PROCESS COMPUTERS and Chemical Engineering Education

An Industry View

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Let's start this paper with a few assertions about computers:

- Process computers as discussed here are on-line digital computers for closed-loop regulation, optimization and sequencing of industrial processes. In a much broader philosophic sense, they are a means for placing corporate managements (business and technical) in almost direct control of production facilities.
- Process computer systems were first installed about ten years ago, but the number of installations has grown rapidly and the activity will continue to expand.
- Process computers can produce significant improvements in process performance under the right conditions.

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- Essential elements of successful process computer installations are a suitable application, well-chosen objectives, adequate hardware and software, a competent and dedicated project team, and aggressive management.
- Installation of a process computer requires many different skills and therefore necessitates a team effort by many people.
- Installation of a process computer is engineering in its finest sense.

These assertions are based on extensive experience in the field and are regarded as fundamental truths. Some of their consequences for chemical engineering education will be discussed in the remainder of the paper.

SOME SYMPATHY FOR ENGINEERING EDUCATORS

Before getting into the subject at hand, we want to express our sympathy for today's engineering educators in their attempts to deal with the winds that now blow through the campuses. We are not speaking of such current problems as protests against the war, the draft, and manufacturers of products used in connection with these unhappy activities. Nor do we mean the perennial problems of "publish or perish" or the related conflict between teaching and research. We are talking about problems of the engineering schools in coping with today's rapid changes in technology and their attempts to meet this challenge by emphasis on *science* as opposed to *engineering*.[1, 14-17]

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The digital computer is, in reality, a post-World War II development, even though it roots go back much farther. Process computers are even more recent, having been introduced in the late 1950's. Having graduated somewhat ahead of the process computer, we had no academic training in this field. It would be very easy to suggest that engineering curricula should be changed to cover this new activity—in the same way that every engineering alumnus probably feels the colleges

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should teach his current specialty, whether it be heat exchanger, crankshaft or telephone circuit design. However, we will resist this temptation, and we urge educators to reject pressures of this type.

Fortunately, it is not necessary to overturn a modern chemical engineering curriculum to fit the needs of students who will be working with process computers. As will be seen subsequently, this field calls upon almost all of the subject areas now taught in progressive departments. Anything the student learns will be useful at some time or other, and very little that a student learns will be wasted.

On the other hand, it is impossible to cram into one student, in the regulation number of credit hours required for a bachelor's or even a master's degree, all the material that will prove useful in his process computer work. In this field, as in others, students must be convinced that education is a life-long activity and that a diploma is, as somebody put it, only a "license to learn." This attitude must be stressed, if only because there will be other new technical fields in the future, just as process computers are new today.

FUNDAMENTAL TRAINING FOR ENGINEERS

To cope with the expansion of technology and the limited hours available in an undergraduate program, engineering educators must emphasize fundamentals, and we wish them well in their struggle to decide what is fundamental. Probably it means a stress on basic science—mathematics, physics and chemistry. However, our work with process computers causes us to urge that engineering schools should produce engineers. And what does this mean?

An early definition of engineering, put forth by the civil engineers in 1818, described it as *the art of utilizing the forces of nature for the use and convenience of man.* A more recent definition[2] states that **Engineering is a general term covering many branches of technology . . . through which the materials and forces of nature are developed and controlled for various purposes of mankind. These branches differ among themselves in areas of specialization, size, and historical background, but the following characteristics which are common to all branches identify them as belonging to the field of engineering:**

- **A concern with specific** practical results, **usually achieved by means of technical projects involving planning, design, execution, and operation;**
- **The application of** principles of science, **together with judgments based upon knowledge of the state of the art in the branch of technology involved, with due consideration of** cost factors, **in carrying out these projects;**
- **A capacity for organizing and directing the** human skills **essential to the accomplishment of complex projects.**

Emphasis has been added to stress that *practical results, cost factors,* and *human skills* are as much a part of engineering as *principles of science.* Process computer work at its best involves all of these characteristics and is, as we have already mentioned, engineering in the finest sense: creating something that works on a schedule, and at a price.

It probably goes without saying that, to train engineers, the teachers should themselves be engineers. In the automatic control field, perhaps more than others, instructors are frequently young PhD's with recent degrees and very little engineering background in the sense described above. The result, evident in the literature of the field, is treatment of hypothetical control problems as mathematical exercises. The situation is unfortunate, and remedies are manifold: hiring experienced engineers as faculty members (waiving, if necessary, the usual requirement of a doctorate for candidates whose other credentials are attractive); having faculty members undertake part-time or summer work in industry; persuading inindustry (instead of government) to sponsor university work;[13] and participating actively in professional society activities concerned with current technology. These corrective measures will not be easy to accomplish, but few worthwhile results ever are.

RECOMMENDED SUBJECTS FOR PROCESS COMPUTER ENGINEERS

Training of chemical engineers has undergone great changes in the last fifty years or so. The changes were capably summarized by Dr. Olaf A. Hougen, Professor Emeritus of Chemical Engineering at the University of Wisconsin, in an address[3] presented at the dedication of the H. K. Benson Hall at the University of Washington on March 3, 1967. His first-hand account of the history of chemical engineering education is extremely detailed, very interesting, and deserves wide circulation. Early in his address, Dr. Hougen made the following remarks about his own undergraduate education:

> "In 1911-15 there were no courses in unit operations, none in diffusional principles, none in material and energy balances, none in chemical thermodynamics! There were no courses in process measurements, none in heat and mass transfer, none in applied kinetics, process design or transport phenomena! I saw no laboratory equipment in unit operations! There was little or no quantitative approach to chemical-engineering problems. The use of higher mathematics beyond the calculus was too time consuming to be of practical value as it is today with our high-speed computers. We had no textbooks and no handbooks in chemical engineering! In the main library we were referred to the German texts of E. Hausbrand and of J. P. Kuenen. The slide rule was still an exciting novelty! Instruction in mathematics, the basic sciences and other branches of engineering was excellent, but there was no integration between chemistry and engineering."

As Dr. Hougen pointed out later in his address and as we are all aware, recent years have seen the introduction of courses in process design, applied kinetics, process control, computer programming, physical chemistry, differential equations, measurements, process dynamics, and transport phenomena. All of these subjects are important for chemical engineers concerned with pro cess computer application. Yet, essential as they are, they are not enough.

Suggested lists of courses or subjects to be studied by process control systems engineers have been presented by many people with knowledge of the field.[4-10] A summary of their suggestions would produce the list given in Table I.

The subjects listed in Table I provide a background for process computer work in the chemical and petroleum industries. For other industries, other useful courses could be added, e.g., courses in metallurgy and ceramics for engineers concerned with iron and steel production or minerals processing. But most of the subjects will be valuable for any kind of process computer application.

We have omitted the introductory science, mathematics, English and other humanities courses which form the basis for an engineering education. Even so, the list is long; we will not attempt to justify putting each subject on the list.

Many subjects are listed under *Mathematics.* Some of these subjects will be covered in engineering courses, either as topics in mathematics or in connection with an engineering subject, while others may only be available from a mathematics department. Analog and digital computer programming, essential subjects for process control systems engineers, are listed here although they may actually be taught in any of several departments.

One group of subjects, those concerned with *Engineering Management,* will be valuable to all engineers, including those who do not become involved with process computers. Indeed, one might argue that engineering schools have an obligation to cover these subjects since it is man-

TABLE I
Suggested Courses for Process Control Systems Engineers

Mathematics	**Chemical Engineering**	**Engineering Management**
Calculus	Inorganic and organic chemistry	Personnel supervision
Differential Equations	Stoichiometry	Industrial organization
Ordinary	Material and energy balances	Elementary accounting
Partial	Mass and energy transfer	Evaluation of investments
Operational calculus	Thermodynamics	Scheduling (PERT, CPM)
Matrix Algebra	Reaction kinetics	Contracts and specifications
Numerical methods	Unit operations	**Electrical Engineering**
Probability and statistics	Process dynamics	Network analysis
Fourier Analysis	Instrumentation (measurements)	Field theory
Optimization	**Control Engineering**	Electronics
Linear Programming	Basic control theory	Logic devices
Gradient Methods	Time-domain analysis	**Other Fields**
Variational Calculus	Frequency-domain analysis	System concepts
Dynamic Programming	Stability	Economics
Computer programming	Synthesis	Operations research
Analog	Sample-data systems	Information theory
Digital	Multivariable systems	Psychology
Boolean (logical) algebra	Nonlinear systems	Human engineering
	Adaptive systems	

agerial skill that distinguishes engineers from scientists. It is interesting to note that Dr. Hougen[3] lists "Contracts and Specifications" among the subjects that moved out of the chemical engineering curriculum in the 1930's to make room for more technical subjects. Perhaps subjects of this type should be restored to the curriculum.

We have already acknowledged that any one student cannot include all of the worthwhile courses in his program. This impossibility leads to two conclusions: (1) the need for further study beyond the last academic degree, and (2) the need for a team approach to process computer projects.* The second of these conclusions reinforces the argument for development of management skills in the education of process systems engineers.

Considering the long list of subjects which form a desirable background for process computer work, it might appear reasonable to advocate training through the PhD for engineers going into this field. Plausible as it might appear, this idea is not necessarily sound. For one thing, it imposes an undue burden on engineers desiring to enter the field and restricts the supply of available manpower. A more important consideration, however, is the nature of PhD training.

Mardon and Cripps have recently published a paper[10] on training systems engineers. They recognize three sources of potential systems engineers: the PhD, the young BS or MS, and the experienced engineer from industry, each with his advantages and disadvantages. They believe each of these individuals will need additional training and on-the-job experience. Mardon and Cripps think a recent BS or MS may be the best candidate, although they point out that he lacks *experience in taking a large-scale unsolved problem, defining it and carying it through to a solution.*

Discussing the disadvantages of PhD's, Mardon and Cripps write:

> "Unfortunately, a PhD is all too often characterized by a second set of qualities which make him undesirable to industrial environments, such as in a systems engineering department. The more important of these qualities are: (1) His narrow scope of interest. The PhD is too often interested only in that problem which has constituted his thesis work. Such a characteristic is to be expected, perhaps, since he has channeled his effort along this path for years. (2) The PhD is usually a researcher, not an applications engineer. That this is generally the case can easily be surmised by noting that the most important characteristic of a researcher is his ability and desire to "channel" effort on one subject. (3) The PhD demonstrates, in almost every case, an attitude of academic aloofness. Needless to say, such a characteristic is disastrous in an industrial environment."

To this gloomy description, we might add another long-standing and strongly-held observation of our own: people with a research orientation often have a difficult time working on a process computer project because their training and experience cause them to concentrate on the unknown rather than the known. Like the pessimistic drinker, who views his glass as half empty, not as half full, they tend to stress the gaps in existing knowledge and always want to investigate one more area or run one more experiment. In short, they are unwilling to *get on with the job* by using what is already known and looking for ways to circumvent the real or imagined difficulties.

TRAITS AND ATTITUDES

Production of engineers with the requisite academic background for process computer work does not require drastic revision of the chemical engineering curriculum. However, there are some essential traits and attitudes necessary for this work[11] which might be developed more fully in the standard curriculum. Let's summarize the characteristics that distinguish the process computer systems engineer:

- **He must be interested in results,** that is, he must be interested in having the process computer perform useful functions. He must concentrate on the solution of problems with economic significance, not those which are merely interesting.
- **He must be able to communicate** with corporate management, members of the project team, and process operators.
- **He must be skilled in human relations.** To design a system used by operators to run the plant for management, he must be diplomatic in guiding the project to a successful conclusion which meets the needs of many people.
- **He must be patient and persistent.** Process computer projects often take many months and require solution of many problems in getting the computer hardware, programs and instruments to work together as planned.

*A typical team might include one chemical engineer with operating experience and another from the process engineering or research department, an electrical engineer with experience in digital equipment and instrumentation, a systems engineer with training in process control techniques, and a specialist in computer programming—although all members of the team should acquire some skill in programming.

• **He must be creative and inventive.** Because the field is still new and packaged solutions are not available he must be able to find his own answers to the multitude of complex problems he faces in designing a system and making it work.

To some extent, these traits and attitudes are personality characteristics acquired in early childhood. Hopefully, they can be enhanced in the course of an engineering education. If so, they are perhaps best acquired as by-products of the regular engineering courses, through such measures as discussions of the instructors' industrial or consulting work; use of problems with a practical flavor; assignments that encourage creative as opposed to strictly analytical activity; emphasis on oral and written communication; projects requiring group efforts, including preparation of plans and schedules; and so on.

DESIGN VS. OPERATION

Finally, the process computer systems engineer—and those he works with in industry—must have a viewpoint toward process operation which may necessitate some adjustments on the part of engineering educators. Operation of a process plant with a computer requires that the plant and its control equipment be considered as a system in relation to its physical and economic environment. The traditional curriculum generally does not adequately prepare a graduating engineer to think in these terms.

An engineer must, of necessity, learn the fundamental principles of science and engineering. Since there are many such principles, they are taken one at a time, and the student practices their use by solving appropriate problems. He becomes accustomed to solving simple problems requiring use of only a few principles. When he moves into more advanced courses in the practice of the technology, he continues in the same pattern.

At some point, the engineering student progresses from analysis to design. Now the result—a product to be made at a specified rate from given raw materials— is stated, and the problem is to determine a suitable process configuration, equipment sizes, materials, etc. If time permits, attempts may be made to optimize the design.* Hopefully, measuring and regulating devices are selected simultaneously with design of the basic processing equipment, rather than added as an afterthought, but we don't want to go deeply into this old problem in this paper! In any case, when all of the equipment is specified, the problem is regarded as solved

In real life, of course, the engineer's job is not finished when the plant is designed and constructed; it must still be operated. Now the problem changes. The equipment layout and dimensions are fixed (barring breakdowns and expansions), but the raw materials, ambient conditions, equipment performance, and market requirements change. Unfortunately, we cannot put plants in a controlled environment (like Houston's Astrodome), supply them with USP-grade raw materials, and turn out a fixed slate of products for delivery at arbitrary prices to easy-to-please customers. People remote from the plants—which means process industry management, plant designers, and engineering educators—seem prone to forget these day-to-day operating problems.

These operating problems are, however, the basic justification for use of a process computer. This device is a tool for improving process performance by near-continuous adjustment of operating conditions to satisfy a pre-established criterion. With a process computer, the objective is not simply to hold everything constant but to react in the best possible way to the inevitable process disturbances.[4] The goal can be as general as maximum profit or as specific as producing at a prescribed rate with minimum variations in product quality. Defining the goal(s) is a task requiring management participation, and developing a system to meet the goals is the job of a team of process computed systems engineers. For success, all parties must have a realistic understanding of process disturbances, objectives, limitations, and permissible operating practices.

CONCLUSIONS

Process computers are here to stay, and engineering schools need to adapt themselves to this fact. Fortunately, since educators already have too many subjects to teach and too few credit hours for teaching them, the necessary adaptation is primarily a change in approach rather than a fundamental revision of curriculum.

Engineering schools now make available the subjects (Table I) which provide the needed background for work

*Perry and Singer[12] have recently published an interesting paper illustrating how a computer can be used to determine both equipment dimensions and operating conditions to meet a production rate specification at minimum cost.

with process computers. If any deficiencies exist, they are found in the area of training in management skills, useful not only for process computer work but for all engineering activities. No student can cover all of the worthwhile subjects, even with graduate study; for this reason, and because many students will find themselves in other new fields in the future, the need for life-long learning must be stressed.

Training through the PhD level is not the only or best way to produce people with the requisite skills. It is an unnecessary hurdle for the individuals, and the total demand would make an excessive load for the universities. More important, the usual emphasis in a PhD program on research in a narrowly-defined specialty does not provide the right technical background and mental outlook for process computer systems engineers.

Above all, we hope the engineering schools will produce **engineers**—men who combine a knowledge of scientific principles with an interest in practical results, an appreciation of cost factors, and skill in human relations. Among their other attributes, they should be able to communicate, patient and persistent, creative and inventive. These traits and attitudes need not be taught in special courses but should be imparted throughout the curriculum.

Engineering students also need to learn that, contrary to much literature on the question, design is not the ultimate goal of engineering; an engineer has to make things work. In the process industries, he must run plants and solve what might be called **the operating problem**: with a given plant facing varying raw materials, product requirements and equipment characteristics, what is the best way to operate? This responsibility does not receive sufficient recognition in engineering education.

The process computer is a tool for attacking the operating problem. Solving the problem (with or without an on-line computer) calls for skills in process simulation, optimization, instrumentation, process economics, and industrial management. Successful installation of a process computer is an engineering achievement of the highest order.

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through this interaction in areas we cannot cover ourselves. The experience can be a tremendous asset to a young Chemical Engineer, and therefore can be a valuable part of his technical education.

Finally, there is a lot of work to be done here, for our local community, for the nation and for the world. In the past, too many times we have said, "Well, I'd like to help, but that is really a political or social problem." The political and social scientists are at the same time calling it a problem in technology. Here is the kind of group where you find out what kind of problem it is and then solve it. This means utilizing our talents for solving some of our most important problems.

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