mmentary

# The Culture of Chemistry: A Graduate Course

by Joseph F. Bunnett

The course I describe ought to be a component of Ph.D. programs in chemistry. But I have not taught this course and have no plan to teach it. The following description must therefore be understood to be in the subjunctive, but I use active verbs instead of numbing repetition of *should* and *would*.

The course title, The Culture of Chemistry, might be misleading. A more descriptive title is What a Ph.D. Chemist Needs to Know, beyond a Good Command of the Facts and Principles of Chemistry and Familiarity with Research Methodologies Gained in Dissertation Research, in Order to Have a Successful, Productive Career. But such a long course title displeases university registrars.

Returning to the formal title, let us ask, is there a Culture of Chemistry? That there is became clear to me about 20 years ago when I was briefly a guest of Guru Nanak Dev University in Amritsar, India. Guru Nanak Dev was the founder of the Sikh religion, and the highest temple of the Sikhs, the Golden Temple, is in Amritsar. The professors at Guru Nanak Dev University were groomed in proper Sikh fashion, the men with turbans and neatly disciplined beards.

My wife and I arrived in mid-afternoon and were soon invited to tea with members of the Chemistry Department faculty. To the eye, the scene was exotic, but as we engaged in conversation it became clear that the Guru Nanak Dev chemists were well-educated, levelheaded, creative people who share with chemists elsewhere in the world certain understandings about our profession: knowledge of chemistry and of our profession, and professional principles. I was in the friendly company of my kind of people, in a worldwide community of chemists, with many shared values. I have had the same realization many times in the course of chemistry-related travels, for example in Ibadan, Nigeria; Huhehot, Inner Mongolia; and Rio Cuarto, Argentina, as well as often in Europe, Japan, and North America.

What does a Ph.D. chemist need, beyond a good command of the facts and principles of chemistry and familiarity with research methodologies gained in dissertation research, in order to have a successful, productive career? Briefly, (i) knowledge of the structure of the institutions of the profession and an awareness of how they operate, (ii) knowledge and appreciation of the ethical principles of the profession, (iii) an understanding of professional practices among chemists, (iv) cognizance of general features of scientific research, including aspects of the philosophy of science and the history of chemistry, and (v) concepts of how a chemist with newly conferred Ph.D. can profitably develop his or her career. By "the institutions of the profession", I mean not only colleges, universities, industrial firms, and government departments, but also scientific meetings, societies and journals.

A few years ago (*1*) I put the same idea in these words: "Besides breadth in the core of chemistry—organic, inorganic, physical, analytical and biochemistry—the well-educated chemist needs some acquaintance with what I will call the *cortex* of our discipline. By the cortex, I mean bodies of knowledge and thought that illuminate the context within which chemistry is pursued. These include the history and philosophy of science in general and chemistry in particular, the social and political contexts of chemistry in the United States and in other countries, the organizational structure of higher education and of scientific research in the United States, and questions of ethics and values in science."

## Mechanics of the Course

The course is taught by the conference approach, in Reed College terminology. The class (of 10 to 20 students) meets around a large table or in a lounge once a week for two and a half hours of discussion, with the professor as discussion guide. Substantial reading assignments are made, and class sessions are devoted to evaluation of the readings, with facts or ideas of other origin often brought in. Most readings are from books or articles that students read as library reserve materials, although some books are purchased.

Relevant reading materials are abundant, in books and journal articles. To list all that are useful would be tedious; and surely some good ones are unknown to me. One book of special value that I recommend to buy, for repeated consultation during the course, is E. B. Wilson, *An Introduction to Scientific Research* (*2*). Wilson treats a wide variety of matters, philosophical and practical, that are important to any experimental researcher. Despite its misleading title, a book by Sindermann (*3*) gives good discussions of a number of topics; several chapters in it are assigned for reading.

Lectures have scarcely any role. Now and then, a professor or visiting resource person speaks without interruption for up to 20 minutes on a topic, but within the round-table or living-room format.

Most resource persons are chemists chosen for professional experiences that differ from mine. Some come from other nations. Others are industrial or government scientists, teachers at community colleges or undergraduate colleges, even a few who have given up chemistry for another line of work. (I know a man who did outstanding research in physical chemistry, and then switched to accounting!) The participation of a resource person is often planned in advance but can be arranged on the spur of the moment if a suitable person shows up. Also desirable as a resource person is a colleague from my department, whose views sometimes differ from mine. The colleague must, however, be in agreement as to the format and scope of the course; to have a scornful colleague acting as a virtual heckler would be destructive.

## Choice of Readings

The readings, chosen by me, tend to advance views that I wish to teach. Some, however, advocate other points of view. In discussion of such "contrary" readings, I do not hesitate to argue against an author's views. As students join in such discussion, they become aware of the complexity of some issues and that superficially attractive concepts are in some cases unsupportable.

Under the rubric Structure of the Profession, and Career Development, readings describe the administrative structures of institutions and how they operate.

Once a young woman student, to whom I had awarded a "No pass" grade, came to ask reconsideration, asking that I take nonacademic factors into account. I expected to hear a tale of woe such as about time spent in care of an ailing grandmother. I replied, stiffly, as though reading from a rule book, that I was obliged to base grades strictly on academic performance. Her response: "Oh, that's what they all say, but you know how it really is." Her request was to no avail.

But taking her statement at face value, let us recognize that "how it really is" may differ in small or large degree from stated principles and procedures. Thus, although in principle promotion is based strictly on the quality of one's work and thought, it is nevertheless unwise for a junior staff member to challenge openly the professional competence or judgment of a senior colleague. No matter how right the junior and how wrong the senior colleague may be. And there is the factor of politics. They say that if two people are isolated on a remote island, in time a stable relationship develops, which may be anything from mutual respect and support to master and slave. But if a third person arrives on the island, you've got politics.

## Colleges and Universities

Course readings describe the various kinds of institutions—research universities, undergraduate colleges, two-year colleges and "remote learning" operations—and what they do. Some readings give objective descriptions, while others are unrestrained in their praise of certain kinds, such as liberal arts colleges, and assert problems with other kinds. Matters of institutional governance are treated, including the roles of governing boards. So also are questions of finance, including current assertions that college tuitions are unnecessarily high.

The various officers, ranks, and job titles in colleges and universities, including faculty ranks, are outlined, as well as the roles of people who hold those ranks and titles. So also processes whereby people get jobs, gain promotions, or change institutions. The tenure system and occasional criticism of it receive due attention. Not neglected are three categories of academics who make important contributions but are often overlooked: postdocs, non-tenure-track teachers, and professors emeriti.

## Industrial Firms

After brief attention to the enormous scope of the chemical industry, which includes operations not usually labeled as "chemical", such as the Portland cement and the pulp and paper industries, the kinds of duties that a Ph.D. chemist may perform are outlined. These include fundamental and "targeted" research, process development, customer service, and production. Other topics are concepts about the place of research in industrial firms; the roles of consultants; and ways in which the situations of industrial chemists are affected by management decisions, including the rearranging of corporations by financiers. Also, how to be an entrepreneur.

## Scientific Societies

Although a few are well known to graduate students, the variety of the world's scientific societies and their differing characteristics need description. Some consideration of scientific societies in historical perspective is necessary. The governance of societies is treated, with tips on how to become involved in governance if that be one's interest. The current restructuring of IUPAC is studied. Mentioned in that connection is the charge sometimes made that IUPAC Commissions, which have met regularly at biennial IUPAC General Assemblies with travel expenses of Titular Members paid by the Union, are in some cases little more than cozy social clubs with principal interest in perpetuating themselves.

The fact that some chemists have satisfying careers in employment by scientific societies is noted in the course, although seldom mentioned elsewhere.

## Scientific Meetings

The various sorts of meetings, ranging from snug conferences on one topic, involving a few dozen specialists, to American Chemical Society national meetings with up to 15,000 chemists of all sorts, are described. Not-so-obvious features of meetings, such as finance, choice of officers, and arrangement of programs, are of interest to students.

## Scientific Journals

Graduate students need to understand something of the history of journals, how they are organized, the roles of editors, publication committees, and editorial advisory boards, the reviewing of manuscripts, and the mechanics of getting journals into print. Consideration of "electronic journals" is inescapable. The ACS Style Guide (*4*) and the *Ethical Guidelines to Publication of Scientific Research* (*5*), issued by American Chemical Society journal editors, provide a good deal of information about the mechanics of publication, as well as statement of ethical principles. Discussions touch on matters such as what determines the prestige of journals and how prestige can be attained, styles of writing in scientific papers (*6*), and the economics of journal publication. Relevant thereto is the economic pressure placed on scientific libraries by the remarkable expansion of scientific literature in recent years.

## Philosophy of Science

Attention to aspects of the philosophy of science makes some colleagues uneasy. Some chemists unfortunately view the area as abstruse, without relevance to research in chemistry, even as their own behavior exemplifies principles recognized by philosophers.

The famous book of T. S. Kuhn, *The Structure of Scientific Revolutions* (*7*), is assigned to be read cover to cover. It provides, in readable fashion, a view of what happens when a scientist proposes an entirely new hypothesis challenging the then-prevailing wisdom. In several instances that new hypothesis was ultimately accepted, but only after much strife. Class discussions inquire whether Kuhn's analysis is valid, and if so, what instances of the phenomenon members of the class can identify on the current scene.

An example of the resistance of scientists to a new hypothesis was discussed by Michael Polanyi (*8*). In 1914–1916 he published a hypothesis concerning the adsorption of gases on solids; at first it was almost universally rejected, but years later was accepted by physical chemists. Nevertheless, Polanyi argued, the early rejection of his hypothesis was necessary as part of the intellectual methodology of science. "There must be at all times a predominantly accepted scientific view of the nature of things…A strong presumption that any evidence which contradicts this view is invalid must prevail" (*8*).

Another important philosopher of science is Karl Popper (*9*). Like me, many chemistry graduate students find his discourse difficult to read. For that reason, Popper reading assignment are comparatively short.

A philosopher for whom I have high esteem, despite his lack of general recognition, is T. C. Chamberlin. An American geologist, he published an important essay (*10*) in 1890 while president of the University of Wisconsin. In it he cautions of the dangers of parental affection for a hypothesis a scientist has developed. "There springs up…an unconscious pressing of the theory to make it fit the facts, and a pressing of the facts to make them fit the theory. …From an unduly favored child, it readily becomes master, and leads its author whithersoever it will." Please think, dear reader: has that happened to any of your scientific acquaintances? Chamberlin advocates that a scientist develop multiple working hypotheses, all to be treated objectively.

The most important philosopher of chemistry was Antoine Lavoisier, for by application of his philosophy (*11*) he founded chemistry as a science.

Discussions of the philosophy of science, as well as of topics such as scientific ethics and mistakes in research, often consider historical examples. In this sense, the history of science and especially of chemistry enter the course. Despite my own intense interest in the history of chemistry, I do not give it major emphasis.

## Ethics in Science

This topic may be the most important in the course. How best to teach it? In the authoritarian approach, one might lay down the rules of proper ethical behavior and accompany that with readings that exemplify why ethical behavior is essential to science. My taste is to start that way, but follow with the article "Is It Ever Right to Lie? The Philosophy of Deception" (*12*), which suggests the answer: sometimes, yes. Searching discussion of such contrasting readings enables students to appreciate the importance of high ethical standards. I then assign readings about reported cases of allegedly unethical behavior, and in conference discussions construct hypothetical situations (*13*) in which ethically proper behavior is not immediately obvious. Noted also are practices of scientists, not infrequent, that are marginally unethical (*14*).

## Mistakes in Research

Mistakes of both observation and interpretation are examined. A case-studies approach is used, and in conference discussions much attention is given to how the mistake could have been averted, given the state of laboratory technology and of theory at the time. In some cases, it is clear how mistakes could have been avoided; in other cases, one can only speculate. I preach the admonition: Don't Make Verifiable Assumptions. Examination of mistakes in my own research and how I could have avoided them brings the discussions "down to earth".

## Education

Principal emphasis is on questions of educational principle. These include remedial education for first-year college students, the educational value of research for undergraduates, the time required for education to the Ph.D., the role of research professor (*15*), and science education for the general public. Techniques of education and matters of course content are underemphasized.

## How to Make Important Discoveries

A more formal rubric would be Choice of Research Problems. Either way, choices of what to study in research affect or determine the impact that a scientist's work will have. Cogent, conservative thoughts are expressed by Wilson (*2*). More provocative, and yet constructive, are recent books by Austin (*16*) and Oliver (*17*). Other readings are in autobiographies of chemists, as well as some published thoughts of my own (*18*). A few case studies from the history of chemistry are also relevant. And in discussion, I bring in tidbits such as Pasteur's remark, "Chance favors the prepared mind."

## Grant Support of Research

Few academic institutions have financial resources sufficient to support modern chemical research. Even theoreticians who work alone need a computer as well as the proverbial pencil and pad of paper. Less obvious are the history of grant support of research, the variety of organizations that provide it, their various purposes, and concepts about why society should support research. Research funding has changed since times when wealthy Cavendish and Lavoisier supported their work from their own means and Priestley made major discoveries in experiments conducted on the window sill in the kitchen.

## Career Development

Like other folks, chemists want to rise in status, rank, salary, and prestige. How this happens is best judged from attention to the careers of individuals. Autobiographies of famous people, including those in the American Chemical Society "Profiles, Pathways, and Dreams" series, are valuable. In respect to academic careers, the Symposium-in-print, "Faculty Renewal and Development", in the December 1980 issue of the *Journal of Chemical Education* is useful.

Success in interaction with people contributes in no small way to professional advancement. A basic principle is that productive interactions between people are facilitated by mutual respect. It pertains between coequal colleagues, but more so between persons of unequal rank, such as laboratory directors and bench scientists, scientists and support personnel, teachers and students. (Teachers must respect the valid interests of students, and must earn the respect of students by their competence and their decency in dealing with students). Early in my career, I now and then needed help from a technician; he was skilled and had other fine qualities, but whenever I went to his shop I had to suffer a few vulgar stories; I suffered, tolerating them sufficiently so that he willingly helped me on the next occasion. I perceived his stories as one of those foibles that we all have. I doubt that he would have been so helpful had I shown disapproval. (Whether my behavior was correct is a topic for class discussion.)

In addition to their direct intellectual value, scientific meetings are valuable for facilitating interpersonal interactions (*19*). Companionship develops as scientists discuss a problem of mutual interest, chat at a reception, go together for dinner, or associate on an excursion. It has been my fortune to form valued friendships with scientists of many nations; many of them are closer friends than neighbors on my street in Santa Cruz. Such friendships are useful when unanticipated problems arise; one can telephone one's friend, whether nearby or in another nation, and quickly get valuable information or assistance. A typical situation concerns a student who wants to do advanced study, but has encountered a difficulty. Even if one has car trouble in a foreign city, a chemist friend who lives there can suggest a good auto repair shop, as I once discovered years ago.

## Research in Industry

Description and policy are the two main foci of this topic. Described are, first, the extent of industrial research in the American chemical industry (broadly defined) and in other nations, both currently and in former years. Second, patterns of organization of research, whether in-house in companies or as industry-wide cooperative research. The roles of consultants in industrial research are also treated.

Matters of policy include the perennial topic of the relative roles of fundamental and applied research in industry. The spectacular discoveries of polymers nylon and chloroprene stemming from fundamental research by Wallace Carothers in du Pont laboratories created a belief that "blue-sky" research in industry was a sure road to riches. But recent pressures in the financial world for increased earnings per share, quarter after quarter, have caused some firms to cut back on fundamental research because it contributes little to profit in the immediate quarter while erasure of its cost immediately increases "the bottom line". The concept that fundamental research on a technology to which a company is deeply committed is a form of insurance is examined. So also are questions of how the quality of fundamental research in an industrial laboratory can be evaluated. Other policy questions include the proper roles for government laboratories in support of industry, and problems as well as rewards from research on industrial problems in university laboratories.

A valuable book, a collection of papers by various authors, is D. Allison's *The R & D Game* (*20*). It offers many points of view, some irreverent. Also assigned are selected articles dealing with industrial research questions (*21*).

In conference discussions, my views are heavily influenced by several years of consulting with the research team at Burroughs Wellcome & Co. led by George Hitchings with Gertrude Elion as his chief lieutenant-scientist. They were extraordinarily successful in the discovery of drugs effective to treat a variety of diseases, as recognized by the later award of a Nobel Prize to Hitchings and Elion. Noteworthy was an emphasis on fundamental research, coupled with encouragement of staff to attend meetings and publish their findings.

A few people with industrial chemistry experience participate in certain class meetings in order that industrial chemistry be adequately represented in discussions. At least one of the current or former industrial chemists has pharmaceutical industry experience.

## Concluding Remarks

So, that is the course. It is atypical as a chemistry graduate course, but much appreciated by the students who take it.

Another professor might teach a course of this character with somewhat different emphasis or choice of topics and readings. That's academic freedom for you.

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