ChE views and opinions

SOME THOUGHTS ON THE NATURE OF ACADEMIC RESEARCH IN CHEMICAL ENGINEERING

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THIS PAPER HAS GROWN from a request to say something about the scope of chemical engineering research in the universities of North America to the Sixth Interamerican Congress of Chemical Engineering held in Caracas (July 1975). From the beginning it seemed hopeless to attempt a comprehensive descriptive review, for with so vast a cargo it could scarcely hope to make passage between the Scylla of platitudinous dullness and the Charybdis of prejudiced particularity. One might, to be sure, form a matrix with a row for each university department, a column for each key-word in the chemical engineering thesaurus and elements proportional to the intensity of activity of research on the j^{th} topic in the i^{th} department. Like a famous text on transport phenomena, such a matrix might be read either by rows or by columns, but what would it say? Of quantity, it would speak equivocally; of quality, it would perforce be silent.

The attempt to divorce teaching and research is fatal to the life of a university department.

Rather than attempting to follow a descriptive path it would seem wiser to ask what kind of research is proper to a university and perhaps even to start on the *via negativa* by noting that purely developmental work is not appropriate to the academy. It is not that this kind of work does not demand great intelligence or resourcefulness—indeed, all the qualities of a good engineer—it is just that it can be done so much better in industry and there it belongs. In saying this I am not in the least denigrating usefulness for chemical engineering has no use for "the mathematician so pure that if you give him a number with a meaning he won't touch it" [1]. It is rather a matter of the obligations of the worker and the genius of the place in which he does his work. The obligations of the industrial scientist are to the interests of his employer or the needs of his industry and if these obligations cannot be conscientiously met he would naturally seek work elsewhere. The obligations of the academic are to the intrinsic nature of his subject and to the traditions of the learned world—scrupulous analysis, imaginative synthesis and painstaking precision of thought and expression—and if, in fulfilling these, his work is immediately useful he is doubly fortunate. The genius of industry is the spirit of inventive adaptability, that of the academy is the grace of vision and conceptual refinement. Industrial research is, in the language of our day, "goal oriented", and, whether that goal be a new product or the improvement of an old process, the success of the research is to be measured by the degree of achievement of that goal—by the reliability of the product or the efficiency of the revised process.

A QUESTION OF PROPRIETY

IN MAKING THESE distinctions I do not mean to divide and sunder, nor do I intend to put these several virtues into conflict or opposition. I am not suggesting that all these qualities cannot flourish in one person nor each in the other's context. Still less am I advocating that they should not interact or claiming that one is a higher road than the other. Such an adversary attitude is unproductive on all counts. It is merely a question of propriety. For the individual worker it is a matter of bent, for "we have only one virginity to lose and where we lost it there our hearts will be." [2]. It goes without saying that a close contact between industry and university must be maintained for it is of the nature of chemical engineering to find expression in industrial processes and fundamental research must not lose sight of its final cause. It is also well to bear in mind that the cooperation of industry and university may often fruitfully follow a pattern in which the fundamental aspects are taken up by the latter but closely meshed with the questions raised by the development program.

An almost trivial illustration may serve to focus the distinction. In the operation of a continuous fermentor in which two organisms A and B are growing on the same nutrient, it is found that by carefully regulating the flow rate, not one but both populations can be induced to grow together at a healthy rate, whereas at higher or lower feed rates one population tends to grow at the expense of the other until the latter is washed out. In this kind of operation there is some difficulty in maintaining the steady state since the flow rate fluctuates to some degree and considerable skill needed to start up. However it is readily determined that (a) an inoculum of A and B in the correct proportions will lead to a steady growth rate in those proportions, and (b) an increase of flow rate favors A over B and vice versa. This information should be in agreement with common sense and confirmed by a fairly cursory examination of the equations. For practical purposes enough may now be known for satisfactory operation. If this matter were the subject of an academic investigation one would want to go further and, while perhaps growing the bugs in a chemostat for the purposes of some other investigation, one would like to ask a number of further questions: What is the stability of the steady state? Why should the flow rate variation have such an effect on the populations? The growth rates are dependent on the nutrient in a known way, but what are other possible dependencies and what would then be the behavior of the chemostat? Above all one would want to get a comprehensive and structural picture to see the inter-relations with other known features of reactor behavior. This desire for comprehensiveness is of course subject to human limitations and short-comings and, sometimes because new techniques have come to light, the work of later authors often repairs the deficiencies of earlier. A study of the behavior of stirred tanks in the early and mid-50's showed the possibility of limit cycles in their behavior [3]. It was however nearly 20 years before Uppal, Ray and Poore, using revived or new methods, gave a comprehensive picture of conditions under which they could appear [4].

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Comprehensiveness is but one aspect of the basic endeavor to understand any subject in which, as always, our "reach should exceed our grasp". It is this fundamental longing after structure which characterises the academic enterprise and from this flow two other characteristics of university research. First, it should be related to the curriculum. The attempt to divorce teaching and research is fatal to the life of a university department. The act of teaching makes just those demands on the understanding of a subject that are needed if a structurally sound insight is to be developed. The opportunity to expound the results of an investigation is normally essential to its healthy development and seminars play an important role at specialized research institutions where there is no regular curricular teaching. Second, fundamental research is more explicitly conscious of methodology than applied or developmental work. Little has been written in any general way on the methodology of chemical engineering. I am not here referring to particular techniques such as mathematical methods for the solution of equations of a certain sort but to the style of method in general and the peculiar character it takes on in a chemical engineering context.

BUT WHAT IS METHOD? Its etymology shows that it is concerned with a way or path

(Greek: hodos). For Descartes it was a set of "certain and simple rules, such that if a man observes them accurately, he shall never assume the false to be true nor spend his mental efforts to no purpose" [5] and he acquires this method by acquiring a sense of order. For Jeremy Bentham [6], method or, as he more frequently called it, "methodization" was primarily a matter of arrangement. It was the manner in which objects or elements of discourse are put together and so united for a particular end. This methodization by exhibition is attuned to the thinking of the Enlightenment but is far too static for a Romantic such as Coleridge [7]. For him, method arises when the mind shakes off "an habitual submission of the understanding to mere events and images" and "becomes accustomed to contemplate, not things alone, but likewise the relations of things". This generates the need "for some law of agreement or contrast between them . . . some mode of comparison". The driving force for Coleridge is the idea which provides the key-note of the harmony to follow—"an idea is an experiment proposed, an experiment is an idea realized". He sees a methodic sympathy between science and literature both of which achieve their excellence from that "just proportion, that union and interpenetration of the universal and the particular" [8]. Inspiration and methodic habit go hand in hand, confounding those who "tread the enchanted ground of poetry" without even suspecting "that there is such a thing as method to guide their steps." Dewey recognizes method as "intelligence in action", noting that though rules are to be followed they themselves arise from the circumstances that give them their scope for application [9]. These are but a few senses that have been brought to the notion of method, the whole concept of which has been admirably discussed by Buchler [10] and who at one point refers to a method as "a power to manipulate complexes characteristically within a perspectival order."

Let us however turn to a contemporary philosopher, Bernard Lonergan. For him the idea of method grows from a consideration of the nature of cognition. Understanding is the central act which, taken with experience and judgment, forms the basis of our knowing anything. By experience is meant the presentations of sense or the representations of imagination. Thus the understanding of the experimentalist may grow on the results of his experiments just as the theoretician's insight is grounded in his imaginative grasp of reality. Understanding grows in response to the human potentiality for wonder, which is the force behind it and provokes the question *Quid sit?* or What is it? But understanding is not an end in itself for it leads to a second question *An sit?* or Is it?—more colloquially Is that *really* so? Here a further stage of reflection is required and an element of judgment, really a judgment of existence, is called for. There is a dynamical aspect to this whole process, for judgment is called for in the decision to consider certain data of experience. Informed by the current state of his understanding the experimentalist decides what experiments he should next do. On the other hand understanding is preconceptual in the sense of being grounded in experience and finding its primary object there. It is thus to be distinguished from concept formation, where the endeavor is to find a universal notion that is not tied to the particularities immanent in experience.

Method is, in one sense, the art of understanding. It is, according to Lonergan, a "normative pattern of recurrent and related operations yielding cumulative and progressive results". In natural science it demands accurate observation and description, the formulation of hypotheses and their confirmation or rejection by further experience. These operations are transitive, in the sense of intending objects; they are also the conscious activity of an operator and so introspective, in the sense of elucidating the content of consciousness. Intentionality and consciousness can exist at several levels: the *empirical* level of sense

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perception; the *intellectual* on which we inquire and come to understand; the *rational* on which we reflect and pass judgment; and the *responsible* level where we are concerned to evaluate and decide. Intelligence takes us beyond experience to ask what and why; reasonableness wants to know if the answers of intelligence are true; responsibility goes beyond fact and possibility to ask what is good and hence what should be put into practice. In the sense that this pattern is not tied to categories or cultural background it is transcendental and forms an objective, normative pattern of the dynamics of conscious enquiry. It must admit of further extensions and clarifications but in one sense it does not admit of revision. For a revision which destroyed the pattern would have to come from without and so be no revision but a rejection, since revision using the methods of the pattern to reject the pattern would reject itself. This transcendental method has to be worked out in a given discipline in the categories which are appropriate to that discipline. However in any context it will function in a variety of ways—normatively, critically, dialectically, systematically. It provides continuity without rigidity, guiding inquiry and laying a sound foundation.

By now the reader will be frothing at the gills "If this is what the fellow means by being more explicitly conscious of methodology, what hope is there for us? He hasn't even talked about a practical method yet." Agreed—but then Lonergan scarcely mentions God in his "Method in theology". However, just as there is a need to articulate this in detail with respect to the particular techniques of chemical engineering (as, for example, Rudd and his colleagues have done for design synthesis [13] so also is there a need to look at the foundations [14] of our style of thinking. This may lead to philosophy in the technical sense rather than in the colloquial. In the chemical engineering literature we have Rase's excellent introduction to the chemical engineering outlook [15]; in the philosophical literature there is a long tradition that has been alluded to only glancingly here—more recent modes are well described by Bochenski [16]. At all events it is not philosophy in isolation and its development and application should produce a heightened consciousness of what the chemical engineer is actually doing and help him, or her, to do it the more effectively.

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ChE book reviews

Mixing—Principles and Applications
by Shinji Nagata
Reviewed by Louis J. Jacobs, Jr., Monsanto Co., St. Louis, Missouri.

This book is a comprehensive coverage of mixing and processing of fluids in agitated vessels. A good balance between theory and practice is provided with several examples given to demonstrate use of the correlations. The late Professor Nagata of Kyoto University was one of the most active researchers in many facets of the field of mixing over the past thirty years. His qualifications to do a book of this type are without question, and we are fortunate that his manuscript was completed prior to his recent death. This book serves many purposes providing, (1) a good introduction for persons new to the mixing field, (2) a basis for people doing further research in mixing, and (3) a source of practical information for people designing mixing processes. I highly recommend this book for persons with each of these three interests.

(Continued on page 27.)