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Industrial Microbiology—Concepts, Challenges, and Motivations

ARTHUR M. KAPLAN

U.S. Army Natick Laboratories, Natick, Massachusetts 01760

President Rogers, members of the Board of Directors, members of the Society for Industrial Microbiology, Ladies and Gentlemen. It is with deep emotion that I acknowledge receipt of the Charles Thom Award from the Society for Industrial Microbiology. It is an honor that is cherished since it is bestowed by my peers and therein lies its special significance for me.

Industrial microbiology, by definition, is based on the talents derived from the disciplines of science, engineering, and economics. It gathers together individuals from industry, universities, government, and private foundations. Here in this room we find microbiologists, chemists, mathematicians, engineers, materials specialists, and administrators to name but a few. To be noted by a group representing such diversity is indeed complimentary by itself. However, it is of particular salience to me because this multifaceted group highlights a frequent reality in our endeavors; that is, the presence of colleagues of various disciplines and interests working together toward the solution of problems calling for their several skills. This has been, for many of us, at once an opportunity and a challenge; an opportunity because it permitted one to understand, to some slight degree, the working and applications of another discipline and a challenge in bringing about meaningful communication between individuals so that efforts could be productive. This is especially true for that segment of microbiology where my efforts have been directed, that of microbial deterioration of materials. This, to many people, is an esoteric, bizarre sort of profession having something to do with moldy books; or, from another aspect, an art practiced by alchemists with a peculiarly modern twist—that of keeping gold from turning into dross! In reality, we concern ourselves with all manner of materials, all aspects of science and technology, and every conceivable industry. As a result, interdisciplinary effort is the very heart of our endeavors.

Many in industrial microbiology have long recognized the value of the interdisciplinary approach. The term "interdisciplinary" has been used interchangeably with the expression, "team" approach. Often, in practice, both are indeed the same. I should like, however, to make a distinction between the two because they are not necessarily synonymous since one can be cognizant of and have the talent to pursue interdisciplinary investigations as an individual. Still, it must be recognized that in this day of extreme scientific specialization there are relatively few people who are so blessed. It is interesting to observe, parenthetically, that the National Science Foundation is now sponsoring interdisciplinary research and that universities have established interdisciplinary studies curricula. As a result of such activity, perhaps we shall see in the future the more frequent appearance of the new renaissance man who is capable of conducting diverse studies by himself. However, in view of present circumstances, where there is a dearth of contemporary Leonardo da Vincis with such inherent proficiency and working with others is thus a necessity, how is the challenge of working with colleagues of other

This paper is the 1970 Charles Thom Award Address.

disciplines managed? How is this accomplished so that each individual involved contributes fully and unstintingly the best of his professional capability and intellect? On the one hand, I presume that this can and is frequently brought about through executive fiat, i.e., do this because I so direct it. In this situation, consequences are apt to be dire if failure results; if well done, tangible reward may follow. Motivation for cooperation is clear and self-evident. I submit, however, that in the greater number of cases the individual is solely or additionally motivated by the sheer excitement of the problem as he sees it or as it is communicated to him by others. He sees the opportunity of employing his talents, of appreciating the fact that without these talents an essential ingredient toward the solution will be lacking, and that somehow his is one of the major touchstones that magically catalyzes the effort into tangible, fruitful, significant results of one sort or another. It is this sense of a person's worth and dignity that leads him to work with scientific strangers, to be tolerant of other approaches, to solicit help, and finally to savor the accomplishment.

At this point, I suspect that the thought must be running through some of your minds that I describe a fantasy that just doesn't happen in the real world, that individual motivation divorced from tangible reward, or lack of it, does not exist. Well, what is the real scientific world? Recently, I attended a conference concerned with disinfection of water supplies and waste water treatments. Early in the conference, there was discussion of a laboratory study. The speaker pointed out that the study, of course, had to be considered in the light of circumstances existing in the real world and experimental conditions were therefore established to simulate "real world" conditions. Following this, there was constant reference during the conference to the phrase "real world," with one speaker finally stating that the leading theme of the conference appeared to be the "real world." Why did the phrase touch a responsive chord? In one instance, because some of the conference attendees were engineers faced with overwhelming pollution problems that required immediate answers in terms of types of treatment plants, treatment procedures, and cost analysis among others. Nevertheless, as the same engineers spoke, it was interesting to observe the broadness of thought as demonstrated by the chemical, biological, and mathematical factors touched on and considered, the pride in tying in these separate but related arts, and finally the obvious sense of accomplishment in describing substantive design solutions. So, for this pragmatic group, there was present the individual motivation toward participating in a multidisciplinary task in exactly the terms described above and in the very real and present world of environmental pollution.

There were others present who were most interested in the mode of action involved in the control by halogens of water-borne pathogenic microorganisms. These people were also intrigued by the real world. Their real world consisted of such concerns as the failure of iodine to react with RNA isolated from representative enteric pathogenic virus, the inactivation of the intact viral particle by specific chemical species of iodine, and the determination of the exact situations required for a given chemical species to exist. Theirs was indeed the real world of providing means for insuring noninfective water supplies. But, in this real world, the dialogue between virologists, biochemists, organic chemists, physical chemists, and engineers generated a great deal of heat as each brought the tools of his trade, if you will, to bear on the problem and each was certain that the other's science simply didn't explain things properly. Here we had inputs of the various crafts but, since this was a world where definitions and proofs were at a basic level, the validity of each position was more difficult to establish as contrasted with the more visible and tangible solutions of the engineers. Each individual protagonist, however, was motivated to contribute his science toward unravelling the chemical, physical, and biological complexity by the sheer challenge of the problem. Thus, I feel that one does not deal in fantasy but indeed finds in the real world of science the justification and drive for individual expression in interdisciplinary research.

In citing examples to illustrate scientific motivation for interdisciplinary effort, I have chosen one example from the very applied area of civil engineering and the other example from a more basic level of science, the mode of action of biocides. Yet, both are parts of industrial microbiology. It is intriguing that in industrial microbiology, by its very title an applied science, there exists significant basic effort. Again, those who are part of industrial microbiology are not surprised because they know that application and technology are based on such studies. Examples can be found in such areas as the mechanisms of transformation of steroids by microorganisms, the production of antibiotics, studies concerned with influencing metabolism of microorganisms to favor elaboration of a given metabolite of commercial value, mode of action of enzymes in breaking down given organic substrates, iron and sulfur metabolism of importance in metal corrosion, concrete erosion, and water pollution, and so forth. What is surprising to us, I believe, is the rather tardy recognition that basic research can indeed be application-oriented research rather than research for its own sake, with no thought given to its ultimate usefulness. I should like to illustrate this point with a specific example to indicate that this thought is neither heretical nor contradictory.

A number of years ago we undertook studies to provide better protection to cellulosic textiles than we were obtaining with fungicides available to us. One of the more promising developments at that time was the treatment of the cellulose with a compound, trimethylolmelamine, that offered passive protection to the cellulose as contrasted to the active protection offered by fungicides where fungal growth is prevented through the toxic action of the fungicide. Obviously, since the compound was nontoxic to cellulolytic fungi, it established a barrier that somehow prevented access of fungal cellulases to susceptible sites of the cellulose molecules. We naturally were curious as to whether this was due to a gross barrier effect on a supramolecular level, i.e., the formation of polymers that would plug pores in the cellulose structure or coat fibers thus blocking enzymes, or whether the effect was due to chemical linkage of the melamine compound with cellulose at a molecular level, altering the cellulose structure so that the enzymes could not approach a susceptible molecular site because of configuration changes in the cellulose. Work carried on in our own laboratories and in other laboratories commissioned by us to study the problem established that there was indeed covalent linkage of the trimethylolmelamine with cellulose and that this linkage occurred at carbons 2, 3, and 6 of the anhydroglucose units of the cellulose molecules. At the same time, it was also shown, using regenerated cellulose gels, that polymer formation occurred in the pores of the gels, plugging the pores. We thus were faced with some support for blocking at either the molecular or supramolecular level or a combination of both.

For a number of reasons, we decided to concentrate on changes at the molecular level and we continued our studies for the most practical of motives. If we could establish the exact number and distribution of altered molecules required to prevent cellulase fit with the cellulose substrate, we would then have a valuable basis for development of treatments on rational rather than empirical grounds. But in order to do this, we must first have an idea not only of the structure of the modified cellulose substrate but, as important, an idea of the structure and exact conformation of the cellulolytic enzymes. This requires the purification, separation, and isolation of crystalline enzymes so that the proper tools of physical, analytical, and biochemistry can be utilized to determine structure and conformation. Where does this lead? To one of the very frontiers of basic science, the elucidation of the exact structure of protein molecules. A study that is certainly fundamental yet, in the present context, one of direction for very practical reasons. It is because of this seeming paradox that in our own laboratory we make no attempt to classify our efforts. We do what is required of us and have used the rather nondescript terms of short- or long-range research to describe our efforts if we are pressed for definitions.

The concern for putting a label on the type of research done has been a matter of discussion for many years and still continues. As recently as June 15 of this year, Dr. Otto Behrens, Associate Director of Research, Eli Lilly Research Laboratories, in an article in *BioScience*, discussed the interrelationship of basic and applied research in the pharmaceutical industry. His was an introduction to four other articles prepared to illustrate various ways in which pharmaceutical research interacts with the basic sciences. The articles used as examples were concerned with interferon inducers, proinsulin, enzyme induction by drugs, and immune suppressants, respectively. The authors included employees of two drug companies, a consultant to a drug company, and a university professor. All the articles demonstrated the preoccupation of the authors with basic phenomena and the authors' biographical sketches confirmed this. For example, one author had written extensively on the amino acid sequence of glucagon and proinsulin, another on the physiological role of the hepatic microsomal mono-oxygenase enzyme system, etc. Nevertheless, all the articles were obviously related to practical goals of drug companies. How to describe such research? Dr. Behrens held to the distinction between basic and applied research but observed: "The consideration of goals for applied research may lead to the realization that certain basic phenomena must be investigated before experimental approaches to the practical problem can be formulated. In such instances, the experimental differences between basic and applied research may be insignificant." He also noted and gave examples of the contributions applied research has made to basic research thus: "With the discovery of the antibiotics came the recognition that these substances also serve as new tools for the study of metabolism." Reiss, in an article in the June 29 issue of *Chemical and Engineering News*, discussing industrial research careers, also is concerned with descriptive terms for research. He prefers the terms phenomena-oriented research to basic research to indicate its involvement with the elucidation of natural phenomena. Concerning applied research, he states: "The term applied research will be retained to indicate involvement with application and creative activity concerned with the integration of knowledge components, in novel ways, into technological constructs." He further states: "Applied, as well as phenomena-oriented, research can involve the investigation of fundamental mechanisms on the atomic and molecular level, and in this sense can be fundamental as opposed to empirical or Edisonian. This fact is often seriously overlooked by students, and leads to an erroneous order of preference in which applied science is usually a second choice."

During the 50's and early 60's when federal funds were bountifully available, basic research was the only research in the minds of many. Presently, both in the United States and Europe, mission orientation is being emphasized. Of course, both efforts must be carried on but I must say, and I have attempted to illustrate the point, that mission orientation offers the same individual and scientific challenge that has always existed in the realm of what some prefer to call pure science. In some ways, the challenge is greater because one is now forced to think beyond the direct job of conducting research in his specialty alone. Perhaps it is for the better if we are forced to broaden our outlook, in spite of ourselves, to consider other elements involved in this "real world" of science and technology, to absorb something of the philosophy and talents of the new renaissance man that I mentioned earlier, and to appreciate the discipline and delicate art of interdisciplinary thinking. And it can be done without any compromise of principle. For it all lies in the mind of man to conduct his research so that it is of value by any orientation one wishes to apply to it or by any term one uses to describe it. The problem is not with the constraints of the real world of industrial microbiology or science, but with the constraints the individual establishes to prevent himself from recognizing the only criterion that matters, and that is the quality of what he does.

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