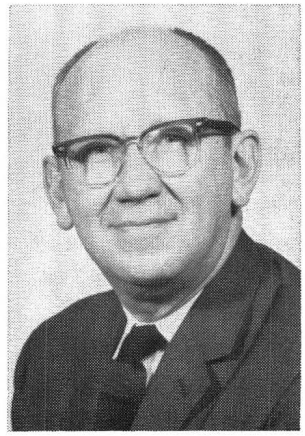
Chemical Engineering INFORMATION And EDUCATION*



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Education by university professors is a knowledge transfer activity. In the same way, so are reading of literature, technical meetings, movies, seminars. An engineer in doing his work is actually part of an information sequence. He starts with information input and finishes with information output. Someone else translates his output into a device, system, process, structure, or product. This paper presents challenges and programs for the engineer-educator. Adoption of the suggestions should improve a curriculum and each course. The result should be engineer graduates tailored to the employer's needs.

INTRODUCTION

Knowledge = Education = Information

Various dictionaries and synonym finders provide the basis for the above equation with such statements as: "Information is knowledge received or communicated concerning an event, instructions, etc."; and "Information is knowledge on various subjects"; and "Knowledge is education." So, to complete the circle, in the ordinary uses of the word, all information is knowledge.

In continuing to build the case, therefore, education is knowledge production and is information transfer. The unit processes are those concerned with the individual, such as training, education, development, exposure, self-study, and experience. The unit operations are the mechanisms of transfer, all the known means of communication, such as:

reading	seminars	experimenting
listening	workshops	working
talking	lectures	thinking
movies	meetings	

Since the university's prime objective in life is to educate or impart knowledge, it is obvious that the educator is transmitting information.

This paper proposes the extension of that objective in several dimensions in defining curriculum needs. The educator, as a Knowledge-Producer, has additional responsibilities to educate the student in how to improve his information input functions and, similarly, in how to improve his information output and information transfer capabilities.

It is easy enough to say that a triangle of only three elements affects engineering education and its direction:

1. The engineer himself.
2. The university which produces the engineer.
3. Industry and government which use the engineer.

However, the problem is an order of magnitude more complicated. There are a number of curriculum constraints (Fig. 1). From the uni-

*Presented at the Annual Meeting of ASEE, June 19-22, 1967.

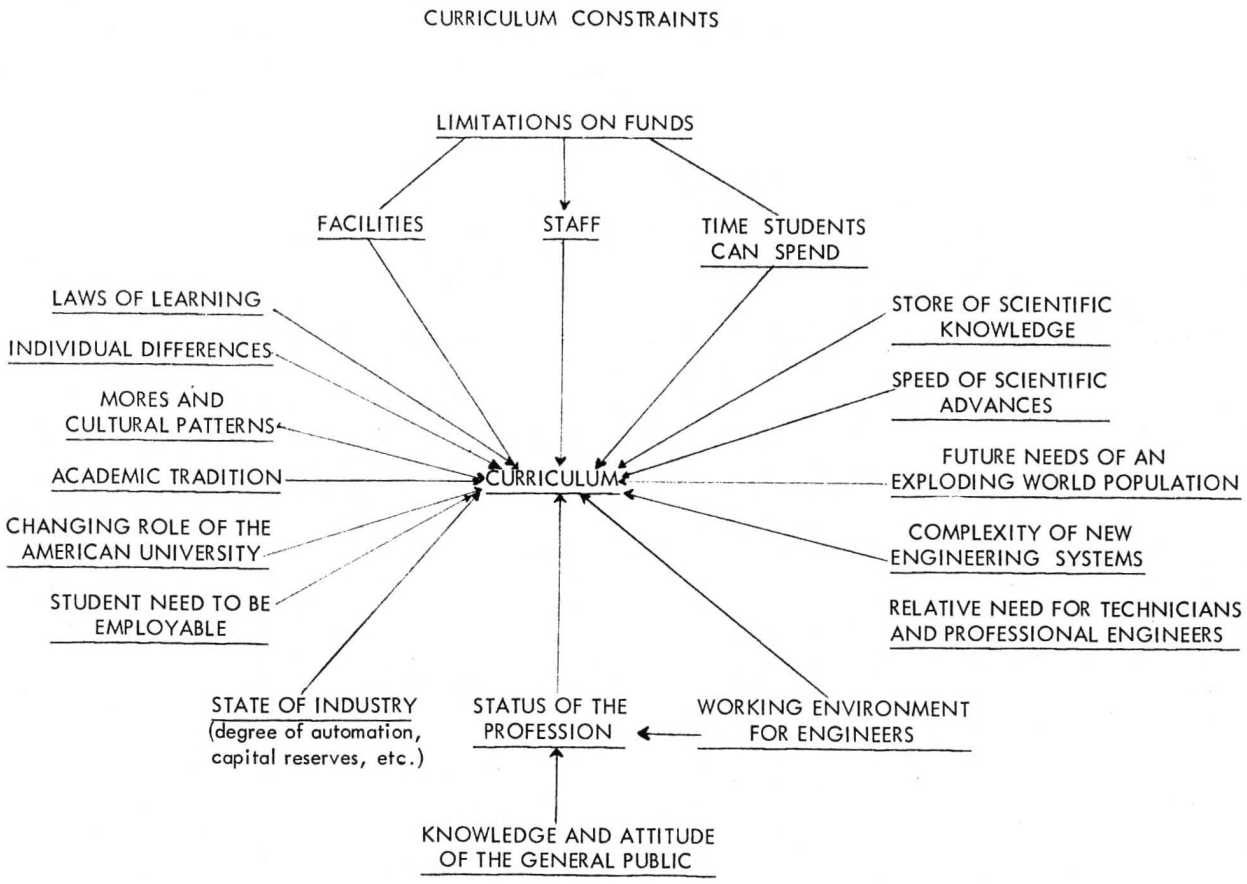


Figure 1[2]

(D. Rosenthal, A. B. Rosenstein, M. Tribus)

versity's viewpoint, there are limitations of funds, which in themselves determine the facilities, the staff, and the time that students can spend in college. The curriculum is affected by such elements as the laws of learning, the individual differences, the morals and cultural patterns—even the academic tradition and the changing role of the American university. The curriculum is influenced by the vast amount of scientific knowledge or information available, the speed of scientific advances, the future needs of an exploding world population which is getting closer and closer together, the complexity of new engineering systems and the engineering systems approach to solution of problems, plus the relationship between what an engineer does and what can be delegated to someone else.

The curriculum is modified by the demands of industry, by the changes in professions, by the environment in which engineers work. Finally, the curriculum is affected by the fact that the student needs to be employable.

In industry, the chemical engineer eventually loses his identity. So does the mechanical engineer and the chemist. It is often startling to realize that some of those associates most knowledgeable about process technology and equipment are chemists now functioning essentially as engineers.

Chemical engineers are today working on many projects and at many tasks that were unknown when their professors were students. It is often said that a chemical engineer should be so trained that he is capable of applying the developments of science to the solutions of the problems of chemical industry. It is also said that he must have enough knowledge in the sciences in sufficient depth to enable him to refer to the literature and to follow the developments that are pertinent to his profession.[1]

If one follows the premise that engineering education is a knowledge-producing industry, and that engineering education affects an engineer's information transfer capabilities throughout his career, then there are a number of factors that must be considered before it is possible to develop

WHAT ENGINEER DOES IN R & D
(ENGINEER IS PART OF INFO. SEQUENCE)

INFO INPUT ⟶	ENGINEERING ⟶ "BEST" ENG'G	INFO OUTPUT
REPORTS	ANALYSIS, SYNTHESIS,	REPORTS
ORAL INFO.	WITHIN LIMITS OF COST,	PRODUCT DESIGN
PATENTS	TIME, UNCERTAINTY,	PRODUCT SPECS.
HANDBOOKS	FEASIBILITY, SAFETY,	PROPERTIES
SCI. JOURNALS	MANPOWER, RELIABILITY,	ECONOMICS
TRADE JOURNALS	EFFICIENCY	MARKET OPPOR.
COMPUTER OUTPUT	+ EXPERIMENTATION	BASIC DESIGN DATA
DATA		

Figure 2

the breadth and depth of an engineering curriculum. Several of these are:

1. The engineer, his career today and tomorrow.
2. What an engineer actually does and with whom he works.
3. Information and information sources.

Of course, all these considerations must live within the curriculum constraints previously mentioned.

THE ENGINEER AND HIS CAREER

As input to the knowledge-production process, the engineer, the prospective graduate, has two questions he must answer:

1. From college to which kind of job?

   Research
   Process Development
   Product Development
   Market Research
   Design & Systems Engineering
   Construction
   Production & Maintenance
   Marketing & Purchasing
   Technical Assistance
   Economic Evaluations
   Technical Writing
   Teaching

From college, the engineer has a number of choices of job types, ranging from the most scientific approaches in research, in process and product development, through the business aspects of market research and evaluations, into design and systems engineering, perhaps even building of plants, and, finally, into production and maintenance. From a business viewpoint, the engineer may go into marketing or purchasing, perhaps even to technical writing. He may go into teaching.

2. From college to which employer?
   Small Chemical Co.
   Large Chemical Co.
   Equipment Manufacturer
   Gov't. Agency
   Research Institute
   University & Res. Foundation
   Technical Journal
   Consulting Firm
   Self

With respect to the employer, the new engineer must choose from a spectrum of alternatives, such as small *vs.* large company, government *vs.* private industry. He has the option to work with equipment manufacturers, research institutes, technical journals, consulting firms, universities. He may elect to go into business for himself.

THE ENGINEER: WHAT HE DOES, WITH WHOM HE WORKS, HOW HE USES INFORMATION

What does the engineer do? An engineer has the responsibility to bridge the gap between theory or basic science and society in the development of various kinds of systems, whether they be chemical plant systems, automobile systems, aircraft systems, water-treatment systems, or building systems. He has to translate his discipline-oriented knowledge into mission- or problem-oriented problem solution. The ultimate objective of engineering work is some kind of useful output: a design, device, system, process, structure, or product.

The important factor is that the output of an engineering effort must work. Once the objective has been established, the engineer must then acquire input information and then do engineering within such constraints of technical certainty, economic feasibility, producibility, efficiency, reliability, safety, cost, timing, manpower limita-

tions. He must do analysis and synthesis to come out with some "Best" result which will eventually become a design, device, system, process, structure, or product.

To repeat, an engineer is part of an information sequence. He starts with input information, does engineering analysis and synthesis, and produces output information.

For example, in R & D (Fig. 2), for information input, the engineer uses reports, patent information, scientific journals, some trade journals, probably some computer output, some raw data, a considerable amount of discussion with associated engineering fields through the interdisciplinary approaches in bioscience and space sciences, through the sciences such as chemistry and physics, and, finally, in those areas which make it possible to get the job done, such as psychology, economics, accounting, etc.

An engineer uses information from many sources. The greatest proportion of these sources are his co-workers. Some of these co-workers are specialists; others are knowledgeable with general experience; still others know where to go for additional aid.

But there are many other sources of useful

WHAT ENGINEER DOES IN DESIGN
(ENGINEER IS PART OF INFO. SEQUENCE)

INFO INPUT	ENGINEERING	INFO OUTPUT
	"BEST" ENG'G	
REPORTS	ANALYSIS, SYNTHESIS	DRAWINGS
STANDARDS	WITHIN LIMITS OF COST,	SPECIFICATIONS
ORAL INFO	TIME, UNCERTAINTY,	MATERIALS LISTS
HANDBOOKS	FEASIBILITY, SAFETY,	PARTS LISTS
CATALOGS	MANPOWER,	EQUIPMENT LISTS
COMPUTER OUTPUT	RELIABILITY,	ESTIMATES
DATA	EFFICIENCY	INSTRUCTIONS
PATENTS		

Figure 3

his friends, an objective to come out with something brand new in appreciation of engineering science. He then applies his best engineering ability in terms of analysis and synthesis plus experimentation, and produces information output as reports, product design, product specifications, properties, economics, market opportunities, and perhaps even basic design data for a plant. But he does not form directly the end effort, the product, or plant.

Similarly, an engineer in design (Fig. 3), in performing his function as part of the information sequence, acquires such information input as the objective itself, reports, standards, information from his associates, handbooks and catalogs, computer output data, and patents. He then does his best engineering analysis and synthesis within limits of time, cost uncertainly, feasibility, safety, manpower, reliability, and efficiency, to produce not a plant, not a product, but designs, drawings, specifications, materials lists, equipment lists, parts lists, estimates, instructions, purchase requisitions.

An engineer uses information from many disciplines. These range from those which are in information. These include the libraries, commercial information services, and the Government agencies. The technical societies themselves have responsibility to produce useful information, and similarly do publishers and universities, research institutes, trade associations, and manufacturers. All of these organizations are knowledge-producing industries which make information available for use by the engineer. And, very importantly, increasing numbers of the information sources are computer-based or in microimage form.

The specialization by individuals has resulted in specialized information centers, staffed by competent specialists who review and provide credibility to the data and information output of the information center. Many of these organizations (Fig. 4) are Government supported; such as the Non-Destructive Testing Information Center at Natick, Massachusetts, and the Electronic Properties Information Center, operated by the Hughes Aircraft Corp. at Burbank, California, for the U. S. Air Force. Some information centers are supported by industry, such as the Institute of Textile Technology at Charlottesville, Va., and

the Copper Development Association, operated by the Battelle Memorial Institute, Columbus, Ohio. Included in the list, of course, are the Government-funded university "Centers of excellence" which will eventually become highly specialized information centers.

EXAMPLES OF SPECIALIZED INFORMATION CENTERS

Non-Destructive Testing Information Center
Electronic Properties Information Center
Copper Development Association Information Center
Institute of Textile Technology Information Center
Reliability Information Center
Reaction Kinetics Information Center
Plastics Technology Evaluation Center
Biosciences Information Service
University "Centers of Excellence"

Figure 4

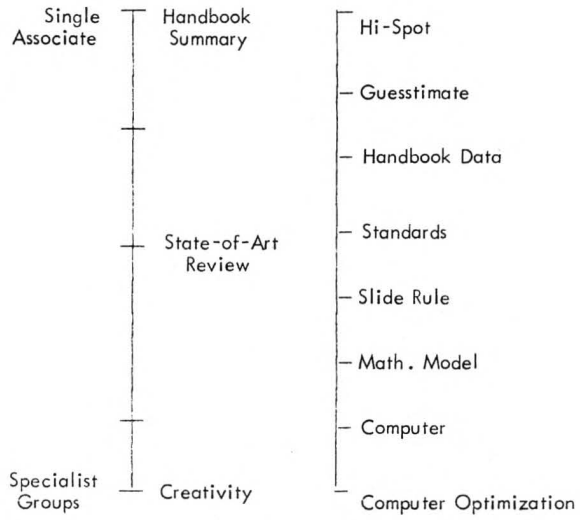
If one were to look at the kinds of information that an engineer uses, one would conclude that it is a broad spectrum (Fig. 5). Every engineer uses handbooks and slide rules, and many are learning to use the computer. In any assignment, regardless of how scientific or sophisticated or theoretical it may be, the engineer scientists must use at different stages all parts of the spectrum.
The same philosophy applies, probably in different ratios, for those engineers who are in production, construction, design, marketing.

Suffice it to say, it is necessary for the engineer to know how to use not only complex but simple information, not only basic scientific facts, but "guesstimates." And, most important of all, it is necessary for the engineer to know that all of the information must be tempered by individual judgment, must involve the right combination of engineering science and engineering technology.

A new engineer must recognize that he will deal with four primary types of engineering personnel: engineers in training like himself, experienced technical engineers, supervisor-or middle-management engineers, and top-management engineers. Different companies may call them by different names, but the four classifications definitely exist.[3]

The engineer must also deal with secondary personnel: technicians, draftsmen, craftsmen, and clerical help.

ENGINEER'S INFORMATION SOURCE SPECTRA *



* Tempered by Individual Judgment & Experience

Figure 5

It is important that there be good communications between the primary types of engineering personnel, so that there will be a correct flow of information to the secondary group. It is the responsibility of the engineer to prepare and formulate the information used by this latter group.

All of the above discussions justify the conclusion that information is a fifth resource. For many years, people have said that there are four resources: men, materials, machines, and money —the four M's. It is time now to include the fifth, "Information" (or perhaps one should say, "Knowledge").

CHALLENGE TO ENGINEERING EDUCATORS

The objective of changing or improving an engineering curriculum is to achieve more effective engineering work by the engineer during his career. As has been described, information transfer, education, and knowledge production are essentially interchangeable terms. It appears reasonable, then, to assume that an effective information transfer philosophy can provide a basis for:

(1) The engineering curriculum.
(2) Every course in that curriculum.

One could make many suggestions to professional educators to improve their knowledge products, the engineer graduates. Of the hundreds, five practicable approaches that follow the philosophy of effective information transfer present themselves as challenges to the engineering educator:

1. Extend the use of a flexible curriculum to match men *vs.* careers and jobs.
2. Improve the use of information resources by an order of magnitude.
3. Double or triple the communications competence of students.
4. Train and develop the student in principles and methodology of getting jobs done.
5. Infuse in the students the motivation to continue learning, self-education, or continuing education.

1. Flexible Curricula

Battelle[4] used a method of identification of creative talent through breaking down engineers and scientists by originality and ability to reason logically (Fig. 6). It appears that there are four types of individuals:

Type 1—People, relatively rare, who are above average in both originality and ability to reason logically. They are intelligent, open to new ideas, but rigorous in evaluating them, independent thinkers, curious, and tolerant of ambiguity.

Type 2—Very original. A man of this bent can keep six Type 4 men busy, but he's not very reliable at following through on the logical consequences of an idea.

Type 3—People below average in both creativity and logical reasoning.

Type 4—Where engineers tend to cluster—people who are highly analytical but are not comfortable with new ideas.

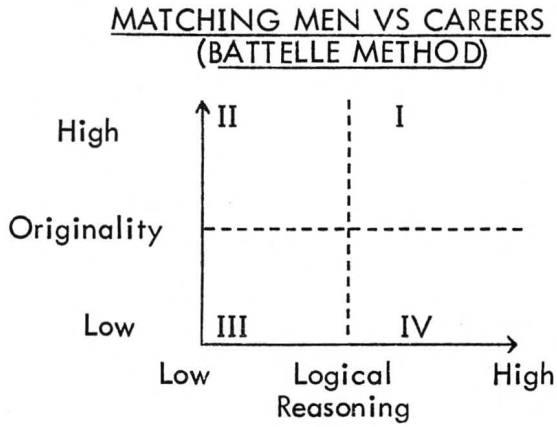


Figure 6

The Battelle study indicated that it is possible to increase creativity three-fold by proper motivation. An important facet of improving creative ability is to encourage people to ask questions. Our educational system places too much emphasis on teaching people to answer questions, not teaching them to analyze problems systematically.

The challenge, then, (Fig. 7) is to classify the prospective engineer when he's a freshman, and adjust his second-year curriculum against the target of a Type 1 product as a senior. At the end of each year, plot the current status and adjust the curriculum accordingly; so that by the time the individual is a senior or a graduate student, he is moving in the right direction.

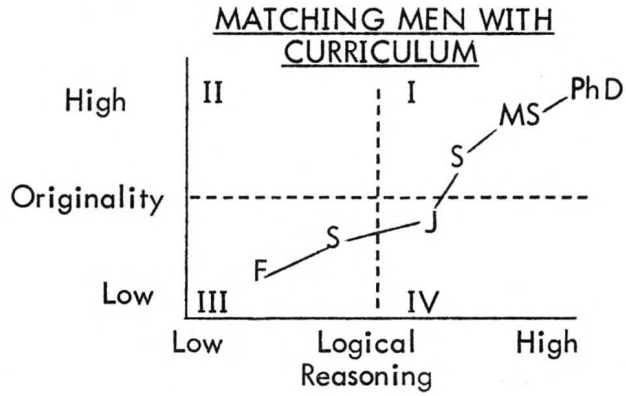


Figure 7

2. Improve Information Resource Use by an Order of Magnitude

There are a number of practical approaches that can be followed:

a. Establish a faculty and/or graduate student as the information contact and as information support. Such an individual or individuals would have the responsibility for accumulating a wealth of knowledge about information sources and could be a referral center.
b. Practice extemporaneous high-spot estimation. Require that students not only estimate how far it is from here to Mars, but the density of a mixture of ten hydrocarbons at a particular temperature, the cost of a particular change in a process, the time for accomplishment of a particular task.
c. Require, practice, and develop judgment in the use of standards and handbooks on the one hand, the use of scientific and the computer optimization approach on the other hand.
d. Require the extensive use of libraries and literature, information centers, facilities provided by the various state technical services act programs. Require that students go to other departments and ask questions of individuals who know most about a particular, narrow subject.
e. Require a detailed report of a limited length on a narrow subject, using multiple information sources. Such a task would require considered judgment and review of the wealth of available information and data.

3. Double or Triple the Communications Competence of Students

a. Require meticulously prepared problem solutions. Insure that every problem has a data reference. Require that the procedures be outlined in specific steps. As often happens, an individual is changed from one assignment to another with no chance for completion. It is critical that a second individual can start from the beginning, or even at intermediate steps, and follow through on the computation sequence or project completion.
b. Require and accept only good-to-excellent reports. A technical report may be correct from the engineering or scientific viewpoint, but may be presented in poor format, with improper grammar, and without adequate review. Suffice it to say, that in many instances, the project is disapproved not because of the technical error, but because of the peripheral factors, such as neatness, which may ascribe a lack of quality to the report as submitted.
c. Increase the opportunity for oral presentations with audience feedback. This means not only opportunity for presentation in class or at student technical societies, but the requirement that individuals use a tape recorder in order to review how they have presented a particular project, report, or summary.
d. Require use of visual aids in presentations and reports. There is no question that a picture or a chart clarifies the written word. And especially is the use of visual aids important in an oral presentation, since the two senses of hearing and seeing are both channeled towards the problem being presented.
e. Require the equivalent to "how to win friends and influence people" of every prospective engineer. Require him to be a diplomat. In arriving at a technical solution to a problem, the engineer may have reached a correct and a qualified solution. However, if he cannot find the means to communicate adequately to those who must make the decision or those who must implement his decisions, then the final result or objective will be extremely difficult, if not impossible, to achieve.

4. Train and Develop the Student in Principles and Methodology of Getting Jobs Done

a. Use formalized network planning programs such as the Critical Path or PERT Systems.
b. Require that objectives and targets be set in each problem.
c. Use such devices as flow charts and decision trees to help present a picture and merits of various alternatives.
d. Develop a logical sequence of proper use of information sources as input to any phase of the engineer's work.
e. Require progress reports.

5. Infuse in Students the Motivation to Continue Learning

a. Point out the advantages of technical society participation.
b. Recommend scheduling of reading/study programs.
c. Suggest the benefits of attending workshops and formal courses of all kinds.

In summary, as soon as one realizes that education equals knowledge transfer, that knowledge production equals information transfer, one can draw a number of conclusions:

1. Communication or transfer of information is an integral part of the education process and must be considered in establishing a curriculum and, most importantly, the development of engineers via that curriculum.
2. An engineer is part of an information sequence. In order to be effective, he must achieve effective information utility for effective results.
3. A graduate is a combination of technical competence and other inseparable capabilities, one of which is his ability to communicate.
4. The university and the professor have a responsibility and an opportunity to produce the whole man, an individual more nearly tailored to his ultimate career.

With such considerations in a curriculum, the following qualitative needs can be partially satisfied:

1. Engineers with competence in a wide variety of fields.
2. Engineers with that kind of intellectual experience and education that enables flexibility in short-term assignments and in career perspectives.
3. Engineers who can communicate effectively.
4. Engineers who are skillful in their interpersonal relationships, who are diplomats.[5]

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