CHEMICAL ENGINEERING AND THE OTHER HUMANITIES*

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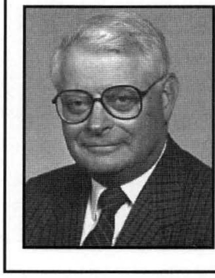
How is engineering related to other intellectual or professional disciplines? What is the role of chemical engineering in a modern university, and how does it fit into the spectrum of knowledge? And, finally, what can possible answers to these questions tell us concerning our educational philosophy and curriculum for training the engineers of the future?

These are difficult multidimensional questions with many aspects. I will discuss here only one aspect, one that is essential but has not received much attention: the need to remember that chemical engineering is not an isolated subject; that it is not limited to applied science, but rather is a significant part of daily life, related to health, to human relationships, to politics and sociology and law, to the way we think and feel about ourselves as individuals and as members of society, to our aspirations, our hopes, and our fears. In other words, I want to emphasize the old but too-often forgotten concept that chemical engineering is not apart from, but indeed a part of, what (broadly speaking) we call the humanities.

Toward introducing that concept, Figure 1 shows a famous painting by Titian. The painting, about 400 years old, is in the Borghese Palace in Rome and is titled *Sacred and Profane Love.* Early in this century, a copy of the painting was on the wall of the seminar room of the Institute for Mathematics at the University of Göttingen in Germany. From the middle of the nineteenth century until 1933, when the Nazis started to destroy the German universities, Göttingen was the world's leading center of mathematics, attracting the best minds of the day. In the seminar room, underneath the painting, was not the original title but a new one, *Pure and Applied Mathematics.*



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We do not know who retitled Titian's painting, but it was not only for amusement. The institute at Göttingen was far ahead of its time; not only was the mathematics done there new, vigorous, and bold, but (what was, and too often is still, unusual) the Institute also did outstanding work in *both* pure and applied mathematics. It was far ahead of other mathematics departments and gave serious attention to numerical methods for solving difficult differential and integral equations.

The painting and its new title were intended to stimulate discussion, starting with the obvious question: there are two female figures—which one represents pure mathematics and which one represents applied mathematics? The question can be argued either way. The woman without clothes could be identified with carnality, with the physical as opposed to the spiritual side of life, and therefore represents applied science, while the clothed, serious, brooding woman represents ascetic values, divorced from earthly concerns, and thereby represents pure science. On the other hand, we could argue that the absence of clothing and the upward ecstatic glance toward heaven represents purity, while clothing (notice that the clothes are coarse and drab) represents earthly values and that the clothed woman's dour, downcast look represents the

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* *Adapted and abbreviated from a lecture delivered at Notre Dame University, The University of Missouri-Columbia, and the University of Michigan (1996-97).*

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applied sciences that must deal with daily realities.

Titian's painting shows that there is a unity in opposites, an old idea in philosophy: truth and ultimate reality are revealed to us in a variety of faces. In today's world, we talk about unity in diversity, we read books about the increasingly similar roles of male and female, and we profess the virtues of blending Eastern and Western cultures. *Sacred and Profane Love* (or *Pure and Applied Mathematics*) illustrates the fuzziness, the growing disappearance of borders between intellectual categories. It shows what is increasingly recognized in universities today—that, while university departments may be necessary for efficient administration, intellectual concerns now overflow departmental division. Intellectual concepts are increasingly delocalized as the interests of faculty in one department overlap those in another.

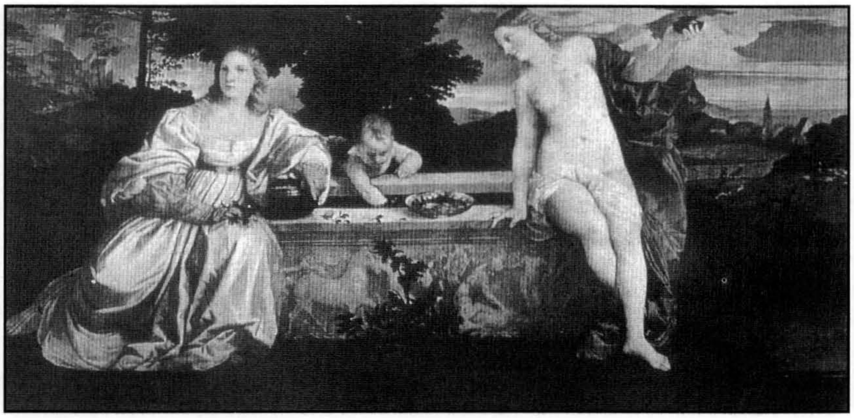

Figure 1. Sacred and Profane Love, *by Titian. In the Mathematical Sciences Institute of the University of Göttingen it was retitled* Pure and Applied Mathematics.

My claim, that chemical engineering is one of the humanities, goes beyond the by-now clear evidence that contemporary chemical engineering is increasingly related to a variety of other physical and biological sciences. What is only slowly becoming apparent is that chemical engineering is also closely related to the social and humanistic "sciences," where "sciences" is now in the original sense of "scientia"—that is, not necessarily natural science, but more generally, knowledge in all of its varieties. This close relationship follows from both practical and intellectual trends in contemporary society, as I shall now try to explain.

The practical trend is so fundamental that we are tempted to forget it: chemical engineers exist because society wants chemical products that will satisfy human needs. Chemical engineering is driven by society's wish for a better life, where better is not only materialistic, but also deeply human—as for example, in medicine and pharmacy for health, in cosmetics for beauty, and in agricultural chemicals for feeding a hungry world.

I can best illustrate the practical and also deeply human basis of chemical engineering by recalling a revealing anecdote from a late colleague, Professor Irving Fatt, in Berkeley's optometry department. He asked his class, "Who is responsible for the multimillion dollar contact lens industry?" As usual, initially there was silence, followed by some students shyly mentioning names of prominent polymer scientists. "Wrong," replied Fatt, "The father—more correctly, the mother—of the contact lens industry was a poet, Dorothy Parker, author of the immortal lines, 'Men seldom make passes...At girls who wear glasses.'"

Chemical engineers are driven into ever-new areas by the needs, often deeply humane needs, of a society that wants to improve its quality of life. Chemical engineers work not only to make girls more attractive, but also, for example, to make acid-free paper for preserving literary and historic documents, to make new drug-delivery systems for chronic illnesses such as diabetes, to make special paints and glues for restoring old paintings and archeological artifacts, to make new wound dressings for severe burns, to make water-absorbing gels for diapers and for providing moisture to the roots of desert trees that yield not only fruit for food, but also shade from the brutal sun. If the goal of chemical engineers is to satisfy human needs, chemical engineers must have some understanding of human nature, of psychology and international relations, of social organizations, and of the clash of cultures.

Chemical engineers do not live or work in a vacuum. They must understand labor laws, health insurance, safety, pollution abatement, and local customs and cultural values—in other words, the concerns of social scientists from economics to sociology. But beyond that, a successful chemical engineer must also understand how his product can either satisfy or offend his constituency; he must have some understanding of the ever-so-complex human soul, and that inevitably leads him to history, to psychology and to art—in short, to the humanities.

Both practical and intellectual trends in contemporary society make chemical engineering one of the humanities. The intellectual trend is not as evident as is the practical one, but it is clear to anyone who is familiar with what literature, art, and philosophy have emphasized for at least two generations: the dissolution of boundaries, the inter-relatedness of objects, phenomena, and observers. Nothing stands alone. Any one thing is without end, related to many other things. Literary critics tell us that to understand a text, we must probe not only into the author's history and his state of mind when he wrote his text, not only must we consider the customs and prevailing values that existed when the text was written, but we must also probe into the reader's history and his values and his state of mind when he reads the text. Thus, every interpretation depends on numerous factors, including the color of the book cover and the type of paper used by the printer. In the limit, this critique leads to the infamous movement "Deconstruction" where ultimately nothing objective remains. The only remaining ultimate reality is inter-relations.

The dissolution of boundaries is strikingly evident in art. Figure 2 shows Escher's *Night and Day.* Notice how the white birds flying to the right change, not abruptly but continuously, to black birds flying to the left.

The dissolution of boundaries extends not only in space, but also in time. Figure 3 shows a famous painting by Marcel Duchamp titled *Nude DescendingStairs* (An unsympathetic critic called this painting "Explosion in a Tile Factory.") We cannot localize the young woman; her fuzziness is not only spatial, but also temporal; she is simultaneously at the top of the stairs and at the bottom.

A related idea is indicated in a remarkably simple modern sculpture by my former graduate student, Dr. Bryan Rogers, who is now chair of the Art Department at Carnegie Mellon University. Bryan is probably the only person in the world who has a joint PhD in chemical engineering and in art. Figure 4 shows a set of clocks as found in any international airport. But the usual designations, *e.g.,*

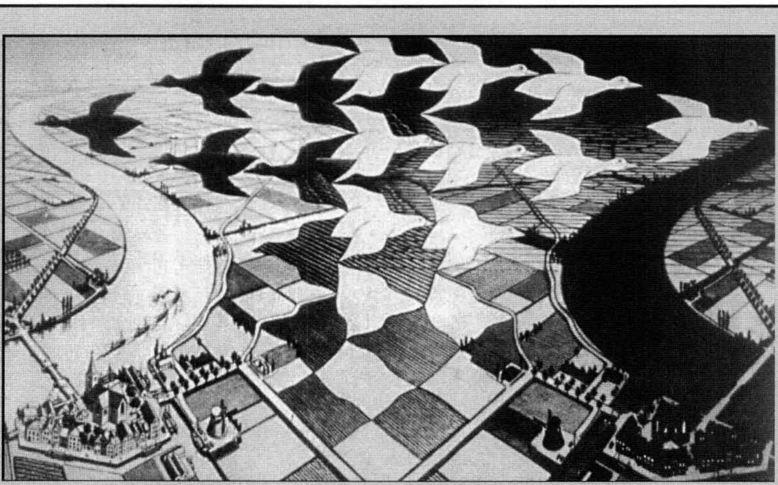

Figure 2.
Night and Day,
by Escher

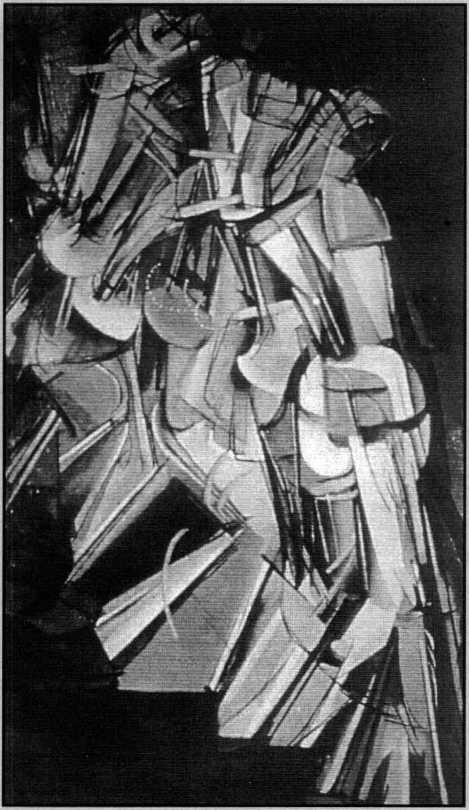

Figure 3.
Nude
Descending Stairs,
by Duchamp

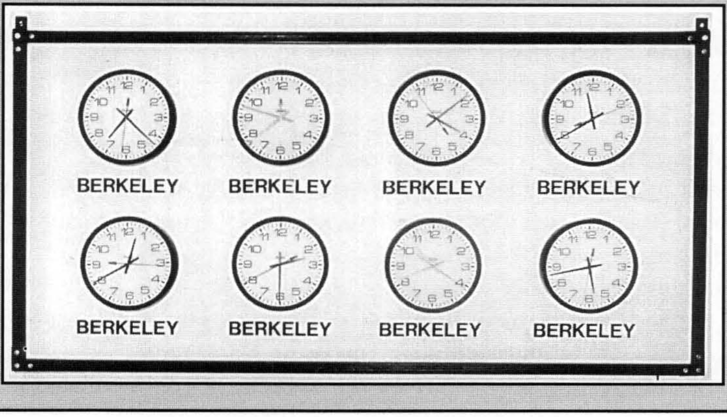

Figure 4.
Berkeley,
by Rogers

New York, London, Tokyo, Moscow, etc., have all been replaced by Berkeley. We see here the idea of inter-relatedness. No place is isolated; what happens anywhere in the world, happens also in Berkeley.

Twenthieth-century philosophers like Heidegger, and especially his German disciple Georg Gadamer, and to some extent his American admirer Richard Rorty, have emphasized the importance of context and contingency. The significance and effectiveness of any object lies not in itself, but in how it interacts with its environment. This fundamental idea has greatly influenced recent and current work in history, literature, economics—in just about every social science and humanities department in every major university.

In literature, history, anthropology, sociology, law, business administration, etc., emphasis is increasingly placed on interrelationships, on how one subject is related to another—in other words, on context. Historians of art are not only looking at what artists were doing at the time when a particular painting was created; they are also looking at the social relations that artists had with each other and their patrons, at the political climate of the time, at the literature of the day, at religious practices and conventions, and at the mechanisms artists used to publicize and market their work. Researchers in business administration are no longer primarily concerned with the internals of a corporation, but instead, with how the corporation relates to the community, with health and safety matters, with how corporations interact with other corporations, with government, and with social groups representing a variety of religions and ethnic traditions. Mathematical economists are interested not only in cash flow, taxes, and interest rates, but also in so-called externalities, including psychological factors, tastes, fads, fashions, perceptions, and the persistence and decay of myths and folklore.

No objects or subjects exist by themselves, but always in relation to other objects or subjects. Chemical engineering, by itself, has no value. The value and legitimacy of chemical engineering arise only when it stands in relation to something else, toward satisfying some human need, toward answering a question of deep human concern. Chemical engineering is an applied science in detail, but it is a humanity in intent.

[We must] show students how technology is related to human needs, both personal and collective; how applied science is a response to human aspirations and how it often is not just a consequence of, but also a stimulus to, pure science; and how the concerns of what men and women want and need drive the academic programs for all departments on campus. Like everyone else at a scholarly institution, engineers or philologists, chemists or economists, physicians or theologians, we strive toward a better understanding of ourselves and toward a more noble life.

For chemical engineering education, the essential role of context should not be delegated to courses in humanities. To be truly effective, they can easily be integrated into the present chemical engineering curriculum. It takes only a little time to show students how chemical sciences relate to the world around us. Toward that end, the main requirement is an open-minded attitude by instructors, a willingness to depart from that confined area where they are expert and feel totally secure and to devote a few minutes to related areas where they are not expert but where the relevance of their subject lies and where they, as role models, can show humanity and openness to the world rather than the confinement of a narrow specialty. All too often the image that faculty present is such that only the instructors' expertise is visible, while their diverse talents, interests, passions, and weaknesses—in short, their humanity—remains hidden. No wonder that so many students think of faculty as a species separate from the rest of humankind!

The regrettable bifurcating mind of many faculty was aptly described in a short story by the Italian writer Ignazio Silone. In this story, the wife of a professor talks about him and gives the concise description, "Oh, he knows everything. But that's all he knows."

When we present the principles of refrigeration, we usually take a few minutes to discuss the desirable properties of refrigerants, including freons. At that time, it is a simple matter to talk briefly about how some freons attack the ozone layer that protects the earth from excessive ultraviolet radiation and to indicate the need for synthesizing new compounds that can serve as environmentally acceptable refrigerants.

To illustrate the principles of heat transfer, we need not confine attention to the time-worn double-pipe heat exchanger. Along with the usual equations for conduction, convection, and radiation, we could also talk about solar energy, cooling requirements for supercomputers, heat effects in reentry of space vehicles, cryosurgery, and such home-related topics as microwave ovens, fire-resistant pajamas for infants, or design of an effective fireplace.

When we talk about flowing fluids, let's mention check valves, rupture discs, human failures, and the tragedies at Bhopal in India and Chernobyl in the Ukraine. When we discuss condensers, let's mention fog at airports. When we derive colligative properties of solutions, let's talk about salt for removing snow on our streets and then about subsequent corrosion of automobiles. When we discuss evaporation, let's mention desalting of sea water and the drought in Ethiopia.

When we encounter the free energy of formation of ammonia, let's also say something about fertilizers, about starvation in Somalia, and perhaps a few words about the latest farm bill passed by Congress. Further, let's recall for our students that ammonia is used for making nitric acid, that nitrates are used for making explosives, and that if Fritz Haber had not invented his synthetic-ammonia process early in this century, Germany would have run out of ammunition in 1915 and would have been unable to continue World War I after the first year.

I mention these examples not only to stress the relevance of chemical engineering, but also to suggest that, when taught with generosity, chemical sciences can serve as an integrating factor for understanding our living world as described in newspapers, television, and history books.

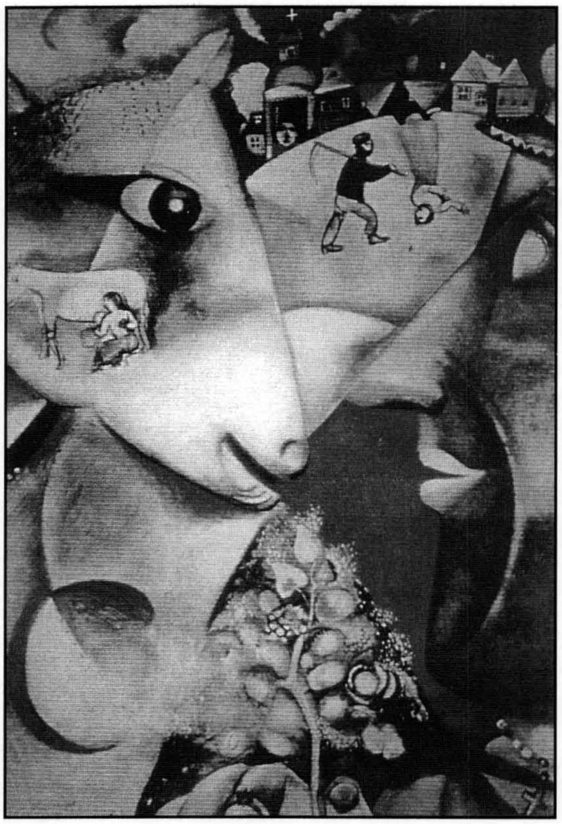

Figure 5.

I and My Village, *by Chagall*

To prepare students properly for meeting the expanded expectations of society, faculty can no longer restrict their undergraduate courses to narrow specialization with the comfortable thought that the student's "other" educational needs will be supplied on the other side of the campus. The responsibility for good education cannot be so easily compartmentalized. There is a crucial difference between the words *integrated* and *separate but equal,* as the U.S. Supreme Court decided about forty-five years ago.

If we believe—and I suspect that we all do believe—that engineering is ultimately not merely a technical but also, essentially, a human enterprise, then we are obligated to communicate that belief to our students in a consistent way. We cannot meet that obligation by merely requiring our students to attend an occasional course in history or anthropology or whatever. If we are to be consistent in our purpose, then it is our task, in our own courses, to show the intimate continuity between applied science and ultimate human concerns.

Pressures from government and its funding agencies are already providing incentives to encourage teamwork in research, better cooperation with industry, team teaching, interdisciplinary courses, and lowering of departmental barriers—in short, toward integrating engineering education and research with those broad areas that engineering serves. Funding agencies now prefer research proposals that are problem-oriented, to be conducted not by separate investigators but by a team of scholars from several disciplines. At the same time, students and parents are demanding that more attention be given to courses that emphasize "why" instead of "how," that stress overall purpose rather than details of method, and, as a perceptive undergraduate at the University fo Rochester said, "to courses that give fewer scales and more music."

As it prepares for the next century, every chemical engineering department faces two challenges. The first one is well known and relatively simple: to keep up with impressive new developments in science and to make them relevant for practice. Surely that is one of the traditional goals of engineering. It is likely that essentially all chemical engineering departments will meet this first challenge with success.

The second, and more difficult, challenge is to humanize the curriculum, not through new courses but by introducing into existing technical courses the human dimension; to show students how technology is related to human needs, both personal and collective; how applied science is a response to human aspirations and how it often is not just a consequence of, but also a stimulus to, pure science; and how the concerns of what men and women want and need drive the academic programs for all departments on campus. Like everyone else at a scholarly institution, engineers or philologists, chemists or economists, physicians or theologians, we strive toward a better understanding of ourselves and toward a more noble life. In our relations with students and faculty in other departments, let us not be separated by our differences but joined by our common purpose.

I plead for teaching this commonality of purpose not only because it is fashionable to reverse the alarming trend of the **uni**versity to a **multi**versity. My plea is motivated by two equally important goals.

First, if we humanize our curriculum, we produce better engineers, we raise the prestige of engineering, and we help to combat the threatening anti-science and anti-technology movements that are growing in our alienated population. Engineers must increasingly communicate, to listen with empathy to those who do not understand or who are frightened by new technology, and to speak to them effectively, leading them toward confidence and trust. Good skills in English are not enough. The engineer must also have some understanding of his audience; in other words, he needs to understand the human dimensions of his work. In the world now emerging, an American engineer must know how to communicate, to listen and to speak, with a peasant in India, a rabbi in Jerusalem, or a lawyer in Washington.

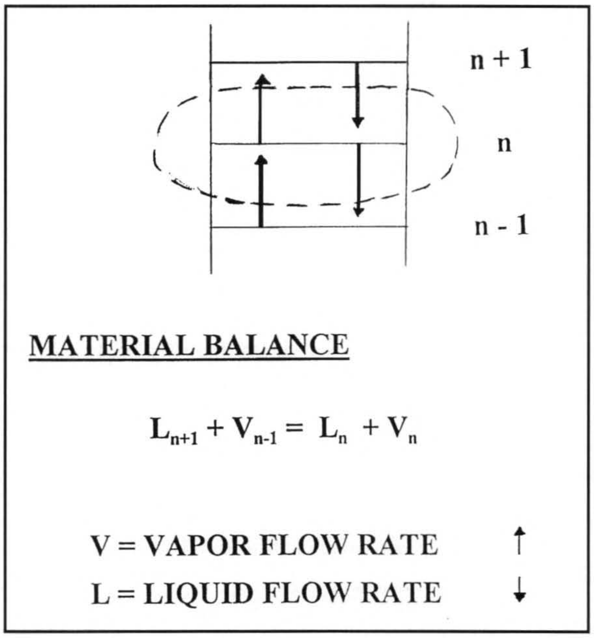

Figure 6. *Free-body diagram for plate n in a distillation column.*

Second, a chemical engineering department is not a trade school. A worthy chemical engineering department is not content to limit its educational efforts toward producing robots for industrial employment; it strives to produce thoughtful, sensitive, and independent-minded graduates who are not only competent engineers but also well-educated individuals, prepared for fulfilling lives both inside and outside their profession. To achieve this educational goal, engineering faculties must integrate and interrelate what we do in engineering with the greater world that engineering aims to serve.

Toward explaining my conviction that engineering is an integral part of our spiritual as well as our physical existence, I have shown examples from several artists. Finally, I would like to show one more: a well-known painting by Marc Chagall, painted about seventy-five years ago when Chagall was a young man remembering his childhood in rural Russia. In a sense, it is an autobiography. It is called *I and My Village* (Figure 5), and it indicates the influences that made Chagall the particular individual that he was at that time. It shows a set of memories that are separate, yet integrated to form a harmonious continuum.

Contrast this painting with the essential image we use to teach applied mechanics—the free-body diagram. In a free-body diagram, we isolate the essentials of our focus of study, we neglect the surroundings, and we ignore the context.

In teaching chemical engineering, we also use free-body diagrams. For example, as shown in Figure 6, in teaching distillation we look at one plate in the distillation column and then write mass balances for all flows that enter or leave that plate. In this exercise we forget not only the rest of the distillation column but also the entire chemical plant and the community that it serves.

I am not opposed to free-body diagrams, nor do I suggest that we refrain from using them in instruction. Free-body diagrams constitute a pedagogical tool that has been, and continues to be, valuable for effective education. But free-body diagrams convey an attitude, a philosophical viewpoint that is seriously incomplete. We should not abandon free-body diagrams, but we should not restrict engineering education to the attitude that they imply. I plead for a shift of balance where we rely not only on the isolated specifics but also, as suggested by Chagall's painting, give attention to the larger view, toward awakening engineering students to see both the leaves on the trees and the forest, the mountains and the cities, and the human beings that live in them.

To illustrate this shift of balance, to help our students broaden their professional horizons and to attain more meaningful lives, it may be useful to recall a well-known (possibly true) story concerning the great physicist Niels Bohr.

Bohr, a distinguished professor of physics at the University of Copenhagen, liked, on occasion, to retreat to a modest cabin in a nearby forest where he could read and think without interruption. But an enterprising journalist discovered this cabin, and wanting to interview Bohr, knocked on the door. Bohr opened the door and the journalist entered. When he did so, he noticed an old horseshoe nailed to the door frame. Surprised, he said to Bohr, "You are a great scientist. Surely you are not superstitious. Surely you do not believe that a horseshoe can bring good luck." Bohr answered without hesitation, "Of course I do not believe that. But I have been told that a horseshoe can bring good luck even if you don't believe it."

This charming story tells us once again that, even for a great scientist, life has a strong non-rational component and that we are all human beings subject to the hopes and fears that characterize the human condition. Let us reflect this duality when we teach our students science and technology. Let us not rely on others to do what we owe to the young men and women entrusted to our care. Let us show by our example and in our classrooms, that engineering, in particular chemical engineering, is also one of the humanities. ❐