earth, and on the other hand, to social or legal acts, as in government where Congress creates a new law, or to artistic acts where a painter or sculptor creates a work of art.

John M. Prausnitz obtained a BChE degree from Cornell University (1950), and a MS from the University of Rochester (1951). His PhD is from Princeton University (1955), where he also served as Lecturer in ChE. In 1955 he joined the ChE department at the University of California, Berkeley. Although his initial professional work was primarily in reactor design, he soon turned his attention to applied thermodynamics, with particular emphasis on phase equilibria in fluid mixtures. He is the author of **Molecular Thermodynamics of Fluid Phase Equilibria** and the co-author of **Properties of Gases and Liquids** (with R. C. Reid and T. K. Sherwood), in addition to numerous articles and monographs.

None of these definitions are satisfactory when we consider creativity in science or in the education of scientists and engineers. Within that context, I much prefer a definition which I once heard from a psychologist: A creative act is one where two ideas or concepts, previously believed to be totally separate, are for the first time, shown to be closely related. A creative act, in other words, is to show that two apparently distinct ideas or concepts are, in truth, not distinct but are merely two aspects of some more general unifying idea or concept. This definition helps us to find ways for encouraging creativity in chemical engineering students, especially graduate students.

Let me now illustrate this definition of creativity by some examples from the history of science and then indicate how that definition suggests some possibly useful procedures for educating creative scientists and engineers.

A striking example is provided by the history of thermodynamics. Until about 1870, thermodynamics (as the name implies) was the science of heat engines, a science concerned with the principles which govern the conversion of heat to mechanical work and vice versa. The research of Mayer, Joule, and Carnot showed that this conversion can be quantitatively described through simple mathematical relations which, however, are characterized by a lack of symmetry; the rules for converting work to heat are not the same as those for converting heat to work. It was this lack of symmetry which led Clausius to the concept of entropy and toward quantitative formulation of the first and second laws of thermodynamics.

While this theoretical development of thermodynamics was proceeding, there was at the same time significant experimental development in chemistry where the early pioneers of what we now call physical chemistry were measuring

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yields of chemical reactions and distributions of components in mixtures among two or more phases. Until about 1870, no one recognized that there was a fundamental connection between what we now call chemical equilibria and phase equilibria. More important, no one had seen any connection between these chemical phenomena and the scientific principles of heat engines. Now, more than 100 years later, we recognize a connection because of our notions of asymmetry and irreversibility: it's easy to convert work to heat but it's not easy to go back again; it's easy to make water and carbon dioxide from methane and oxygen but it's not easy to do the reverse; it's easy to mix water and alcohol but, having mixed them, it's not easy to separate them to their former condition.

We all know that it was Gibbs who first recognized the connection between physical chemistry and thermodynamics, two sciences which, prior to Gibbs, had been believed to be unrelated. Through his invention of a unifying concept—the chemical potential—Gibbs constructed a theoretical framework which has tremendously influenced and advanced many fields of science, with particularly beneficial effects in chemical engineering. Gibbs' unifying action, showing the relationship between apparently separate fields of inquiry, is a striking example of what we mean by creativity.

Gibbs' creative work related one science to another; he used the scientific principles of heat engines to obtain a theoretical treatment of equilibrium in chemical systems. However, the essence of creativity—tying together two separate ideas—need not be limited to those cases where both ideas come from the world of science. Creative acts interconnect intellectual ideas regardless of origin or classification. For example, Sigmund Freud's autobiographical writings indicate that psychoanalysis was born from the interaction of two major factors. First, as a young man, Freud worked in a psychiatric hospital in Paris where he treated women afflicted by hysteria; second, Freud had read the philosophical works of Friedrich Nietzsche and had been impressed by Nietzsche's observation that human behavior was only superficially conditioned by the rational rules of society, while in its essential acts, human behavior was governed by deep-seated, irrational motives. Freud saw a connection by establishing the now well-known concepts of id and super ego which allowed him to interpret hysteria as a consequence of emotional supression, usually dating back to early childhood; once the patient recognized the source of her problem, she could, with counseling, find an accommodation which often led to a cure. Freud's creative act was to apply to medicine what at that time was far-out, radical philosophy.

A third and final example is provided by the physicist Niels Bohr whose complementarity theory is now accepted by most scientists as one of the basic cornerstones of physics. This theory, also known as the Copenhagen interpretation of quantum mechanics, is a concept of nature which believes that duality is not an apparent, but a fundamental feature of natural phenomena: light is not uniquely corpuscular nor is it uniquely a wave; it is both, such that, depending on what observation we want to interpret, one is more evident and sometimes the other. If duality is fundamental, then classical causality and determinism are not possible, as shown by Heisenberg's uncertainty principle. According to the Copenhagen view, probability and statistics are not just approximations which follow from our inadequate knowledge; they are the fundamental laws which govern natural phenomena.

Bohr tells us that his theory of complementarity has two roots: spectroscopy and the philosophy of Søren Kierkegaard, a Dane like Bohr, who bitterly opposed the deterministic philosophy of Hegel that dominated Europe during the nineteenth century. Hegel's famous sequence (thesis, antithesis, synthesis) expressed the notion that with time, like a pendulum, a particular idea (or thesis) generates its opposite (antithesis) and that with more time, the two opposed ideas merge to form a new idea (synthesis). Kierkegaard was a deeply religious Christian who doubted that man could ever attain absolute knowledge; such knowledge was reserved for God. Kierkegaard denied that with time one idea is followed by its opposite; he stressed instead his belief that two opposed ideas exist simultaneously. Opposites coexist and if we examine any one deep truth, we find its opposite to be true as well. Kierkegaard's view is succinctly expressed by the title of one of his books, *Either/Or*.

Bohr studied Kierkegaard in his youth, shortly before he became interested in interpreting transitions of electronic energy states, as measured by spectroscopists. Before Bohr, most physicists had never heard of Kierkegaard and, even if they had, it would not have occurred to any one of them that Kierkegaard's highly abstract criticism of Hegel had any connection with electronic transitions. But Bohr saw the connection. His creative act was to establish an interpretation of physical phenomena using concepts from what was (and still is) obscure philosophy.

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What do these examples suggest toward fostering creativity in education? If we accept the definition of creativity that I have indicated, then we must see to it that our students are exposed to a variety of subjects, including some that are remote from chemical engineering. If the essence of creativity is to do something new or to do something in a new way, then we should give our students the intellectual tools that are needed for novelty; to do that, our students should become familiar with modes of thinking and with procedures of inquiry which are different from those we use in common chemical engineering. Simply put, creativity is likely to be stimulated by intellectual breadth.

The most common argument for breadth is, that for professional success, a chemical engineer must not only be technically competent but must also be familiar with economics and with all those humane skills that allow him to interact positively with a variety of co-workers and that, in general, lead to good citizenship. A further argument is that our alumni are not only chemical engineers but also intelligent human beings who seek to fill their leisure hours with satisfying enjoyment, and therefore it is proper to include music, art and literature in a chemical engineering curriculum. Without in any way subtracting from the weight of these arguments, I would add that breadth is necessary for creativity, not necessarily to produce a Gibbs or Freud or Bohr—because that is unlikely—but to provide our alumni with a broad attitude toward problems they are likely to encounter, to give them the capability to think beyond common chemical engineering when they face those new challenges—as they surely will—which cannot be solved by the conventional wisdom that is contained in standard chemical engineering.

In any one field of human endeavor, progress is inevitably attained by borrowing from another. The great advances recently made in medicine and in biology have come about primarily because of progress in experimental physics and analytical chemistry. Today, doctors can diagnose previously hard-to-detect pathology because of the CAT scanner which utilizes sophisticated x-ray technology combined with computers. Further, while recent discoveries in molecular biology promise to produce cures for serious diseases, they are only possible because of powerful electron microscopes, refined chromatographs and sensitive detectors of isotope radiation. Similarly, regardless of what opinions we may have of modern art and modern music, we recognize that the new art forms that are appearing in the United States and Europe are increasingly influenced by the encounters that our artists and musicians have with non- Western cultures, notably African, and with electronic tools and gadgets, including the computer. I mention all this only to emphasize once more that progress results from cross-fertilization and to stress that in any area of human activity, significant novelty is only achieved by going beyond the frontiers of that area through adoption of achievements from other areas.

Let me close by reflecting briefly on how these general ideas of breadth and creativity can be put into practice, given the inevitable boundary conditions under which we must operate. In undergraduate programs, our primary educational obligation is to impart professional competence such that our alumni, within a year or less, can make productive contributions to their employers. To achieve that end in a reasonable number of semesters, we tend to believe that we must fill the curriculum with numerous required courses, leaving little room for breadth. I suspect that we have gone too far in specific course requirements and that at least a few required courses are in our curriculum not because they are truly necessary but because of tradition (because the professors responsible for the curriculum took these courses when they were students) and because every professor in the department insists that *his* particular specialty must be taught to everyone, essentially because he likes to teach it.

If we are serious about encouraging creativity for undergraduates, we must open up the curriculum and encourage at least our better students to become familiar with intellectual concepts and tools that are not now common in chemical engineering. Clearly, not all students will benefit from such exposure, and therefore we should have flexibility such that our average students will do more or less what they do now but where the student with unusual potential is permitted and encouraged to deviate from the norm and to direct at least a part of his imagination toward other intellectual disciplines.

For graduate education, where the curriculum is less rigid, we should insist that our students take some high-level courses in other departments. By high-level, I mean courses with significant intellectual content; that is, courses taken by majors in other fields, and not survey courses designed for general education. Further, we should encourage independence and develop self-confidence by insisting that in their second year of graduate study, our PhD students pass an oral proposition examination where the candidate proposes an original research project on a subject remote from his PhD thesis. The student must defend his proposal to a committee of professors that should include one or two colleagues from departments other than chemical engineering. Except for remoteness from his thesis, there should be no restriction concerning the subject of the proposed research. The important point is that the student must choose the proposed research topic himself, that he receive minimum guidance in preparing his defense and that in judging the proposal, the examining committee insist on high intellectual standards, regardless of utility.

Given the job-oriented goals of the chemical engineering curriculum, it is not likely, nor is it desirable, that there be a major shift in the intellectual menu for most chemical engineering students. But for those students who have creative potential, I hope that we can relax our sectarian interests and expose them to intellectual vistas that at present have nothing to do with contemporary chemical engineering but that some day, through the inventive genius of our younger colleagues, may broaden and enrich the domain of our profession. ☐

ChE book reviews

ENGINEERING WITH POLYMERS

by Peter C. Powell
Chapman & Hall, 733 Third Ave., New York;
$49.95 HB, $25 PB (1983)

Reviewed by
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Engineering with Polymers by Peter C. Powell, Mechanical Engineering Department, Imperial College, London, is a text designed for final year undergraduate students in mechanical engineering. It assumes no prior knowledge of polymer science or chemistry on the part of the student. It is the author's stated intent to present the "minimum useful knowledge of engineering with polymers within a mechanical engineering degree course."

There are four main sections to the book: (1) The first four chapters provide an introduction to the language, terminology, and technology of polymers. This includes an introduction to polymer physics, polymer materials science, and polymer processing. (2) Two chapters provide an introduction to the mechanical behavior of polymeric materials, one on stiffness and the other on strength. (3) One chapter outlines the mechanics of fiber reinforced composites, and (4) Two chapters provide an introduction to polymer fluid flow, heat transfer and the effect of processing on properties.

Given the mechanical engineering orientation and purpose of the book it is not surprising that the book's most comprehensive treatment is given to the mechanical behavior of polymers and the mechanics of composites. The treatment of polymer processing is largely descriptive and somewhat superficial. A valuable part of the book are the problems associated with each chapter and an outline of the solutions, which makes the book well suited for self-study. The sections on polymer and composite mechanics would be a useful adjunct to a first course in polymers for chemical engineers, which would probably provide a more comprehensive introduction to property-structure relationships and processing. ☐